AN ABSTRACT OF THE DISSERTATION OF

Stephanie Larson-Praplan for the degree of Doctor of Philosophy in Range Ecology and Management presented on December 15, 2009.

Title: Modeling Animal Movement to Manage Landscapes

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John C. Buckhouse

Managing rangelands with livestock grazing is a tool that can be applied to obtain vegetation management objectives. Animals utilize available resources, which vary in quantity and quality, across the landscape. Their movements are adjusted to the spatial and temporal heterogeneity of resource distribution. Controlling livestock distribution is fundamental to economically and ecologically sustainable livestock production systems on range and pasturelands. Having an understanding of animal movements in relations to scale will help develop strategies to better management livestock over entire landscapes.

The research site was the Sierra Foothill Research and Extension Center (SFREC) in Marysville, California. The study was conducted on four annual rangeland pastures, average 25 hectares each. Two 20 cow herds grazed one pair of pastures one week and the pair the following week during January, March, April-May and August, during 2001, 2002, and 2003. Beef cow locations, turning angles, travel paths, and travel speed were determined with six cows in each of two herds of 20 cows equipped with global positioning collars. Individual measurements were recorded at five-minute intervals throughout the entire 5-7 days, recording longitude and latitude positions, date, time, elevation and a general measurement of horizontal and vertical activity. Cattle positions were analyzed to determine the fractal dimensions of movement and then modeled to determine what landscape attributes affected this movement. Domains of scale were detected whereas cattle movement at smaller ranges (< 40 meters) was less tortuous than at the larger ranges, 40 to 200 meters. Animal activities (grazing, resting and cruising) were also affected by landscape attributes. The research provided an understanding of how to apply spatial models of livestock movements that will aid in managing cattle distribution. Understanding how the ecological attributes and managerial options can affect distribution can lead to a better understanding of methods to manipulate cattle movement.

MODELING ANIMAL MOVEMENT TO MANAGE LANDSCAPES

by

Stephanie Larson-Praplan

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Dean of the Graduate School

I understand that my dissertation will become part of the permanent collection of Oregon State University libraries. My signature below authorizes release of my dissertation to any reader upon request.

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Stephanie Larson-Praplan, Author

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INTRODUCTION

Livestock Distribution

Seventy percent of the earth's surface and 61 percent of the United States is classified as rangelands (Holecheck et al. 1989). In the western half of the U.S., rangelands are dominated by vegetation that is predominantly grasses, grass-like plants, forbs, or shrubs. Rangeland ecosystems provide a variety of services including minerals, wildlife, forage, carbon storage and open space. As watersheds, they capture, store and safely release water that has numerous beneficial uses downstream. Rangelands are dynamic ecosystems that continually change in response to anthropomorphic influences, climatic and geomorphic changes, invasive species, fire, and animal pressures. These lands, whether public or privately owned, must be maintained and managed to sustain their ability to provide a variety of ecosystem services, i.e., water capture, wildlife habitat, carbon sequestration and recreation.

Concern about livestock impacts on rangelands such as water reduced quantity and quality, continues to influence public policy and regulations. Research has explored different attributes to understand livestock movement and their distribution across rangelands. These studies showed that abiotic attributes i.e., slope and distance to water and biotic attributes i.e., forage quantity and quality, influence livestock distribution (Harris et al. 2002; Ganskopp and Bohnert et al. 2009). Understanding what influences livestock movement across rangelands will assist researchers and rangeland managers to manage livestock distribution and reduce further impacts.

The introduction of Global Positioning Systems (GPS) has automated the acquisition of sequential animal positions that are more accurate than in older studies, setting the stage for more accurate modeling of animal movement across rangelands, especially in regards to landscape attributes. Models that predict animal movement patterns based on abiotic and biotic landscape influences allow managers to better manipulate livestock distribution. This could enable improved forage utilization, invasive species control, wildlife habitat and riparian area management.

Project Description

Animals utilize available resources, which vary in quantity and quality, across the landscape. Their movements adjust to the spatial and temporal heterogeneity of this resource distribution. Cattle distribution patterns are strongly influenced by vegetation patchiness (Brock and Owensby 2000; Walker et al. 1989; Senft et al.1987), vegetation crude protein (Ganskopp and Bohnert 2009), slope (Ganskopp et al. 2000), and weather (Malechek and Smith 1976). Subsequently, understanding animal movement and the influence of landscape attributes on movement is a vital tool for land managers. The long term sustainable use of these rangelands throughout the western states will rely on the development of advanced management methods that allow for an improved prediction of animal movement across the landscape.

Reducing the impact of livestock on water quality, aquatic and riparian habitat, and biodiversity is a continuing goal for livestock producers, natural resource managers, and conservation groups (George et al. 2007). This research project targeted management of annual rangelands in California to reduce potential grazing impacts and provide a better understanding of cattle distribution. Models developed should give land managers the ability to make better livestock management decisions on rangelands. The goals of this study were to (1) detect differences in animal movement; and (2) model landscape influences on livestock movement. In this study beef cattle movement and landscape attribute interactions were assessed on annual rangelands in the Sierra Nevada foothills.

Project Objectives

The objectives of this study were to (1) detect differences in animal movement, i.e. fractal dimensions, turning angles and daily travel in different pastures, seasons and vegetation cycles and (2) develop models to determine if landscape attributes could be used to predict livestock movement and distribution.

Hypothesis

The stated null hypothesis was:

Ho: there is no difference in movement tortuousity between pastures, seasons and vegetation cycles

H_1: there is a difference in movement tortuousity between pastures and seasons and vegetation cycles.

Ho: Cattle movement across heterogeneous landscapes is not affected by landscape attributes, such as slope, canopy cover, vegetation, etc.

H_1: Cattle movement across heterogeneous landscapes is affect by landscape attributes.

Project Location

This study was conducted at the University of California Sierra Foothill Research and Extension Center (SFREC) 27 km northeast of Marysville, California. This research station is located in the Sierra Nevada foothills adjacent to the Yuba River and Englebright Reservoir (39.2607022977, -121.239967346). The climate at the SFREC is Mediterranean, characterized by hot, dry summers and mild, rainy winters. Annual precipitation at the SFREC has ranged from 22.8 centimeter to 132 centimeters, occurring almost exclusively as rainfall, and mostly from October through May. Monthly precipitation for the forage years included in this study is presented in Table 1. Seasonal air temperatures typically range from a low of 4.4 C^o in winter to a high of 32.2 C^o in summer.

Table 1. Weather Data from SFREC

YEAR	Cycle	Sept	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Year Ave
2000	1	1.46	3.35	1.65	1.06	4.25	5.38	2.64	2.36	0	.12	0	0	22.2
2001	2	.51	1.22	5.16	8.75	3.46	1.7	4.69	.64	1.49	.04	0	0	27.6
2002	3	0	0	2.63	11.05	3.1	2.18	3.58	6.25	1.68	0	0	1.47	31.9
AVE		.39	1.77	3.96	4.87	5.61	4.66	4.01	2.22	.94	.39	.06	.11	2.42

Study Pastures

The study was conducted on four oak-woodland pastures (Forbes 1, Forbes 2, Haworth and Porter), that average 25 hectares each. Forbes 1 (39.247855, -121.312278) and Forbes 2 (39.246276, -121.309866) are dominated by blue oak (*Quercus douglasii* H. & A.) and interior live oak (*Q. wislizenii* A. DC.) until the pastures were cleared in the 1970s. Most woody vegetation is along the riparian corridor. Haworth (39.245920, -121.330340) and Porter (39.262576,-121.322176) pastures are a mosaic of open grassland and oak-woodland patches. Percent slope in all pastures ranged from 0 to greater than 30. The soils in these pastures are complexes of the Auburn (loamy, oxidic, mixed, thermic Ruptic-Lithic Xerocrepts), Sobrante (fine-loamy, mixed, thermic Mollic Haploxeralfs) and Timbuctoo Series (fine, mixed, thermic Typic Rhodoxeralfs). In addition to blue and interior live oak, other woody species included wedgeleaf ceanothus (*Ceanothus cuneatus* (Hook.) Nutt.), whiteleaf manzanita (*Arctostaphylos viscida* Parry), and poison oak (*Toxicodendron diversilobum* Torr. & Gray) in the uplands and figs (*Ficus carica* L.), willow (*Salix* spp), and interior live oak in the riparian corridors. Understory vegetation was composed largely of annual grasses and forbs. Annual grasses included: soft chess brome (*Bromus hordeaceus* L. *ssp. hordeaceus*), rip gut brome (*Bromus diandrus* Roth), annual ryegrass (*Lolium multiflorum* Lam.), wild oats (*Avena fatua* L.), annual fescue (*Vulpia myuros* (L.) K.C. Gmel.), foxtail barley (*Hordeum murinum* L. *ssp. leporinum*), and medusahead (*Taeniatherum caput-medusae* Nevskii). Dominant annual forbs included: red stem filaree (*Erodium cicutarium* L.) rose clover (*Trifolium hirtum* All.), and subterranean clover (*T. subterraneum* L.).

LITERATURE REVIEW

Overview of Animal Distribution

Sustainable rangeland management depends on reducing the impact of livestock on biodiversity, habitat, water quality and other ecosystem services. Uneven livestock distribution results in many of the impacts associated with livestock grazing in extensive rangeland systems (Bailey 1995). Livestock distribution is the result many factors including abiotic and biotic influences, animal behavior, and instinct all which effect animal movement. Spatial memory also allows animals to remember where they have foraged and that information aids to determine where they will travel and forage (Howery et al. 1999). Using knowledge about all these factors can aid in predicting grazing patterns to manipulate distribution through management.

Models have been used to predict grazing distribution patterns (Cook 1966, Senft et al. 1983, Gillen et al. 1984), but the success of these models has varied. Difficulties in developing these models arise from the large number of cofactors that create a high degree of spatial and temporal heterogeneity across landscapes (Brock and Owensby 2000). Abiotic effects such as slope and distance to water are usually consistent and can be predicted more reliably than biotic factors (Bailey et al. 1996). Many models cannot be transferred to other sites (Senft et al. 1985b), are over simplified, or do not consider actual mechanisms of foraging (Coughenour 1991). Coughenour (1991) suggested that models can describe movement and foraging processes, but are difficult to apply over large areas. Approaches to assess spatial heterogeneity are needed at both small scale such as vegetation defoliation and patch grazing and at large scale patterns such as rotation and migration. Herbivory patterns at these different scales are interrelated (Coughenour 1991).

Loza et al. (1992) developed a simulated model to predict patterns of landscape use by cattle as a function of environmental conditions and spatial distribution of key landscape attributes. Their model yielded reasonable predictions of landscape use by free-ranging cattle based on their physiological and behavioral needs, which resulted from the interaction of ambient environmental conditions and the spatial distribution of landscape components. However, the simulated model contained very little landscape complexity. It lacked spatial data detailing locations of shade and water points, as well as slope, shrub patches, and forage availability. Research has shown that cattle do react to landscape complexity, especially at spatial scales (Bailey et al. 1996). Therefore landscape attributes and their complexities should be included in future animal movement models

Factors Affecting Movement

Howery et al. (1999) reported that spatial memory allows animals to remember where they have foraged and they use that information to determine where they will travel and forage next. Wallace et al. (1995) stated that the spatial pattern of herbivory is based on a complex interplay of abiotic variability and biotic interactions. Abiotic (e.g., slope, distance to water, weather and barriers) and biotic factors (e.g., forage quality, forage quantity and secondary compounds) influence animal movement and therefore animal distribution (Bailey et al. 1996, George et al. 2007).

Slope influences movement by imposing physical barriers, increasing time and energy required to move a certain distance (Roath and Kruger 1982a; Harris 2001). Mueggler (1965) found that 75 percent of use was within 810 yards of the bottom of a 10 percent slope but only 35 yards from the bottom on a 60 percent slope. Slope was the most important of 21 factors that Cook (1966) used to explain cattle distribution. Gillan et al. (1984) found that slope gradient was the only physical factor related to cattle grazing. Pinchak et al. (1991) found that 79 percent of cattle use was on slopes under 7 percent. Ganskopp et al. (2000) reported that beef cows select travel paths that are very similar to computer-selected, least-effort routes between distant points.

Aspect is generally defined as the direction to which a mountain slope faces the sun. In the northern hemisphere, north-facing slopes experience less radiation than south-facing slopes. McCuchan and Fox (1986) showed that aspect differences can have a greater effect on temperature than elevation in mountainous areas. Because temperature is such an important component of mountain climate, they suggest that development of a simple geographic model of temperature differences would be an important first-step in many landscape-scale ecological studies. Senft et al. (1985a) found that 48 percent of summer bedding activity occurred on east-facing slopes, 30 percent on south-facing slopes, and peak daytime use was on north-facing slopes. Senft et al. (1983) and Senft et al. (1985a and 1985b) also found that resting sites changed through the year. They reported that daytime resting sites occurred on warm south-facing slopes and lowland areas from September through May, and in low-laying areas, fence lines, livestock-watering areas and cooler north facing slopes from June through August. When arid temperature data are compared with daylight cattle distribution, other thermal comfort patterns are exposed. Harris (2001) noted cattle using sheltered camps 83 percent of the time when daily temperature maximums were below 36Cº. When temperatures were higher, cattle congregated on ridge tops. Senft et al. (1983) and Marlow and Pogacnik (1986) found that during the summer daytime resting areas were generally on cooler north-facing slopes. During winter or cooler seasons, daytime use mostly occurred on warmer south-facing slopes. Harris (2001) found 70 percent of grazing on the south-west aspect during cooler seasons.

Research has shown that animals will move to maintain a desired body temperature and their ability to do this are influenced by landscape attributes (Ehrenreigh and Bjugstad 1966). Malechek and Smith (1976) found cattle changed their foraging behavior during periods of weather stress. Cattle spent more time grazing and less time standing during warm days than cold days. They also found that the distance cattle traveled daily was related to average daily wind velocities. Moen (1973) found similar findings for white tailed deer (*Odocoileus virginianus*) in winter when food is scarce. He concluded that the dynamic behavioral response of deer to cold temperatures seems to be a function of heat conservation rather than the energetically more expensive heat-production response.

Temperature is an abiotic factor that has a large effect on biotic properties; it can initiate behavioral changes in cattle and influence their distribution (Malechek and

Smith 1976). Smith et al. (1985) showed there may be subtle interactions between the influences of heat, thirst, and hunger on sheep behaviors; and that these interactions can make it difficult to predict behavior on the basis of a single index. According to Stuth (1991), when winter air temperatures are below an animal's thermal neutral zone, less grazing will occur in the evening and more will occur in direct sunlight. Researchers (Bennett et al. 1984, Reppert 1960, Roath and Krueger 1982b, and Senft et al. 1985b) have found that livestock use rest areas to avoid high temperatures and restrict movement during the day.

By maximizing solar exposure at cooler temperatures, cattle can reduce thermal stress while simultaneously pursuing required activities like grazing (Smith, 2006). During warm summer temperatures, Harris (2001) found cattle loafed in the shade for seven to eight daylight hours (72 percent of daytime positions). Prescott et al. (1994) found daily temperatures positively correlated with grazing time and assumed feed consumption. Harris (2001) found that with warmer temperatures, cattle seek sheltered rest locations during the middle of the day. Bennett et al. (1984) found a strong correlation between respiration rate while in the sun and time spent in the shade and Loza et al. (1992) developed a thermal submodel to predict respiration rate that was then used to determine shade seeking behavior in cattle. With their landscape submodel, Loza et al. (1992) found spatial relationships among and within different habitat patches, and thus landscape attributes, such as slope and vegetation, influenced animal behavior and animal habitat then influenced landscape characteristics.

Throughout arid and semi-arid environments, water availability is the chief cause for poor livestock distribution. Mueggler (1965) stated that distance to water was a factor affecting cattle distribution. Miller and Krueger (1976) found the environmental factors of distance to water and salt, soil depth, and canopy cover were highly correlated with utilization. Water is in short supply on most rangelands, thus location and amount of watering areas can impact livestock distribution. Pinchak et al. (1991) recorded 77 percent of animal use was within 366 m of water, but approximately 65 percent of the land was beyond 723m from water and it only received 12 percent of observed use. Roath and Kruger (1982a) found water and vegetation type to be the most important factors in determining area and degree of use. Vertical distance from water was the most important factor in determining vegetation utilization on moderately steep slopes. Cook (1966) also found distance to water an important factor in explaining cattle distribution accurately. Senft et al. (1985a) found season-grazing distribution to be correlated with proximity to water and forage quality indicators. Ganskopp (2001) found the movement of water was the most effective tool for altering cattle distribution but salt manipulations did not significantly changed livestock distribution. Ganskopp et al. (2000) showed factors, such as distance to water and slope, can greatly affect cattle distribution. Clary et al. (1978) conducted one of the few studies that did not find distance to water related to livestock distribution. This may be because their study area was adequately watered and not a limiting factor. They also did not find any correlation with slope, but suggested that the topography of their study site was so gentle that slope was not a factor.

Rangeland use by cattle was significantly correlated to standing crop and crude protein (Pinchak et al. 1991). Adler et al. (2001) found that the animal distribution depended on the interaction between the spatial pattern of grazing and the spatial pattern of vegetation. Ganskopp and Bohnert (2009) found grazing cattle spatially responded to forage quantity and quality attributes, however, relating grazing distribution to geophysical and forage quality/quantity characteristics were extremely poor predictors of where cattle grazed.

Bailey and Welling (2007) evaluated the effectiveness of supplement placement for improving livestock distribution. They suggested that supplement placement was an effective practice for attracting livestock into areas where grazing is desired and would reduce livestock use of environmentally critical areas such as riparian zones. George et al. (2008) assessed the effectiveness of nutrient supplement placement for changing livestock distribution. Bailey and Welling (2007) and George et al. (2008) found livestock distribution was changed when supplement placement was extended out to about approximately 600 meters.

Global Position Systems (GPS) with Animal Movement Application

Before radio telemetry and global positioning systems (GPS) observations of movement of large grazing animals over large areas was conducted by direct observation for periods of 24 hours or less. Moorefield and Hopkins (1951) observed animals from 8 AM to 8 PM and noted a regular polyphasic activity pattern with animals alternating between foraging and resting activities. They detected three distinct daylight grazing bouts; early morning, mid-day and evening.

Peterson and Woolfolk (1955) followed groups of cows in Montana for 24-hour periods. During August, over one-third of all grazing occurred at night. By October, night grazing decreased by 1.5 hours and daytime grazing increased by almost 2 hours. Wagnon (1963) reported grazing habits of cattle observed continuously, by watching one cow at a time for 24 hour periods in California's annual rangelands. He calculated that 25 percent of grazing occurred at night. Most of these studies used individual observation intervals less than one hour, most often at intervals of 15 minutes. Hull et al. (1960) concluded that an observation interval of up to 30 minutes was adequate for reporting major behavior patterns (grazing, ruminating, and idling). Nelson and Furr (1966) also concluded that observation intervals of 15 or even 30 minutes accurately estimate major behaviors, but failed to give reliable estimates of activities such as walking, sleeping, nursing calves, defecation, urination, and drinking. Other researchers have followed several individuals around the landscape for various lengths of time (Harris et al. 2002). This procedure lent itself to human error, with missed observations and biased animal movement due to human presence. Zuo and Miller-Goodman (2004) were able to observed cattle behavior from daybreak to dark at 15 minute intervals, with the assistance of binoculars, from a point that avoided disturbance of the cattle. They divided this period into morning (dawn to 1100 hours), midday (1100 to 1300 hours), afternoon (1300 to 1700 hours), and evening (1700 hours to dusk) periods.

Use of GPS tracking technology has increased the ability of researchers to accurately locate individual animals and correlate their location with abiotic and biotic landscape characteristics represented by layers in a geographic information system (GIS) (Turner et al. 2001). Collection of tracking data using GPS and spatial analysis of GPS data using GIS has reduced human errors associated with direct observation of large herbivores (Brock and Owensby 2000). The integration of GPS receivers into light weight collars has increased observation periods to several weeks or more and frequency of observation to 5 minutes or less (Turner et al. 2001). This GPS technology now assists researchers in assessing pasture shapes and sizes; fence designs; grazing systems; forage composition and availability, location of shade, water, and supplement (Bailey 1995; Harris et al. 2006; George et al. 2007).

Scale and Movement Patterns

The relationship between animal movement and environmental heterogeneity can influence the distribution of animals (Turchin 1996). Animals interact with their environment in complex ways and these interactions can produce complex movement patterns (Jonsen et al. 2003). A better understanding of the interactions between livestock behavior, natural habitat factors, and management factors should aid in developing more effective methods of livestock distribution (Gillen et al. 1984).

Animal movement and dispersal, has been described as a correlated random walk, dependent on three parameters including number of steps, step size and distribution of random turning angles (Byers 2001). Kareiva and Shigesada (1983) analyzed cabbage white butterfly (*Pieris rapae*) movement using a correlated random walk model. They quantified movement sequences in terms of move length and turning angle probability distributions and concluded that animal movement was more complicated than a simple correlated random walk. Garcia et al. (2005) analyzed sheep movements in homogeneous and heterogeneous swards. They found that correlated random walk models adequately described movement in a homogenous sward but after a few weeks of grazing sward structure became more complex and animal movement more sinuous. In the heterogeneous swards they concluded that fractal dimension better described path tortuousity.

Nams (1996) developed a technique (VFractal) for analyzing the tortuousity or crookedness of animal movement paths using fractal dimension (D). Fractal dimension is a measure of tortuousity (Mandelbrot 1967). At one extreme fractal dimension for a straight path is 1 and at the other extreme is 2 for a path that is so tortuous that it covers the plane (Turchin 1996). Nams (1996) used D to determine at what scale red-backed voles (*Clethrionomys gapperi*) viewed their habitat. He concluded that VFractal adequately estimated D at different spatial scales gave an estimate of variation and combined data from many path segments that had been gathered at various spatial scales.

Weins and Milne (1989) used fractal dimension to show that beetles' (*Eleodes sponsa, E. longicollis, E. caudifera*) movement was influenced by bare ground in semi-arid grassland. They proposed that their approach could be used to answer other questions such as the influence of heavy grazing on beetle movement trajectories. Crist et al. (1992) found that the overall structure of movement pathways of the same three different beetle species (*Eleodes* spp.) in various micro landscapes was similar when pathway structure was analyzed as a function of length or distance moved. Their research suggested that there are basic similarities, as measured by fractal dimension, in movement processes among animals that because of the different body size, may respond to the patch structure of the landscape at different spatial scales. Webb et al. (2009) found D could be used to measure tortuousity of deer movement paths thus providing useful information on the causes of and constraints on animal movement strategies, creating empirically based models of animal movement and thus a firm foundation for modeling movement processes.

Fractal Dimensions Across Scales

The study of animal movement patterns provides a basis for understanding their foraging decisions, space use, and distribution (Crist et al. 1992). Animal movement can be divided into scale segments. Movements of animals at fine spatial scales (short segments) should be related to feeding station and patch scales within feed bouts described by Bailey et al. (1996). At larger scales movement is related to feeding site and camp level decisions such as moving to water or resting sites resulting in larger movement segments. Wiens (1989) called such scale segments “domains” and called the boundaries between these segments, “transitions”. Nams (2005) suggested understanding how animals perceive and react to landscape structures; we need to detect the boundaries of these domains of scale (i.e. locations of transitions), and then study how to the animals react to their landscape within each domain. He divided animal movement into two domains, the small scale when the animal forages and the larger scale when the animal travels. He hypothesized the small scale domain movement pattern is heterogeneous, as the animal enters and leaves patches of food, and in the large scale domain the movement pattern is homogeneous, as the animal travels in a directed walk. Thus one could conclude that scale and the pattern of grazing are connected and effect animal distribution across a landscape.

Habitat selection is traditionally assessed by how much time an animal spends in each habitat type. However, more information can be obtained by analyzing the structure of animal movement paths. Roshier et al. (2008) evaluated grey teal (*Anas gracilis*) movement responses to variable resource distributions in agricultural and desert landscapes in Australia. They found grey teal in the two different landscapes differed in the fractal dimension of their movement paths. The movement path of grey teal in the desert landscape was less tortuous overall than their counterparts in the agricultural lands; however, the most striking difference found were the high levels of individual variability in movement strategies, with different animals exhibiting different responses to the same resources. Nams and Bourgeois (2004) mapped American martens (*Martes americana*) paths and found that they differed significantly from those described by correlated random walk models. When they examined the D versus spatial scale for marten movement paths they found a natural break in D (path tortuousity) at a scale of approximately 3.5 meters. Their research found that marten travel was more direct at scales <3.5 meters than at scales > 3.5 meters. They concluded that fractal analysis of movement patterns provides a unique approach to examining habitat use as well as a means of identifying the spatial scales at which an animal responds to its habitat.

Animal Movement Across Landscapes

On grasslands, herbivores make a trade-off between the quality and the quantity of their intake (Garcia et al. 2005). Animals improve their search efficiency by modulating their foraging velocity and/or their path sinuosity through the perception of their feeding environments. Ungar et al. (2005) studied landscape use of individual animals over time. They used data collected from GPS collared cattle to predict activity on extensive rangeland in two contrasting foraging environments. They classified grazing, traveling (without grazing) and resting activities. They found that distance alone was a poor indicator of animal activity, but grazing, traveling and resting activities of cattle could be inferred with reasonable accuracy from GIS collars. Putfarken et al. (2007) classified cattle and sheep behavior, using GPS collars, as 'resting' if the calculated distance was less than 6 meters (over a 5 minute period), 'grazing' if movement changed more than 6 meters but less than 100 meters, and 'directional movement over grazing' if the movement was more than 100 meters. The term directional movement over grazing was used to indicate direct movement by animals to facilities, water, etc.

Understanding how landscape attributes affect cattle distribution will greatly improve rangeland management's ability to reduce the impact of grazing on ecosystem services. Analysis of movement path tortuousity, landscape complexity, domains of scale, classify foraging activities and determine landscape attributes that influence these activities will improve understanding of livestock distribution and impacts. A few studies, often of small animals, have shown that landscape heterogeneity (abiotic and biotic landscape attributes) influences the tortuousity of animal movement paths and that these attributes can be predictors of animal movement and distribution. In a very few studies researchers have detected "domains of scale" and were able to segregate small scale movement associated with feeding stations and patches and larger scale movement toward attractants such as water or shade. Few studies have applied fractal analysis in the study of movement paths of beef cows or other large herbivores. This study proposes to apply fractal analysis and multiple regressions to analyze movement paths and the influence of abiotic and biotic landscape attributes on beef cow movement.

METHODS

Study Design

In this study we analyzed animal movement, determined landscape complexity, segregated domains of scale for animal movement, and modeled the relationship between landscape attributes and cow activities (grazing, resting, and cruising).

Pastures

The relationships between animal movement and landscape attributes were measured in four pastures. One pair of pastures (Haworth and Porter) was open woodland and the other pair (Forbes 1 and Forbes 2) had been cleared and was mostly devoid of trees except in the riparian corridor. The two 20-cow herds grazed one pair of pastures one week and the other pair the following week during April 2001 (flowering), August 2001 (dry season), January 2002 (early vegetative), March 2002 (vegetative), April-May 2002 (flowering), August 2002 (dry), January 2003 (early vegetative), and March 2003 (vegetative) (Table 2).

Cattle

Forty cows (*Bos taurus*) were randomly selected from the SFREC cattle herd and split into two groups. Within each group, six cows were equipped with GPS collars (Lotek™ 2200 LR and 3300 LR Series, Lotek Engineering, Newmarket, Ontario). The same cows were collared for each grazing season except for two replacement cows during the last year of the study. Animals ranged from three to seven years of age and were Hereford, Angus or Herford-Angus crosses. Cows were bred to calve in the fall as is common on Mediterranean type rangelands in California. All cows had calves during each grazing season except during the dry season (July-August). All animals had previously grazed the four pastures used in the research study.

The Lotek™ GPS collars were programmed to record a position every 5 minutes for each one-week grazing period. The five minute recording period was the most up-to-date technology at the time of the research. The collars recorded longitude and latitude, date, time, elevation, temperature, and satellite ephemeris information. The positions were downloaded from the collars, following each grazing period, differentially corrected and loaded into ArcGIS™ geographic information system software from ESRI®.

Table 2. Dates when Cattle Grazed in Four Pastures during Phenology Periods 2001, 2002 and 2003

	Forbes 1	Forbes 2	Haworth	Porter
	Herd 1	Herd 2	Herd 1	Herd 2
		Year 1 (2001-2002)		
Flowering	4/11/2001	4/11/2001	4/18/2001	4/18/2001
Dry	8/15/2001	8/15/2001	8/22/2001	8/22/2001
Early vegetative	1/15/2002	1/15/2002	1/22/2002	1/22/2002
Vegetative	3/13/2002	3/13/2002	3/20/2002	3/20/2002
		Year 2 (2002-2003)		
Flowering	4/21/2002	4/21/2002	5/07/2002	5/07/2002
Dry	8/5/2002	8/5/2002	8/12/2002	8/12/2002
Early vegetative	1/14/2003	1/14/2003	1/21/2003	1/21/2003
Vegetative	3/3/2003	3/3/2003	3/10/2003	3/10/2003

Animal Movement

Cow locations (northing and easting) were placed in an MS Excel™ spread sheet, converted to the comma separate version (csv) format and loaded into the Fractal 5.0 software (Nams 2006b). Sequential cow locations are vector data of cow movement and were analyzed to determine the means for Fractal Dimension (D), means for cosine (turning angle) and travel distance (m/day). All cows' positions were analyzed for each of the eight (8) seasons, four (4) pastures and three (3) vegetation cycles. The results gave the mean of the fractal dimension (value 1 to 2), the mean of the cosine (value -1 to 1) and mean travel (m/day) over the 6 day grazing period. The means of fractal dimension, cosine and travel for pasture, season and vegetation cycle were compared using Mixed Linear Models in Jump 7 (JMP 7), a statistical package from SAS.

The model(s) were:

$(D, C, T)_{ijklm} = Cow_i + S_j + CS_{ij} + P_k + SP_{jk} + VC_l + Error_{ijklm}$

Where as:

D, C or T = the overall mean for Fractal Dimension, Cosine, or Travel

Cow_j = random effect for the $_j$th cow

$Season_j$ = the affect of season

CS_{ij} = interaction of Cow_i by $Season_j$

$P_{k\,=}$ the affect of pasture

$SP_{ik\,=}$ interaction of $Season_i$ by $Pasture_k$

VC_l = the affect of Vegetative Cycle$_l$

ε_{ijklm} = error

Landscape Attributes

Slope, elevation and aspect were derived from a 10-meter USGS Digital Elevation Map (DEM) using ArcGIS. Using the DEM, three slope classes (0-15, 15-30; and 30-60) were segregated for each pasture. Other researches have used a variety of slope classifications. Valentine (1990) used eight different categories of slope (0%, 10%, 20%, 30%, 40%, 50%, 60%, and 70%) to show its influence on relative cow use. Wagnon (1968) used slope classifications of 0, 0-10%, 10-25% and >25%. Holechek et al. (1989) used 0-10, 11-30, 31-60, and over 60% for slope classifications. Aspect was calculated and expressed as a hillshade model, using ArcGIS. Using a stock water GIS layer, distance to water was calculated as a horizontal Euclidean distance from the water source. Canopy cover for each pixel was classified as 0 for no canopy cover or 1 for canopy cover using the National Agriculture Imagery Program (NAIP) image in ArcGIS.

In each of the four pastures permanent north-south transects were established every 30 meters. At 30 meter intervals along each transect species composition (forbs, palatable grasses, unpalatable grasses and medusahead), percent grazed, litter, and bare ground were ocular estimated in a .09m^2 quadrat. Stubble height was averaged using 5 height measures in each quadrat. Pre-grazing standing crop was estimated using the comparative yield (CY) method (Haydock and Shaw

1975). George et al. (2007) found that the CY method can be used with confidence throughout the year to estimate herbage standing crop from CY or stubble height.

Landscape Heterogeneity

Variations in slope and presence or absence of canopy cover are landscape attributes that other researchers have shown to influence beef cow movements (Harris et al. 2002; Harris et al. 2006; George et al. 2007). Fractal dimension for canopy cover (presence or absence) and the two extreme slope categories (less than 15 percent and greater than 30 percent) compared slope and canopy cover complexity for the four pastures. The image files in Tagged Image File Format (TIFF) for slope generated from the DEM were downloaded into Image J, a public domain Java image processing program. The program calculates area and pixel value statistics of user-defined selections. The same procedure was used to process the canopy cover images extracted from the (NAIP) images for each pasture.

The TIFF images were opened in Image J©, by selecting the “Stacks” drop down menu, selecting “add Slice” and paste. The Image option “change to an 8-bit file” was then selected. In the image drop down menu “adjust thresholds” is selected, and MaxEntropy selected. MaxEntropy is a statistical process that analyzes the distributions of assigned features, such as canopy cover. The file created was placed in the Pluggins application and scanned to give the Fractal dimension across the assigned scale of the two extreme slope classifications, canopy cover or no canopy cover, processing the 8-bit image.

Fractal dimension for the two slope classifications and canopy cover are calculated using FracLac_2.5. In FracLac "Standard Box" was selected and then "Scan Image" was selected, resulting in calculation of the mean Fractal dimension for slope or canopy cover.

Fractal Dimension Across Scales

The fractal dimension of cow movement paths are analyzed to determine if animal movement is affected by scale, as shown by "domains or ranges" of scale. Nams (2005) used both large and small scales to define "domains of scale". In the large domains of scale, Nams (2005) considered movement pattern to be homogeneous and animals travel in a direct path. In small domains of scale, movement pattern is heterogeneous or more tortuous. All cow fractal dimension observations (VFD) are compared to predicted fractal dimension (PredD) by a polynomial regression. Two different models were developed for 0 to 40 meter scale and 40 to 300 meter scale. The model(s):

logVFD (0-40) = M…..+ Cow_i + $Season_j$ + CS_{ij} + $Pasture_k$ + SP_{jk} + $\beta_1$log scale + $\beta_2$log scale^2 + $\beta_3$log scale^3 + $\beta_4$log scale^4 + $b_i$log scale + $\gamma_k$log scale + γjlog scale + γ_{jk}log scale + γ_{2j}log scale + γ_{2k}log scale + ε_{ijkl}

where:

x = log scale

Mean = overall Mean

Cow_i = random effect for the $_i$th cow

$Season_j$ = effect for the $_j$th season

CS_{ij} = interaction of cow_i by $season_j$

$Pasture_k$ = effect for the $_k$th pasture

SP_{ij} = interaction of the $season_j$ by $pasture_k$

b_i = random effect of cow_i on slope of log scale (x)

γ_j = effect of $season_j$ on slope of log scale

γ_k = effect of $pasture_k$ on the slope of log scale

γ_{jk} = interaction effect of cow_i by $season_j$ on slope of log scale

γ_{2j} = effect of season on $slope_j$ of log $scale^2$

γ_{2k} = effect of $pasture_k$ on slope of log $scale^2$

$Error_{ijkl}$ = error

Model logVFD (40-300) = M…..+ Cow_i + $Season_j$ + $Pasture_k$ + SP_{jk} + $\beta_1$log scale + $\beta_2$log $scale^2$ + $\beta_3$log $scale^3$ + $\beta_4$log $scale^4$ + $b_i$log scale + $\gamma_k$log scale + γjlog scale + γ_{jk}log scale + b_{2i}log $scale^2$ + γ_{2j}log $scale^2$ + γ_{2k}log scale2 + γ_{2jk}log $scale^2$ + b_{3i}log $scale^3$ + γ_{3j}log $scale^3$ + γ_{3k}log $scale^3$ + γ_{3jk}log $scale^3$ + b_{4i}log $scale^4$ + γ_{4j}log $scale^4$ + γ_{4k}log $scale^4$ + γ_{4jk}log $scale^4$ + ε_{ijkl}

where:

x = log scale

M = overall mean

Cow_i = is a random effect for the $_i$th cow

$Season_j$ = effect of the $_j$th season

$Pasture_k$ = effect of the $_k$th pasture

SP_{jk} = effect of the interaction of $season_j$ by $pasture_k$

β_1 = slope of the logscale (x)

β2 = slope of the logscale (x^2)

β_3 = slope of the logscale (x^3)

β4 = slope of the logscale (x^4)

b_i = random effect of cow_i on slope of log scale (x)

γ_j = effect of $season_j$ on slope of log scale

γ_k = effect of $pasture_k$ on the slope of log scale

γ_{jk} = interaction effect of cow_i by season on slope of log scale

b_{2i} = random effect of cow_i on slope of log $scale^2$

γ_{2j} = effect of $season_j$ on slope of log $scale^2$

γ_{2k} = effect of $pasture_k$ on slope of log $scale^2$

γ_{2jk} = effect of interaction of $season_j$ by $pasture_k$ of log $scale^2$

b_{3i} = random effect of cow_i on slope of log $scale^3$

γ_{3j} = effect of $season_j$ on slope of log $scale^3$

γ_{2k} = effect of $pasture_k$ on slope of log $scale^3$

$\gamma 3_{jk}$ = effect of interaction of $season_j$ by $pasture_k$ of log $scale^3$

b_{4i} = random effect of cow_i on slope of log $scale^4$

$\gamma_4 j$ = effect of $season_j$ on slope of log $scale^4$

γ_{4k} = effect of $pasture_k$ on slope of log $scale^4$

γ_{4jk} = effect of interaction of $season_j$ by $pasture_k$ of log $scale^4$

$Error_{ijkl}$ = error

The subscripts are the exponential of log scale and the level of the nominal factors.

Correlation of Cosine

The correlation of cosine (CrCs) is the most important estimator to detect use of a hierarchical patchy structure (Nams 2005). At first analysis, correlation of cosine had heterogeneity of variance. Therefore the correlation of cosine was transformed exponentially to the 2.5 power. The model developed was:

$[ExpCrCs*2.5] = M \ldots + C_i + S_j + P_k + SP_{jk} + \beta_1 x + \beta_2 x^2 + \beta_3 x^3 + \beta_4 x^4 + b_i x + \gamma_i x + \gamma_j x + \gamma_{ij} x + b_i x^2 + x_{2j} x^2 + \gamma_{2i} x^2 + \gamma_{2ij} x^2 + b_i x^3 + \gamma_{3i} x^3 + \gamma_{3j} x^3 + \gamma_{3ij} x^3 + b_i x^4 + \gamma_{4j} x^4 + \gamma_{4i} x^4 + \gamma_{4ij} x^4 + error_{ijkl}$

where:

x = log scale

M = overall mean

Cow_i = is a random effect for the $_i$th cow

$Season_j$ = effect of the $_j$th season

$Pasture_k$ = effect of the $_k$th pasture

SP_{jk} = effect of the interaction of $Season_j$ with $Pasture_k$

β_1 = slope of the logscale (x)

$\beta 2$ = slope of the logscale (x^2)

β_3 = slope of the logscale (x^3)

$\beta 4$ = slope of the logscale (x^4)

b_i = random effect of cow_i on slope by log scale

b_{2i} = random effect of cow_i on slope by log $scale^2$

$\gamma 2j$ = effect of the $_j$th season by log $scale^2$

$\gamma 2_k$ = effect of the $_k$th pasture by log $scale^2$

$\gamma 2_{jk}$ = effect of interaction of $_j$th season with $_k$th pasture by log $scale^2$

b_{3i} = random effect of cow_i on slope by log $scale^3$

γ_{3j} = effect of the $_j$th season by log $scale^3$

γ_{3k} = effect of the $_k$th pasture by log $scale^3$

$\gamma_3 j_k$ = interaction of the $_j$th season with $_k$th pasture by log $scale^3$

b_{4i} = random effect of cow_i on slope by log $scale^4$

$\gamma_4 j$ = effect of the jth season by log $scale^4$

γ_{4k} = effect of the $_k$th pasture by log $scale^4$

$\gamma_4 j_k$ = interaction of the $_j$th season with $_k$th pasture by log $scale^4$

$Error_{ijkl}$ = error

From this model the [ExpCrCs*2.5], the Predicated CrCs (Pred), and the confidence intervals (CIs) were calculated. Once the transformation was conducted, the variance is analyzed and deemed acceptable. The values are back transformed by the formula: log[ExpCrcs*2.5]/2.5 to obtain the CrCs, Predicted CrCs and CIs in the original CrCs scale without the heterogeneous variance.

Influence of Landscape Attributes on Cow Activities

Multiple regression models were used to determine if landscape attributes influenced beef cow occupation of grid cells (pixels) for three activities (grazing, resting or cruising). Cow speed was used to classify activity. Cow speed was calculated from changes in cow positions (easting, northing, time). Following methods similar to Putfarken et al. (2008) cow movement paths over a 5 minute period were classified as “resting” if the speed was less than 6 meters per 5 minutes, “grazing” if the speed exceeded 6 meters per 5 minutes but was less than 100 meters per 5 minutes, and ‘cruising’ if the speed was more than 100 meters per 5 minutes. Cruising is a term to indicate direct movement by animals toward facilities, water, or other attractants. Vegetation attributes (easting, northing) are field based data collected along a 30 meter grid and then rasterized by converting attribute location to the closest northing-easting grid cell center point.

A selectivity index (SI) was calculated to determine occupancy of grid cells for each of the three cow activities (grazing, resting, and cruising). For each grid cell SI was calculated where SI= number of positions for each activity/total positions for each activity in the pasture. In the regression model the log of the SI for each activity was used. Models of the influence of landscape attributes (X) on the three cow activities (Y) were determined using multiple regressions. With terms for Slope (%); Elevation (m);, Distance to Water (m); Canopy Cover (%); Vegetation Height (cm); Pre-grazing Standing Crop (PGSC) (kg/ha); Forbs (%); Palatable grass (%); Unpalatable grass (%); Medusahead (%); Collar Mean Temperature (C);Slope * Elevation; Slope * Distance to Water; Slope * Canopy Cover; Slope * Vegetation Height; Elevation * Distance to Water; Elevation * Pre-grazing Standing Crop; Elevation * Medusahead; Distance to Water * Canopy Cover; Distance to Water * Pre-grazing Standing Crop; Distance to Water * Mean Temperature; Canopy Cover * Vegetation Height; Canopy Cover * Mean Temperature; Vegetation Height * Pre-grazing Standing Crop; Pre-grazing Standing Crop* Unpalatable Grass; Pre-grazing Standing Crop * Mean Temperature; Palatable Grass * Mean Temperature; Unpalatable Grass * Medusahead; Medusahead * Mean Temperature; Canopy Cover * Canopy Cover; Mean Temperature * Mean Temperature; Medusahead * Medusahead.

RESULTS

Fractal Dimension

There were significant differences ($p<0.05$) between pastures, seasons and vegetative cycles for the Fractal dimension least square means (LSM) for all cow pooled movements. Fractal dimension can be influenced by behaviors such as foraging intensity and habitat selection. The results show D for Forbes 2 and Haworth pastures were greater than for Forbes 1 or Porter (Figure 1, Table 3), indicating animals travelled a more tortuous path than in Forbes 1 or Porter. Fractal dimension for a path can vary between 1 (straight line) and 2 (very winding line that tends to cover the whole plane. A value of 1.5 represents a very tortuous movement path, is rarely seen in nature (Nams 1996). The results indicate the D for all pastures have a high level of tortuousity.

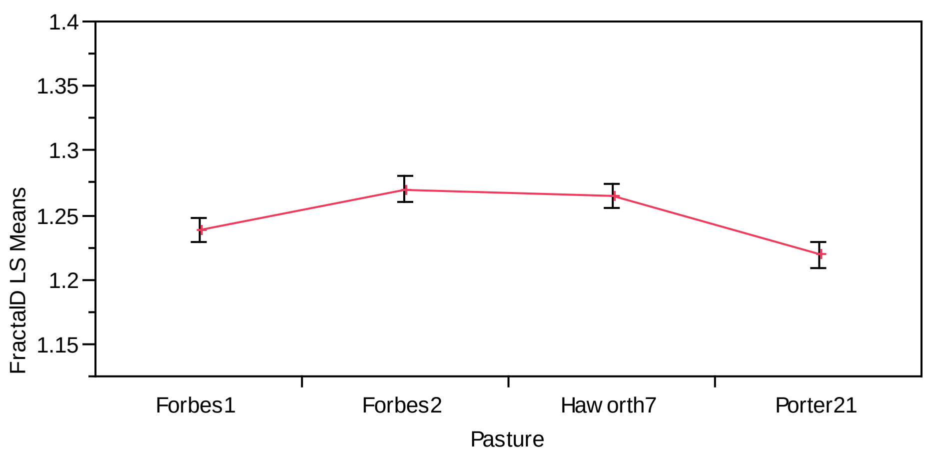

Figure 1. LSM Fractal Dimension for all Cow Movement (Y axis) in Four Pastures (X axis)

Table 3. LSM Fractal Dimension for all Cow Movement in four Pastures

Pasture			**Least Sq Mean**
Forbes 1	B		1.26
Forbes 2	A		1.27
Haworth		A	1.24
Porter		B	1.22

Spatial memory allows animals to remember where they have foraged and use that information to determine where they will travel and forage Howery et al. (1999). The research did not explore spatial memory but when the eight different seasons were examined, the four same seasons are significantly similar, and thus combined. This could have been a result of the cattle having a spatial memory of the pastures as all but two collared cattle remained in research during the three years. The fractal dimension least square means for the winter, early spring, late spring and summer are shown in Figure 2 and Table 4. Fractal dimension least square means are significantly greater in winter and early spring than in later spring and summer.

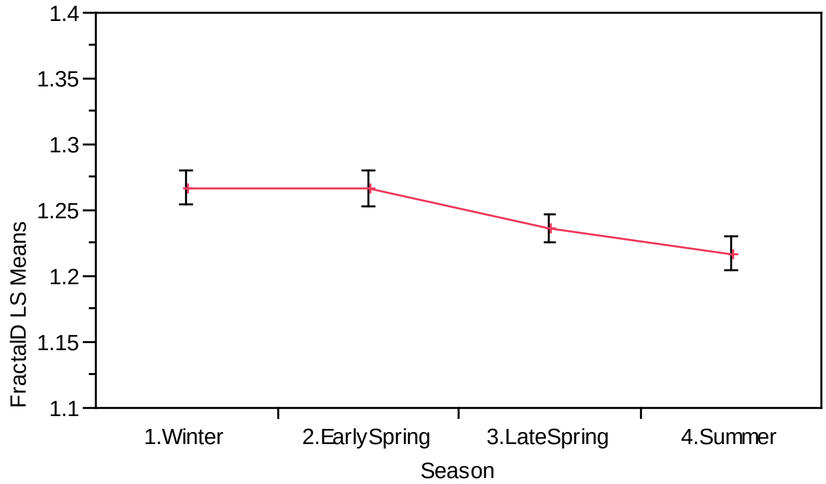

Figure 3. LSM Fractal Dimension for all Cow Movement (Y axis) in four Seasons (X axis)

Table 4. LSM Fractal Dimension for all Cow Movement in four Seasons

Season			**Least Sq Mean**
Winter	A		1.27
Early Spring	A		1.27
Late Spring		B	1.24
Summer		B	1.22

Fractal dimension least square means for the 2001 vegetation cycle are significantly greater than Fractal dimension least squares for the 2002 and 2003 vegetation cycles (Figure 3, Table 5).

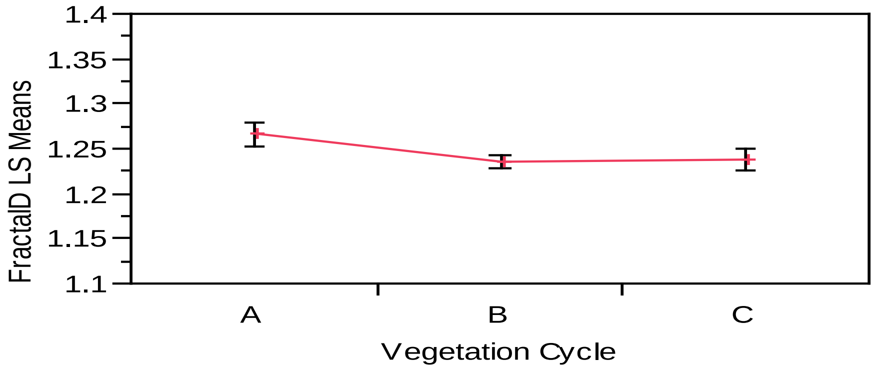

Figure 3. LSM Fractal dimension for all Cow Movement (Y axis) in three Vegetation Cycles (X axis)

Table 5. LSM Fractal Dimension for all Cow Movement in three Vegetation Cycles

Vegetation Cycle			Least Sq Mean
A	A		1.3
C		B	1.2
B		B	1.2

Mean Cosine of Turning Angles

There were significant differences ($p < 0.05$) for pastures, seasons, and vegetation cycle. The mean cosine for turning angles for all cow positions was significantly lower for the Haworth pasture than the other three (Figure 4, Table 6).

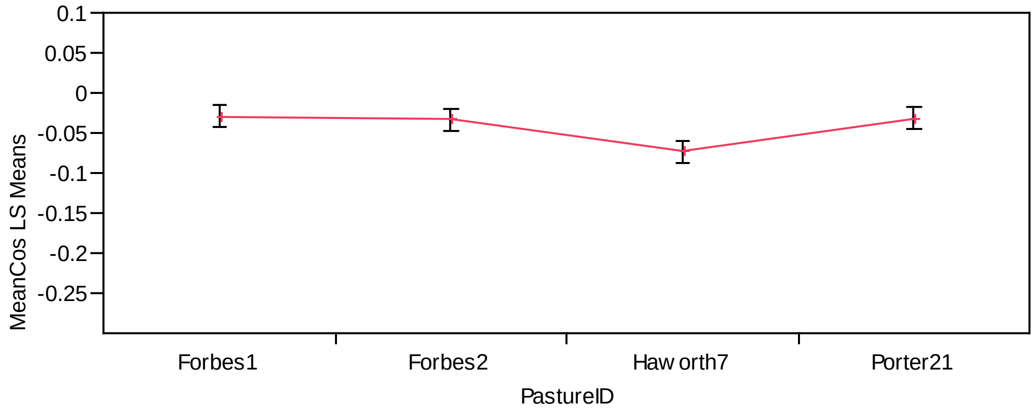

Figure 4. LSM Cosine for turning angles for all Cow Movements (Y axis) in four Pastures (X axis)

Table 6. LSM Cosine for turning angles for all Cow Movement in four Pastures [1]

Pasture		Least Sq Mean
Forbes 1	A	-0.0291596
Forbes 2	A	-0.0332392
Haworth	B	-0.0737222
Porter	A	-0.0312928

[1]**In the VFractal software, angles are measured between two segments of the path. Thus, a straight path will have a mean cosine of -1.0. Negative values near -1.0 indicate the path is straight.**

Mean cosine for turning angles for all cows is significantly different for each season (Figure 5, Table 7) indicating that turning angles decreased through the seasons.

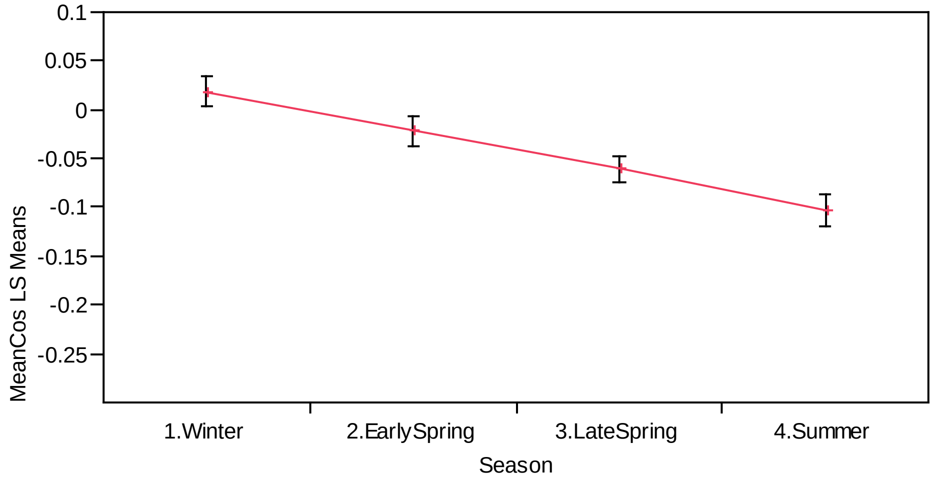

Figure 5. LSM Cosine of turning angles for all Cow Movement (Y axis) in four Seasons (X axis) [1]

[1]**In the VFractal software, angles are measured between two segments of the path. Thus, a straight path will have a mean cosine of -1.0. Negative values near -1.0 indicate the path is straight.**

Table 7. LSM Cosine of turning angles for all Cow Movement in four Seasons[1]

Season					Least Sq Mean
1. Winter	A				0.019
2. Early Spring		B			-0.022
3 .Late Spring			C		-0.061
4. Summer				D	-0.104

[1]**In the VFractal software, angles are measured between two segments of the path. Thus, a straight path will have a mean cosine of -1.0. Negative values near -1.0 indicate the path is straight.**

The mean cosines for turning angles in the 2002 and 2003 vegetation cycles are significantly different. Mean cosine for the 2001 vegetation cycle is not different from the 2002 or 2003 cycles (Figure 6, Table 8).

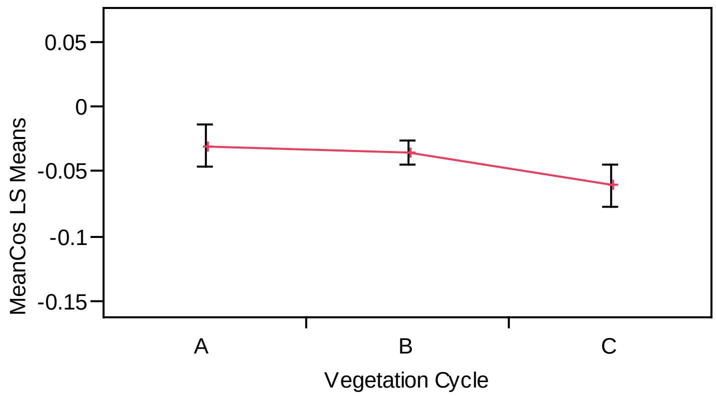

Figure 6. LSM Cosine of turning angles for all Cow Movements (Y axis) in three Vegetation Cycles (X axis)[1]

[1]**In the VFractal software, angles are measured between two segments of the path. Thus, a straight path will have a mean cosine of -1.0. Negative values near -1.0 indicate the path is straight.**

Table 8. LSM Cosine of turning angles for all Cow Movement in three Vegetation Cycles[1]

Cycle		**Least Sq Mean**
A	A	-0.03
B	A	-0.035
C	B	-0.06

[1]**In the VFractal software, angles are measured between two segments of the path. Thus, a straight path will have a mean cosine of -1.0. Negative values near -1.0 indicate the path is straight.**

Travel Distance

Mean distance traveled per day for Haworth and Porter are significantly greater than Forbes 1 and Forbes 2 (Figure 7, Table 9). Travel means for winter are significantly greater than the means for summer and late spring (Figure 8, Table 10). The travel means for early spring are not significantly different from the other seasons. There are no significant differences between the three vegetation cycles.

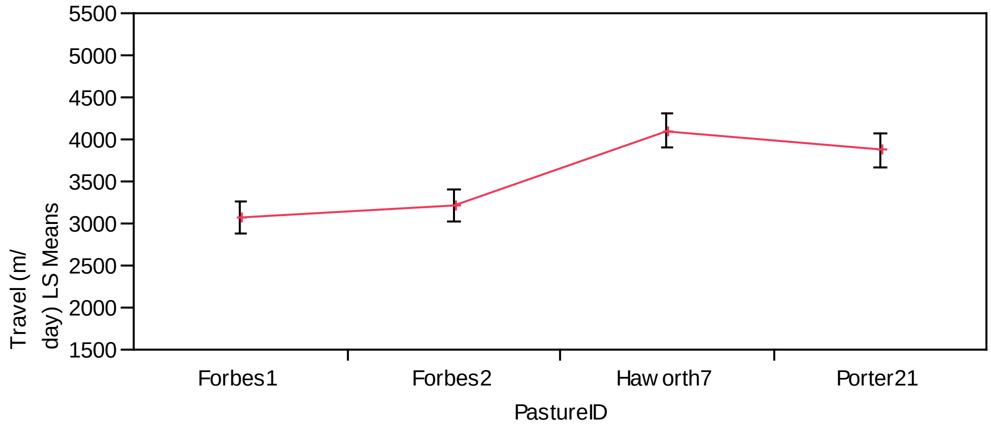

Figure 7. LSM Distance traveled (m/day) for all Cow Movement (Y axis) in four Pastures (X axis)

Table 9. LSM Distance traveled (m/day) for all Cow Movement in four Pastures

Pasture			**Least Sq Mean**
Forbes 1		B	3210.5
Forbes 2		B	3078.4
Haworth	A		4100.2
Porter	A		3869.9

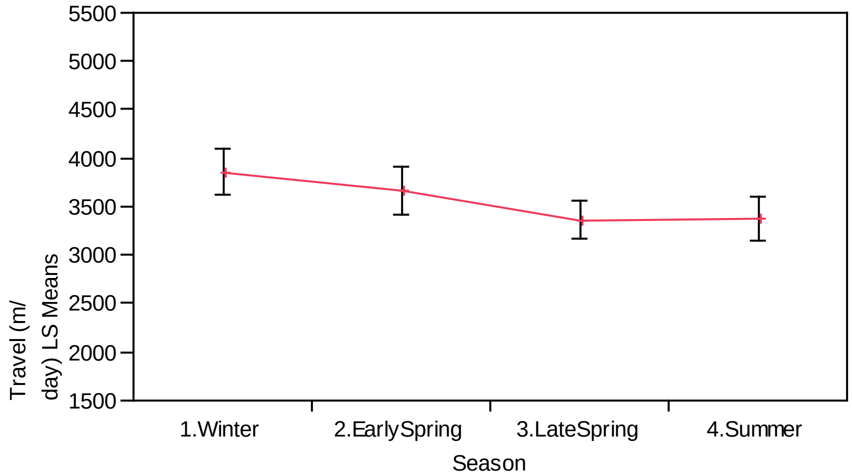

Figure 8. LSM Distance traveled (m/day) for all cows (Y axis) in four Seasons (X axis)

Table 10. LSM Distanced traveled (m/day) for all Cow Movement in four Seasons

Pasture			**Least Sq Mean**
Winter	A		3854.1
Early Spring	A	B	3666.5
Summer		B	3376.1
Late Spring		B	3362.3

Travel is calculated for the three vegetation cycles. There are no significant differences between the three vegetation cycles.

Landscape Heterogeneity

Slope

To determine if there was landscape heterogeneity due to slope, the Fractal dimensions of the gentle slope class (<15 %) and the steepest slope class (>30 %) were determined. The slope's Fractal dimension is an indication of the complexity of the spatial distribution of gentle slopes and steep slopes in each pasture. Figures 9-12 illustrate the three different slope classes.

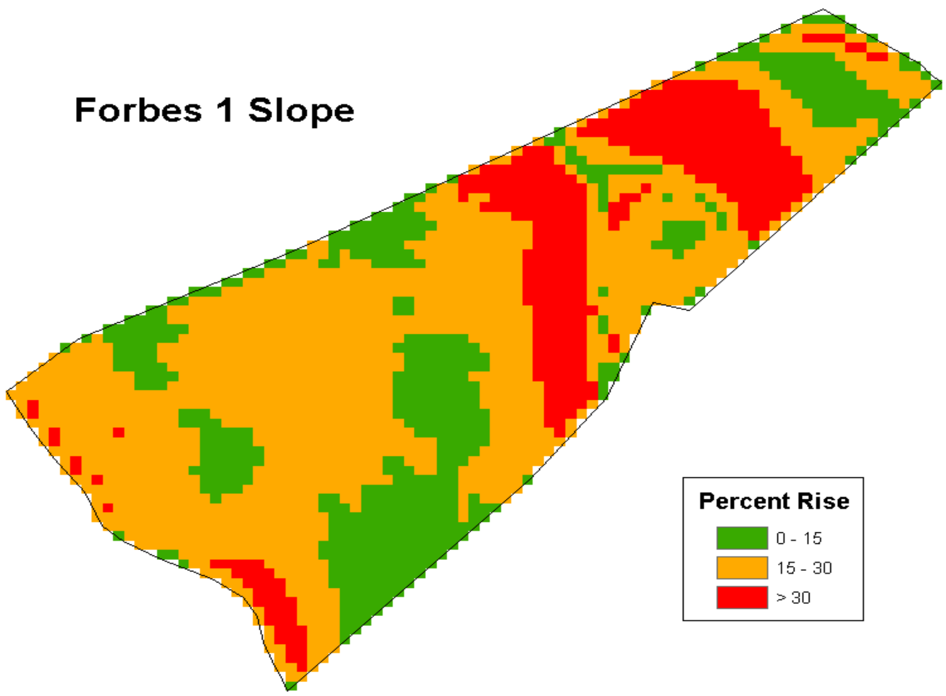

Figure 9. Forbes 1 – Slope Classes, 0-15%, 15-30%, >30%

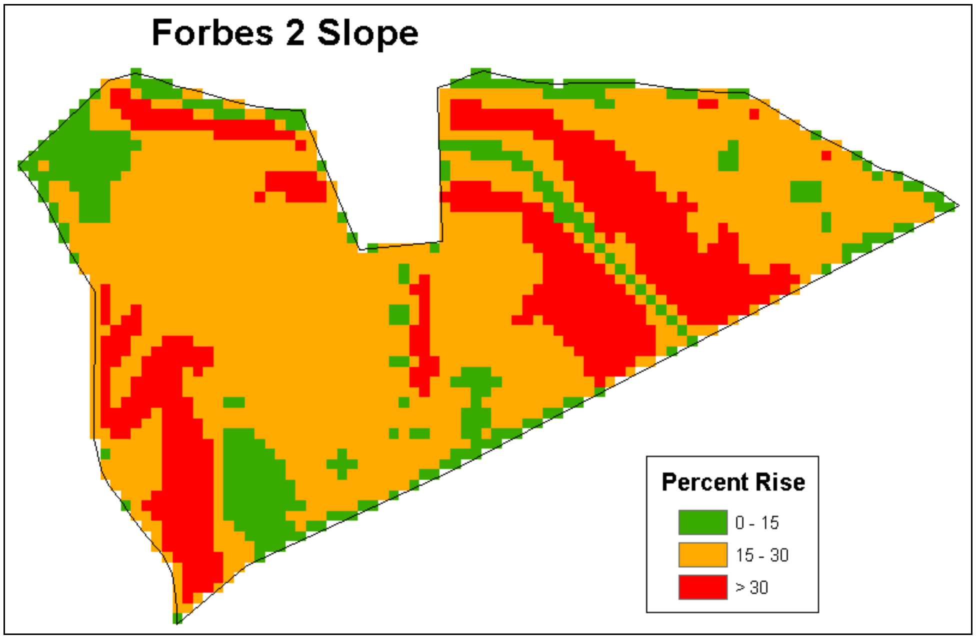

Figure 10. Forbes 2 – Slope Classes 0-15%, 15-30%, >30%

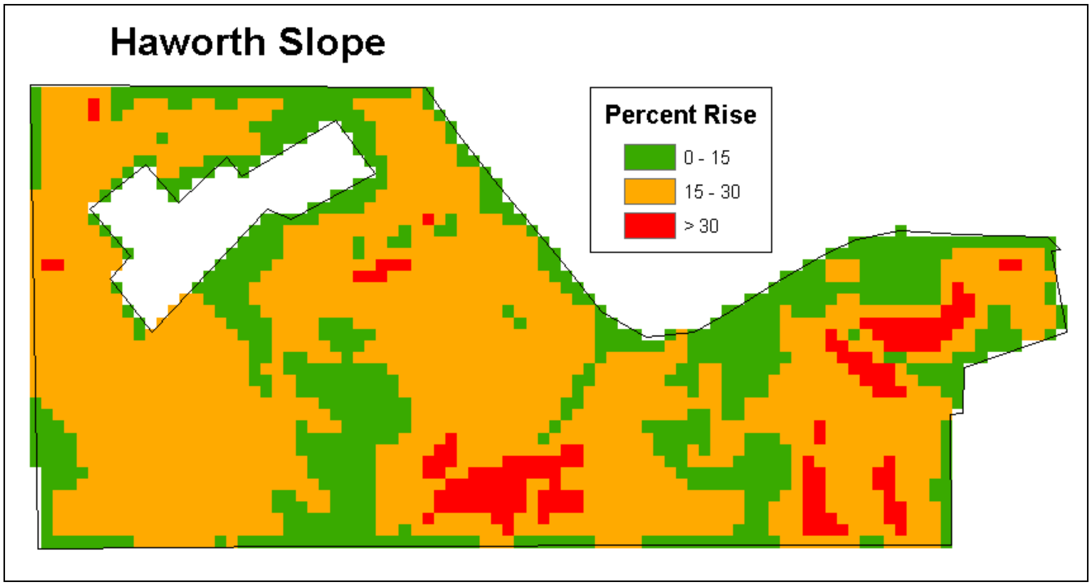

Figure 11. Haworth – Slope Classes 0-15%, 15-30%, >30%

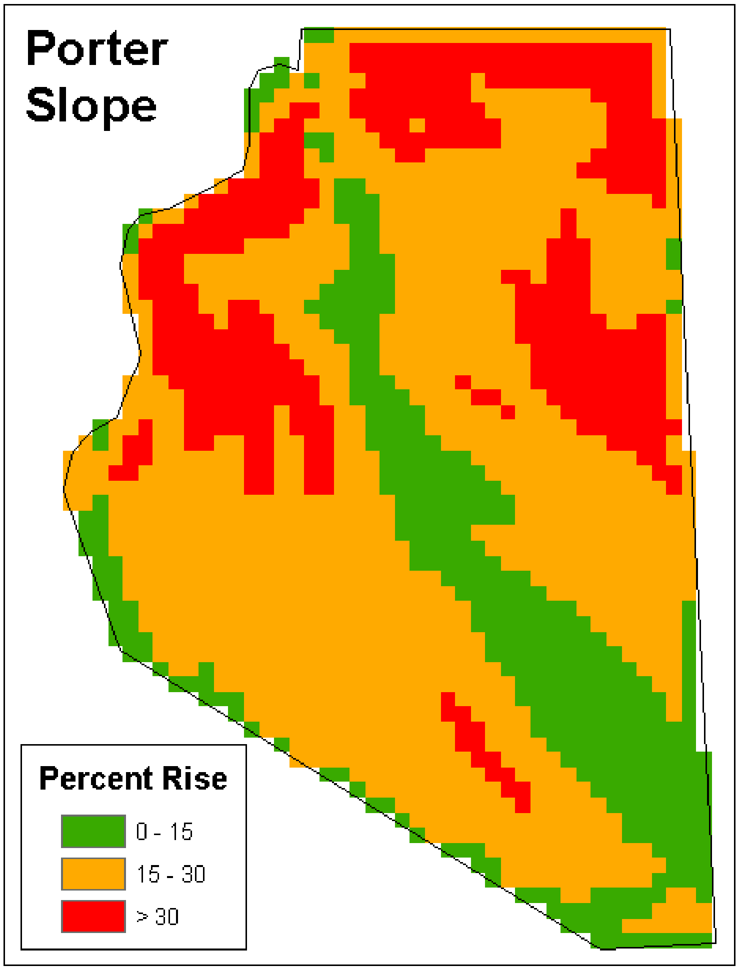

Figure 12. Porter – Slope Classes 0-15%, 15-30%, >30%

Canopy Cover

Figure 13 illustrated the four pastures and the percentage canopy cover.

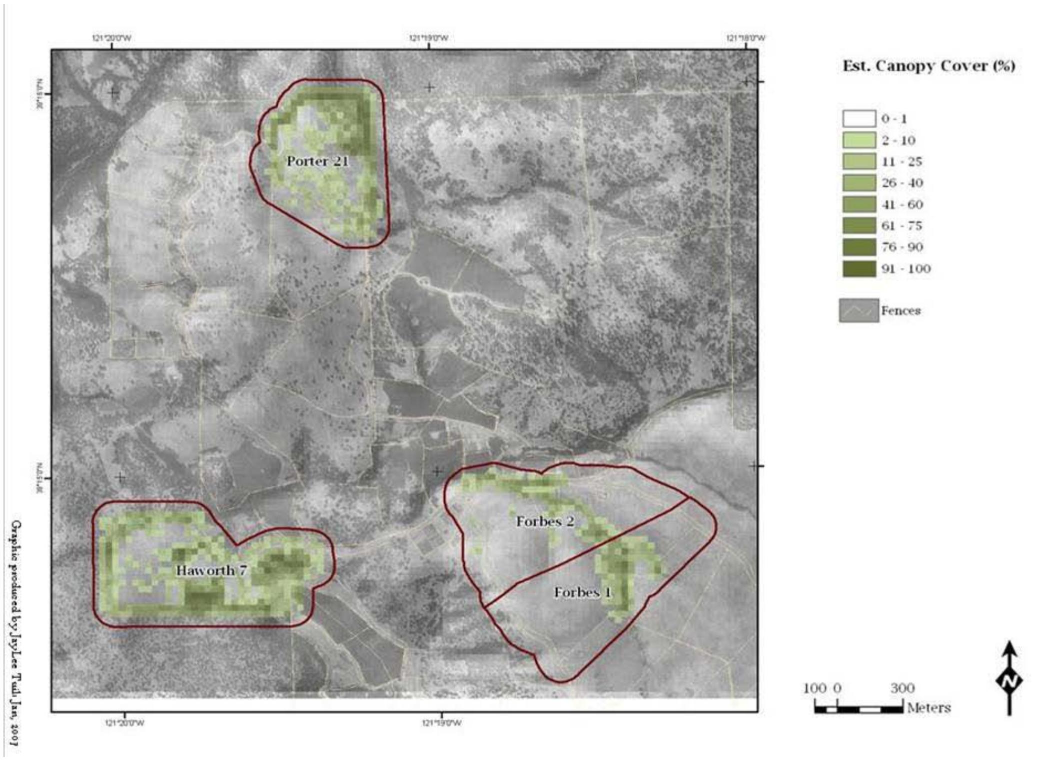

Figure 13. Canopy Cover %: 0-1, 2-10, 11-25, 26-40, 61-75, 76-90, 91-100 for all four pastures

Landscape heterogeneity due to canopy cover was determined for the four pastures by first transforming each pasture's NAIP into a binary picture where areas with canopy cover are black on a white background, with D calculated using the FracLac pluggin for ImageJ. Fractal dimension for canopy cover was greatest in Haworth and Porter pastures (Table 11)and least in the Forbes 1 and 2 pastures indicating that the patterns of canopy cover was more complex in the Haworth and Porter pastures (Figures 19 & 21). Forbes 1 canopy cover occurs in a narrow corridor dividing the pasture into two distinct areas (Figure 15). Forbes 2 has the least amount of canopy cover along the riparian corridor that also divides the pasture (Figures 15). Haworth and Porter pastures have a more complex canopy cover pattern with areas of dense canopy cover mixed with areas of sparse canopy cover (Figures 19 & 21).

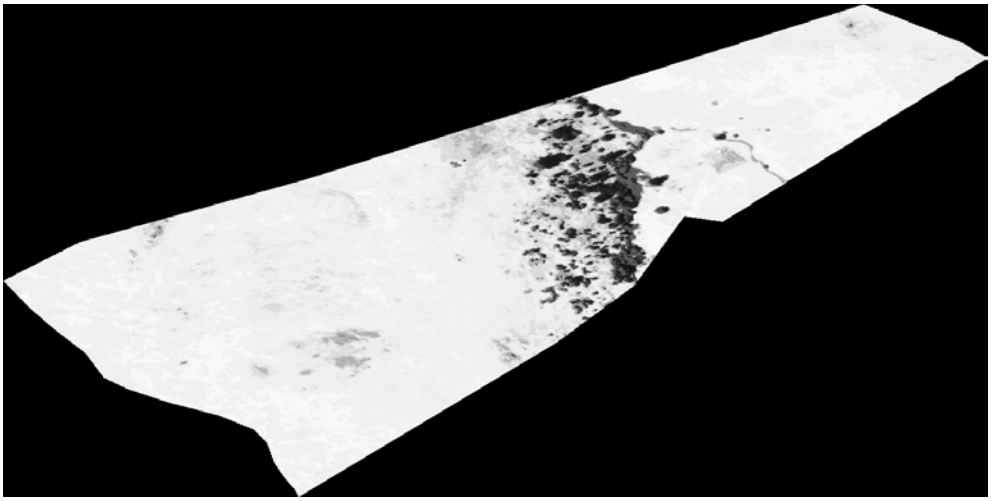

Figure 14. Forbes 1 Pasture; NAIP Referenced Digital Photo

Figure 15. Forbes 1 Pasture, Transformed Photo

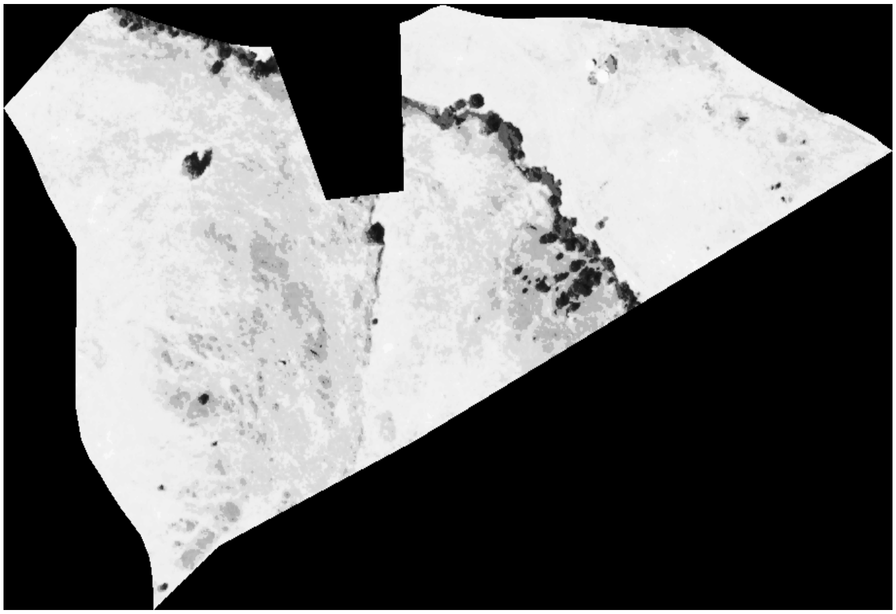

Figure 16. Forbes 2 Pasture, NAIP Referenced Digital Photo

Figure 17. Forbes 2 Pasture, Transformed Photo

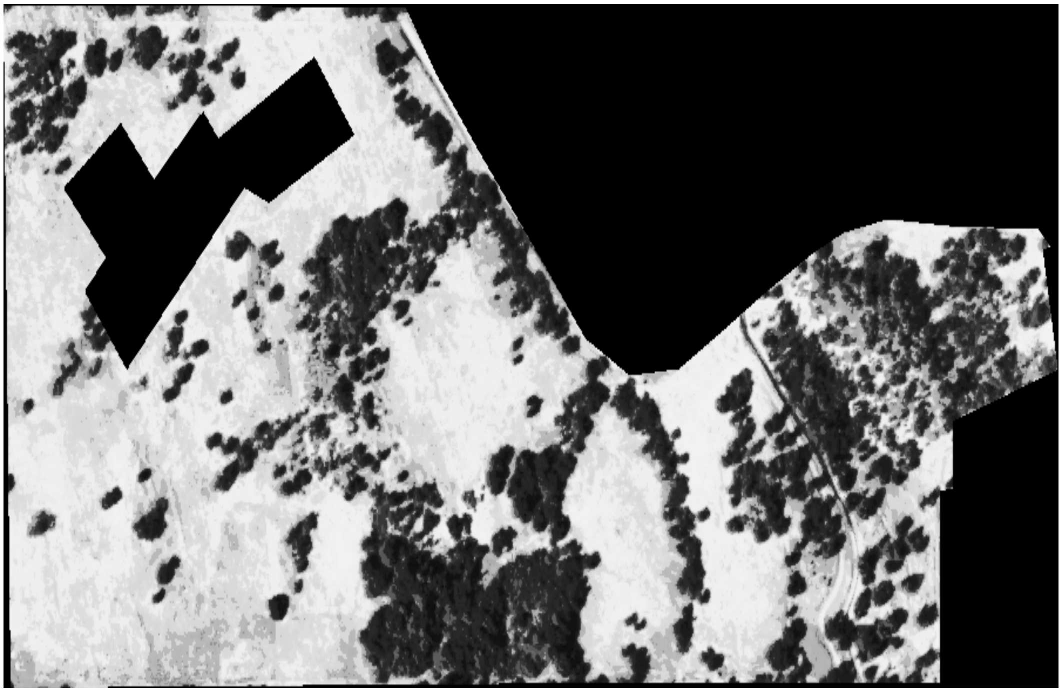

Figure 18. Haworth Pasture, NAIP Referenced Digital Photo

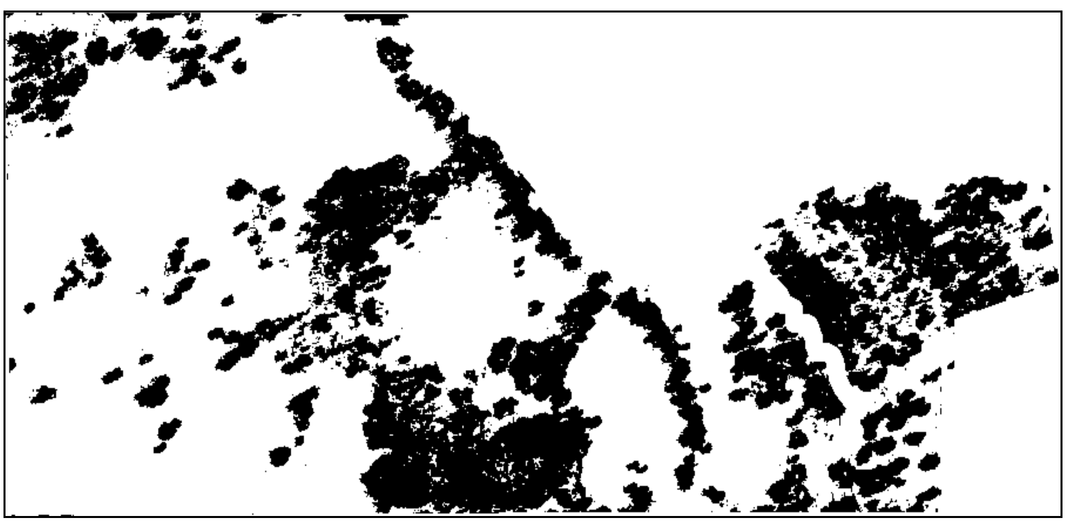

Figure 19. Haworth Pasture, Transformed Photo

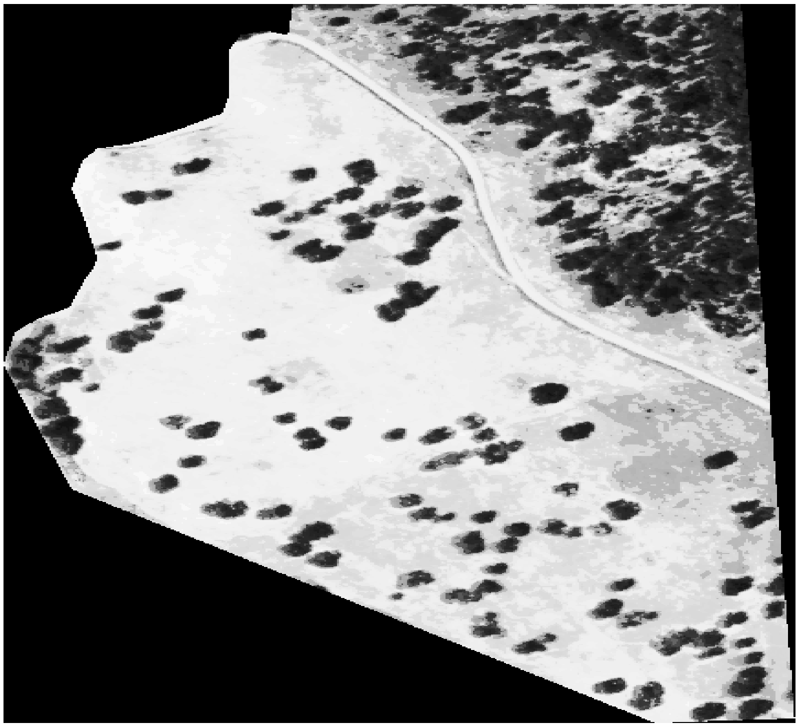

Figure 20. Porter Pasture, NAIP Referenced Digital Photo

Figure 21. Porter Pasture, Transformed Photo

Table 11. Fractal Dimension Means for all cows movement, Slope, <15 & >30%, & Canopy Cover

Pasture	All Cows Fractal Dimension	Fractal Dimension Slope <15%	Fractal Dimension Slope >30%	Fractal Dimension Canopy Cover
Forbes 1	1.2	1.38	1.29	1.45
Forbes 2	1.3	1.31	1.36	1.18
Haworth	1.3	1.49	1.17	1.67
Porter	1.2	1.38	1.48	1.61

Domain of Scale

The fractal dimension plotted across scales from 0 to 300 meters shows a braking point (Figure 22) at approximately 40 meters. This suggests that there are different mechanisms and patterns of movement below and above 40 meters. Figure 23 is a higher resolution example (Forbes 1, early spring) of the plots in Figure 22. With this finer scale, we see another transition after 200 meters; however, this is more likely a function of the pasture size as opposed to animal movement. Cow movements at the scale of 200 meters probably include responses in movement to the presence of a fence, and not necessarily a response to a natural landscape element or intrinsic behavioral process. Therefore, the transitions at scales of 200 and larger are not interpreted as domains of scale because they are not necessarily a result of the interaction of intrinsic movement behavior and landscape characteristics.

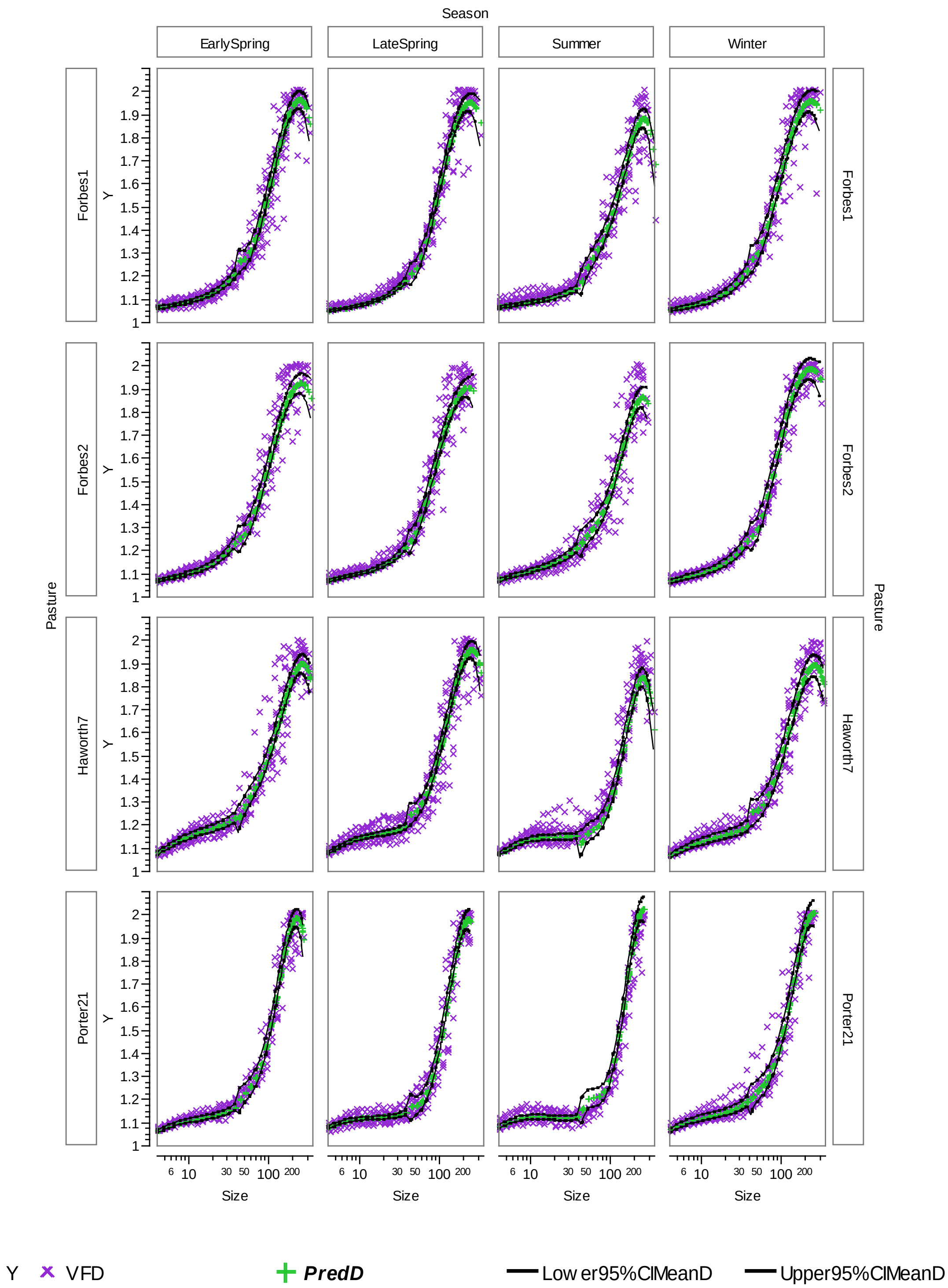

Figure 22. Fractal Dimension of cow movements (Y axis) as a function of scale or "step size" (X axis in m logarithmic scale) in all pastures, all seasons. X's represent the data; +'s represent predicted values; lines represent the 95% confidence interval.

To better examine transitions, Figure 23 shows Forbes 1, Early Spring, with the X axis representing the scale 0 to 300 meters (depicted as Size) and the y axis, the fractal dimension of the paths of all cows pooled.

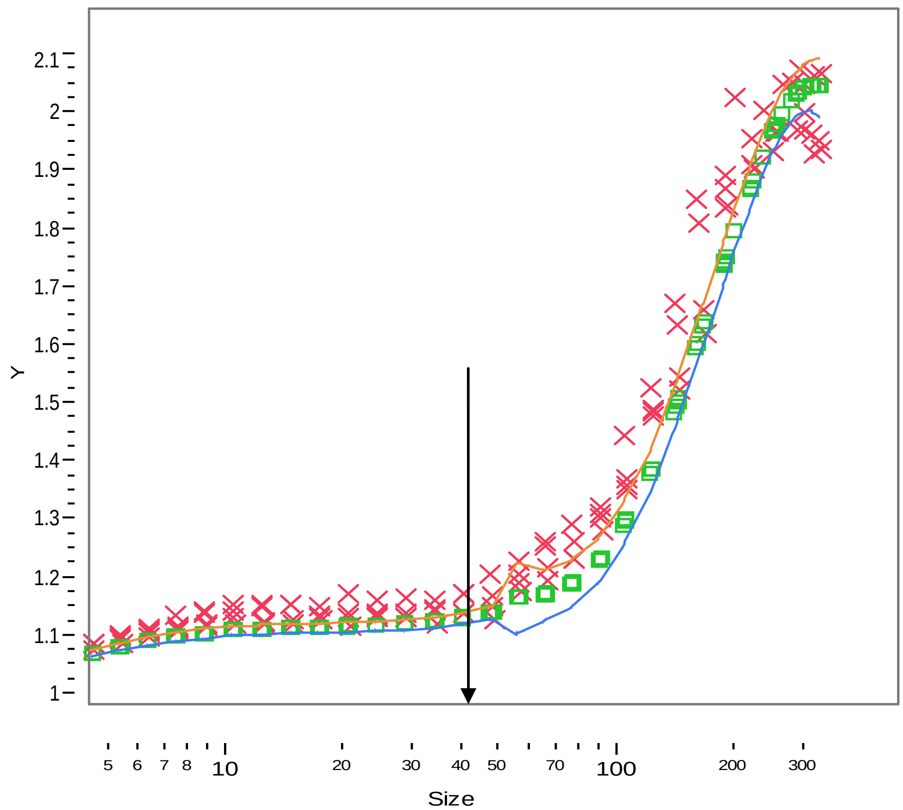

Figure 23. Fractal dimension of cow movements (Y axis) as a function of scale or "step size" (X axis in m logarithmic scale) in Forbes 1, early spring. X's represent the data; □'s represent predicted values; lines represent the 95% confidence interval.

Because the large change in D beyond 40 meters may mask finer patterns below this scale. Figure 22 was partitioned into two ranges, 0 to 40 and 40 to 300, respectively (Figures 24 and 25). When the fractal dimension of cow movements was partitioned, the two ranges of scale became more apparent. Below 40 meters, (Figure 24) additional patterns are present between pastures and seasons. An additional range of scale between 10 to 30 meters appears to be present in some cases. Fractal dimension of paths in Haworth and Porter exhibit a clear change in the slope as size of steps (scale) increases. In these pastures D increases fast at very small scales and then either increases much more slowly or flattens, as is clear in summer. Such patterns are not present in the other two pastures. The overall D for cow movements (Table 11) did not show such differences. Figure 25 shows the fractal dimension of cow movements at a larger range of scale, 40 to 300 meters. We see additional ranges of scale, depending on seasons and pastures. The two prominent ranges or “domains” were seen at 40 to 100 meters and 100 to 200 meters. A constant D would indicate a straighter path of cow movement across landscapes. In Figure 25, we see the D increases as size of steps (scale) increases. The D changes from 1.2 to 1.9, across a range of 40 to 200 meters.

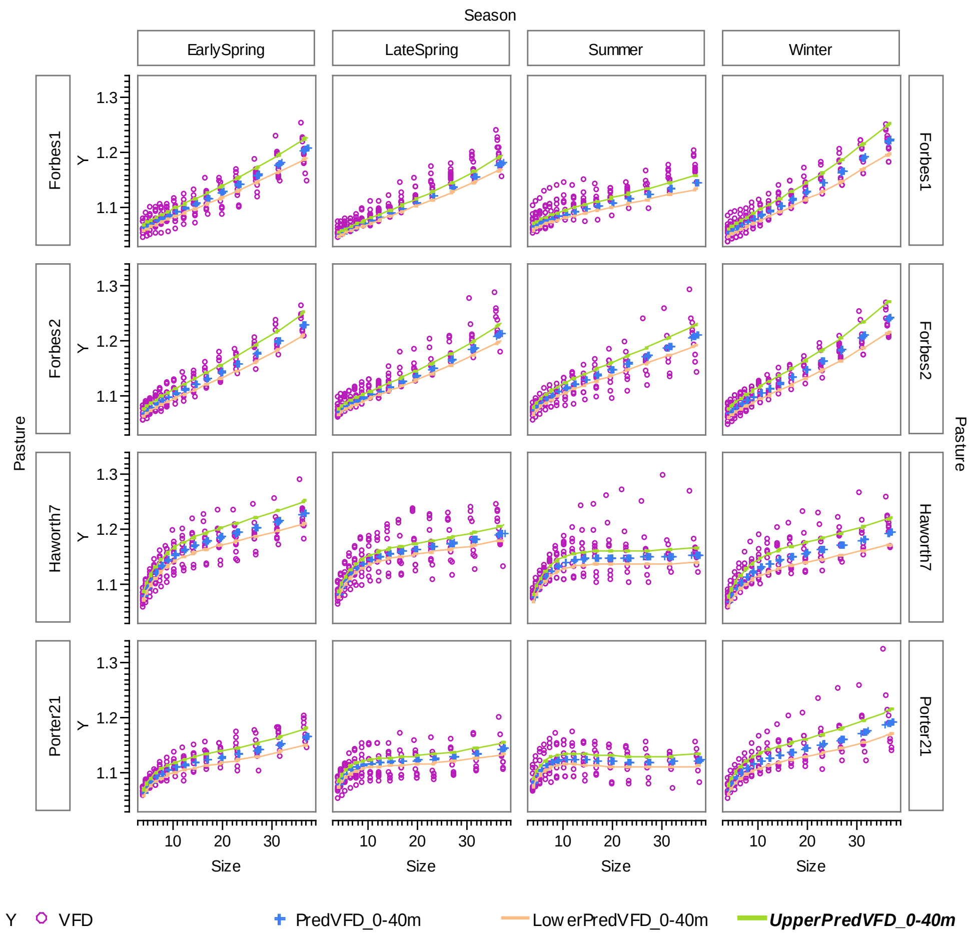

Figure 24. Fractal dimension of the cow movements (Y axis) as a function of scale or "step size" (X axis in m logarithmic scale) in four pastures and four seasons. ◦'s represents the data; + represent predicted values; lines represent the 95% confidence intervals.

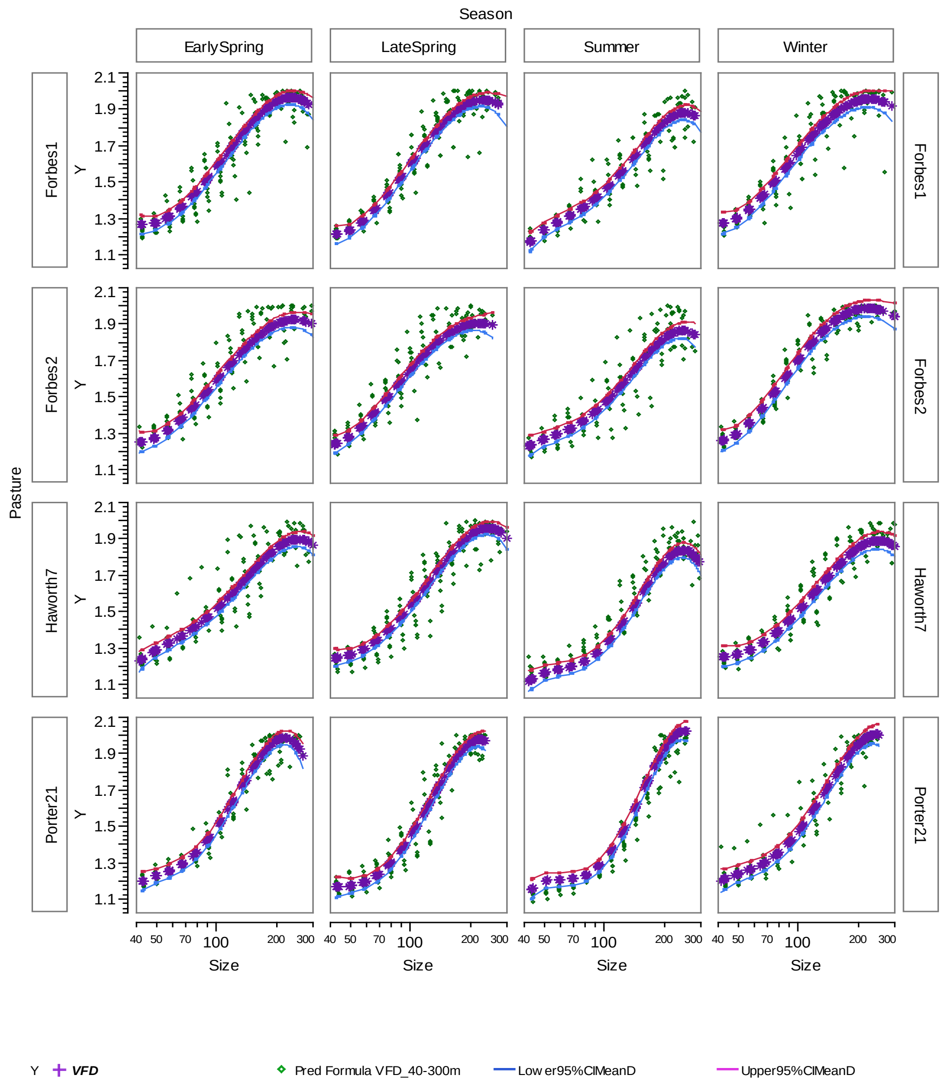

Figure 25. Fractal Dimension of cow movements (Y axis) as a function of scale or "step size" (X axis in m logarithmic scale) in four pastures and four seasons. X's represent the data; ◊'s represent predicted values; lines represent the 95% confidence interval.

Correlation of Cosine

Analysis of Fractal dimension is considered a conservative tool for detecting transitions between domains or ranges of scale (Nams 2005). Correlation of cosine is related to domain of scale, and it is the correlation between the cosines of turning angles separated by a straight distance (d). The clusters of acute angles in the path form movement patches, whereas clusters of large angles form straight sections of the path. As d increases below the scale of movement patches, the correlation is positive, and it becomes negative when d reaches the typical patch size. Correlation of cosine for cow positions were plotted across the 0 to 300 meter scale and grouped with pastures and seasons (Figure 26). Movement paths detected patch sizes in different pastures and seasons.

Correlation of cosine further defines the degree of landscape heterogeneity as a result of patches in the environment. As animal's move along their path, they go in and out of a patch. This is demonstrated by a change from positive to negative correlation.

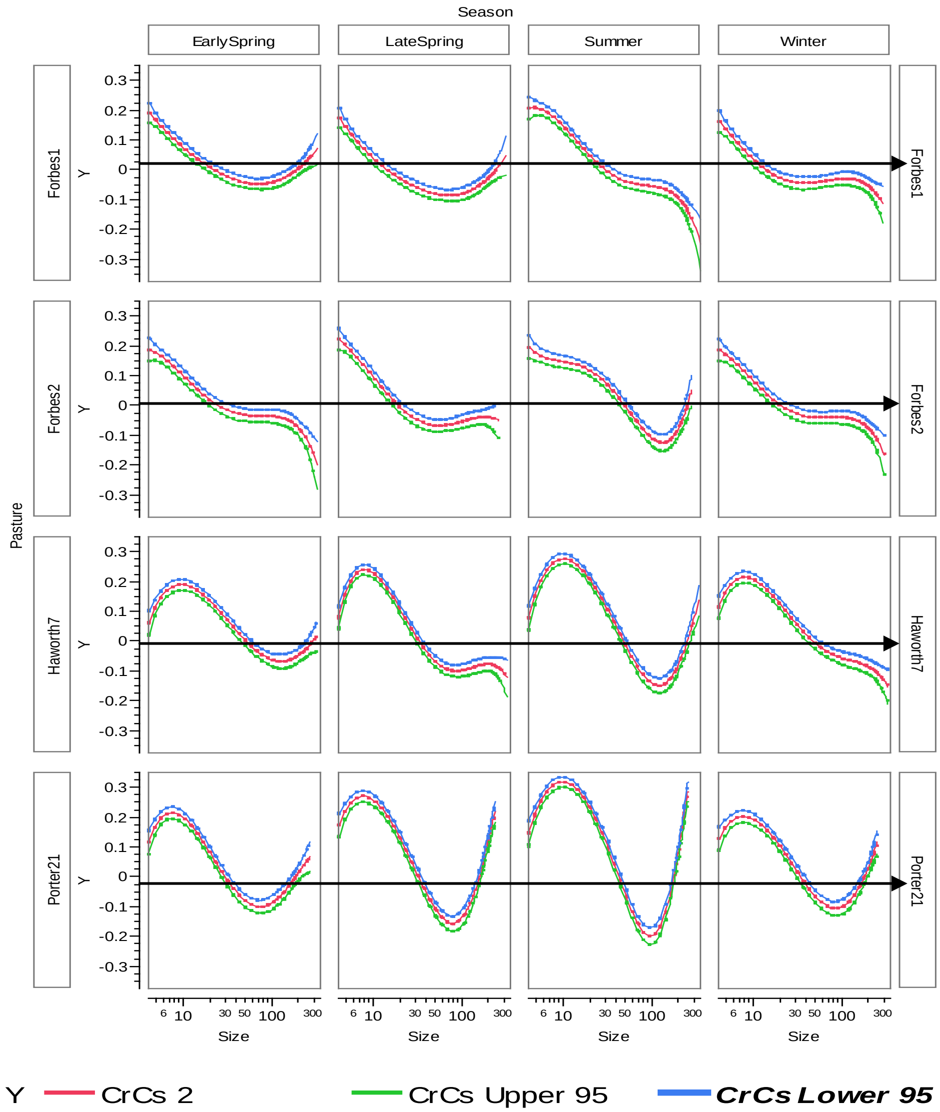

Figure 26. Correlation of Cosine of cow movements (Y axis) as a function of scale or "step size" (X axis in meter logarithmic scale) in four pastures and four season, above (Blue) and below (Green) lines represent the 95% confidence interval. Arrow marks at zero correlation.

Figure 26 shows correlation of cosine plotted across logarithmic scale, 0 to 300 meters, grouped with pastures and seasons. As correlation values go from positive to negative; there is a change in patch size, whereas a zero correlation indicates that there is no patch use. Figure 26 shows there are changes in patch size for the different pastures and season. We detected tortuousity in animal movement paths and heterogeneity of slope and canopy cover classes and scale effects on animal movement.

Landscape Attributes and Animal Activity

Multiple regressions assessed the influence of several landscape attributes on three classes of animal activity: resting, grazing, and cruising. Activity is classified as resting if animals moved less than 6 meters during the typical 5-minute interval between GPS locations Movement, between 5 and 100 meters per 5-minute interval was classified as grazing, and movement of more than 100 meters was classified as ”cruising” (Putfarken et al. 2007). Result s are shown in Tables 12, 13, 14 with significant attributes listed as having positive or negative intercepts. The p values were not corrected for spatial autocorrelation.

Grazing Use

Multiple regression analysis found several variables (Table 12) that were significantly related to grazing activity (R^2 = .24). Grazing was positively associated with forbs, palatable grasses and vegetation height (Ht) and negatively associated with slope, distance to water, pre grazing standing crop (PreDwt), unpalatable grasses and medusahead (*Taeniatherum caput-medusae (L.) Nevski)*. Unpalatable grasses included medusahead, barbed goatgrass (*Aegilops* spp.*)* and ripgut brome (*Bromus diandrus (Roth) Lainz*). The height of the grass positively influenced grazing use but the pre-grazing standing crop negatively affected grazing use.

The negative effect of slope and distance to water on grazing has been reported by several researchers (Mueggler 1965, Cook 1966, Roath and Krueger 1982a, Pinchak et al. 1991, and Ganskopp et al. 2000). These two landscape attributes predict livestock distribution more reliably and consistently than most other abiotic or biotic attributes (Bailey et al. 1996). Clary et al. (1978) conducted one of the few studies that did not find that slope or distance to water influenced distribution. This lack of significance may have been because the study site was well watered and slopes were gentle.

On California's annual rangelands cattle prefer forbs such as filaree *(*Erodium cicutarium (L.) L'Hér. ex Aiton), rose clover (*Trifolium hirtum* All.*)* and subterranean clover (*Trifolium subterraneum* L.) and palatable grasses such as soft brome (*Bromus hordeaceus* L.*)* and wild oats (*Avena fatua* L.). Seeking high quality forage of sufficient height for rapid intake is one explanation for the positive effect of vegetation height, forbs, and palatable grasses. The unpalatable grasses, medusahead, barbed goatgrass and ripgut brome produce abrasive inflorescences in late spring that cattle tend to avoid in late spring and through the dry season. Large patches of medusahead and smaller patches of ripgut brome and barbed goatgrass were present in the four study pastures. The negative influence of these species on grazing activity and the large areas of California rangelands dominated by these species underscores the impact of these unpalatable grasses on grazing capacity throughout much of the state.

The positive influence of temperature on grazing activity means that grazing activity increases with increasing temperature. While this may be true during most of the year, high summer temperatures often result in a shift of grazing to cooler evening hours. Night resting periods (no grazing) are associated with cooler temperatures explaining why grazing activity might decrease with decreasing temperature. Malechek and Smith (1976) found that cattle spent more time grazing and less time standing on warm days than on cold days in Utah. Researchers have also found that cattle seek out cooler north-facing slopes as resting sites during summer days (Senft et al. 1983, Marlow and Pogacnik 1986).

Table 12. Grazing Use, response variable, compared with landscape attributes depicted in rows and columns

Attribute	Simple Effect	Slope	Elev	Dist H20	Can Cover	Ht	PGSC	% Forb	% Pal Grass	% Un Pal Grass	% Mh	Temp C
Slope	---		----	----	----	----						
Elevation	NS	----		+	+		+				----	
Distance to (H_2O)	---	----	+		----		----					----
Canopy Cover	NS	----	+	----	----	+						+
Height (cm)	+	----			+		----					
PGSC	----		+	----		----				+		+
Forbs	+											
% Pal Grass	+											----
% Un Pal Grass	----						+				+	
% Mh	----		----							+	+	+
Temp (C)	+				+		----				+	----

Significant	Interaction (+/---)
Not Significant	NS
Not Analyzed	

Resting Use

Multiple regression revealed several variables (Table 13) are significantly related to resting activity (R^2 = .20). Elevation, stubble height, and forbs had a positive influence on resting activity. Slope, distance to water, canopy cover and medusahead are negatively associated with resting activity. Several of the variables significantly associated with resting activity are also significantly associated with grazing activity. Cattle commonly grazed near their night resting place which could explain the similar explanatory variables for rest and grazing activity (Bailey et al. 1990). Our results are similar to those seen in Harris et al. (2002) and Bailey et al. (1990).

Table 13. Resting Use response variable, compared with landscape attributes depicted in rows and columns

Attribute	Simple Effect	Slope	Elev	Dist H20	Can Cover	Ht	PGSC	% Forb	% Pal Grass	% Un Pal Grass	% Mh	Temp C
Slope	---		----	----	NS	----						
Elevation	NS	----		+	NS		NS				NS	
Distance to (H_2O)	---	---	+		----		----					----
Canopy Cover	----	NS	NS	----	----	+						+
Height (cm)	+	----			+		----					
PGSC	NS		NS	---		----				+		+
Forbs	+											
% Pal Grass	NS											NS
% Un Pal Grass	NS						+				---	
% Mh	----		NS							---	+	+
Temp (C)	NS			----	+		+		NS		+	----

Significant	Interaction (+/---)
Not Significant	
Not Analyzed	

Cruising Use

Cruising activity is positively associated with canopy cover and temperature (Table 14) and negatively associated with slope and distance to water (R^2 = .07). The negative effect of slope on cruising may be the result of rapid movement (decreasing distance) toward water which is usually on gentle slopes. The negative effect of distance to water on cruising may also be the result of rapid movement toward (decreasing distance) stock water. The positive influence of temperature and canopy cover on cruising activity may reflect increased cattle movement to shade when temperatures increase. Harris et al. (2002) found that thermal environment was an important factor in cattle distribution, with cattle resting under trees during the hottest part of the day. Cruising is influenced by large scale abiotic factors such as canopy cover, temperature, slope and distance to water. Regression analysis found no relationship between smaller scale variables such as species composition, standing crop and stubble height. This suggests that cruising is a larger scale activity associated more with movement between patches, foraging sites and camps (Bailey et al. 1996) than with lower level activities associated with a feeding bout.

Table 14 Cruising Use response variable, compared with landscape attributes depicted in rows and columns

Attribute	Simple Effect	Slope	Elev	Dist H20	Can Cover	Ht	PGSC	% Forb	% Pal Grass	% Un Pal Grass	% Mh	Temp C
Slope	---		NS	NS	NS	----						
Elevation	NS	NS		---	+		+				NS	
Distance to (H_2O)	---	NS	-----		----		NS					----
Canopy Cover	+	NS	+	----	----	+						NS
Height (cm)	NS	NS			+		----					
PGSC	NS		+	NS		----				+		NS
Forbs	NS											
% Pal Grass	NS											NS
% Un Pal Grass	NS						+				NS	
% Mh	NS		NS							NS	NS	+
Temp (C)	+				NS		NS				+	NS

Significant	Interaction (+/---)
Not Significant	
Not Analyzed	

DISCUSSION

Fractal Dimension, Mean Cosine, and Travel

Results from fractal dimension mean, cosine mean, and distance traveled in meters per day showed differences in pastures, seasons, and vegetative cycles. A high D indicates that animals search and spend more time in a smaller area than an animal that exhibits a lower D (Etzenhouser et al. 1998). A lower fractal dimension suggests a more direct, less tortuous path. Other studies also demonstrated that animal movements can be interpreted in this fashion (Wiens and Milne 1989; Crist et al. 1992; With 1994).

Fractal dimension means are greater in Forbes 2 and Haworth, indicating a more tortuous path across the scale as opposed to the other two pastures (Table 11).

Fractal dimension for all cow positions is greater during the 2001 vegetation cycle with reduced precipitation. The reduced rainfall could have resulted in reduced forage production, leading to a more tortuous path as cows searched more for forage. However, according to the mean cosine, travel paths are most tortuous during the 2003 vegetation cycle. Rainfall amounts increased over the three year period (Table 1). This could have resulted in the production of more heterogeneous forage, increasing the cosine mean as cattle searched for more diverse forage. Seeking adequate forage may have resulted in this complex path as it appears that cows increased their travel to secure adequate food intake without adversely effecting thermal comfort in the mild California winters. This suggests that cows followed tortuous paths as they selected for forage quantity and quality. Garcia et al. (2005) found grazing paths to be more tortuous in one season (summer) than another (winter) and research results similar when compared as phenology cycles. Webb et al. (2009) found with increased precipitation, monthly movement paths of female deer became more tortuous. Our research saw different results as animal movement became less tortuous as rainfall patterns progressively increased over the three vegetation cycles (Table 1). Perhaps the greater abundance of forage reduced the need for animals to implement fine-scale search paths to find suitable foods. Garcia et al. (2005) also saw less searching behavior in heterogeneous swards and more tortuousity in homogeneous swards. In addition, increased rainfall could have resulted in more available vegetation allowing animals to increase their feeding site scale.

According to the D and travel m/day, Forbes 1 has the least amount of tortuousity. This indicates that Forbes 1 has a less complex pattern, reduced heterogeneity. This would also explain Haworth's significantly different cosine mean from the other pastures. Distance traveled was greatest for the two smallest pastures (Haworth and Porter) also suggesting a more tortuous path. Thus based on these three indicators one could conclude that animal travel paths are more tortuous in Haworth than the other pastures. According to Ganskopp et al. (2000) cow travel paths tend to follow least energy cost paths. If cows in Haworth are seeking gentle slopes for travel paths, then their route would have been more tortuous than other pastures that have relatively continuous gentle slope corridors (Figure 11).

Fractal dimension mean, cosine mean and distance travel m/day decreased as the seasons progressed from winter, to early spring, to late spring, to summer. This suggested the cattle had an increased tortuous path as forage become more limiting. Conversely, travel is less in late spring and summer due to the increasing temperatures usually experienced in northern California. Garcia et al. (2005) saw a seasonal affect to distance traveled. Not only temperature but also heterogeneity of forage affected the travel of animals in both experiments. During winter and early spring, forage is short and often mixed with and covered by residual liter from the previous year. Seeking patches of green leafy material of sufficient height may have resulted in complex movement patterns. By late spring when green leafy material is plentiful and residual litter from the previous year has lodged travel paths are less tortuous. In the summer, forage is uniformly dry but plentiful except in extremely dry years. Thus tortuous travel paths are not required to find sufficient forage. In the summer, water is available only at specific points resulting in daily directed travel to a specific location. Cows also tend to use the same shade areas, often near water, also directing travel to specific locations. Miller and Krueger (1976) found the environmental factors of distance to water and salt, soil depth, and canopy cover were highly correlated with utilization.

Landscape Heterogeneity

Slope

Fractal dimension means for gentle slopes is greatest in the Haworth pasture, least in the Forbes 2 pasture and the same for Forbes 1 and Porter pastures (Table

11, Figures 9-12). Additionally steep patches and dense canopy cover often coincide with steep slopes and may also impede travel forcing circuitous routes. In Forbes 1 and Porter there are relatively continuous gentle slope corridors that facilitate movement across the pasture and provide access to steeper portions of the pastures (Figures 9 & 12). Relatively flat roads in these two pastures may have facilitated animal distribution with less circuitous travel paths. Fractal dimension means for the steepest slope are lowest for the Haworth pasture, followed by the two Forbes pastures and greatest for the Porter pasture. Haworth has the steepest pasture and the >30% slope had the smallest D (Table 11). It is possible that the cattle did not utilize the steepest slopes and therefore congregated and searched more in the lower sloped areas. This could explain the higher D seen in Haworth.

Canopy Cover

Forbes 2 has the smallest canopy complexity and could lead to a greater abundant and diversity of forage. This could explain a greater heterogeneity and increased searching behavior, thus a higher D. As reported earlier, these two pastures have the greatest influences from canopy cover (Table 11). This canopy cover significantly affected the animals' path movement.

In this study we detected changes in movement patterns in response to spatial differences (pastures) and temporal differences (season and vegetation cycle). While we discussed these differences with respect to slope and canopy cover complexity, these results do not directly identify the cause of these spatial and temporal differences.

Domains of Scale

The domains or ranges of scale have been demonstrated in a variety of research, but never in cattle. The sequence of cow positions obtained from a GPS collar provides the movement path for the animal over the period of data collection. This would include feeding bouts where foraging behavior is associated with small scale processes related to feeding stations and patches and travelling associated with larger scales such as feeding sites and camps (Bailey et al. 1996). In these study pastures the less tortuous path associated with the smaller scale domain (less than 40 meters) might equate to the patch and feeding station scales of foraging while the greater tortuousity seen in domains exceeding 40 meters could be related to searching behavior between patches and large scale movements associated with daily travels to feeding sites, water and resting locations. This research indicated cow movement is scale variant at a scale below 40 meters, with distinct patterns representing the way the cows interacted with the landscape. Roshier et al. (2008) saw individual grey teal (*Anas gracilis*) movement paths were different in a desert landscape, moving less tortuously overall than their counterparts in the agricultural landscape. Nams and Bourgeois (2004) found a natural break in fractal dimension at a scale of approximately 3.5 meters in the movement path of American martens (*Martes americana*). They found that path tortuousity is affected at smaller scales but not at larger scales indicating a different response by the martens to their environment at these two scales above and below 3.5 meters.

There are apparent differences in the paths of all cows D between pastures across the scale less than 40 meters (Figure 24). We see a D that continues to rise (increasing D) in Forbes 1 and Forbes 2 as compared to the Haworth and Porter pastures where the D remains flat, a straighter path (constant D). This differs from the all cows Fractal dimension (Table 11) but does agree with the higher D in landscape complexity as related to slope and canopy cover (Table 11). The greatest seasonal difference was seen 4. during winter for the paths of all cows fractal dimension. This increase would be a result of cattle having to increase their searching behavior at a small scale due to the limited amount of vegetation available. In the paths of all cows fractal dimension across the scale greater than 40 meters (Figure 25) we saw similar patterns in the four pastures. Analysis of domains of scale revealed that the cows in this study responded differently at scales below and above 40 meters with less tortuous paths at the smaller scale in certain pastures and seasons. Forage path tortuousity is an animal movement response to landscape heterogeneity (Crist et al. 1992, With 1994, and Etzenhouser et al. 1998). Increases in tortuousity associated with the larger scale indicate non-directed movement such as that associated with searching.

During the summer season, we see a different transition in Forbes 1 as compared to Forbes 2, Haworth and Porter pastures. Forbes 1's only canopy cover occurs in a riparian area. This difference in searching behavior may reflect the animals' path during the summer, searching in the riparian zone. Another transition was seen during the winter season in Forbes 1, Forbes 2, and Haworth pastures. All three pastures had negative correlations, starting at 200. However, this pattern was not seen in Porter pasture, as the correlation was negative from 40 to 200, becoming positive at 200. The Porter pasture is very heterogenic, across slope and canopy cover, as shown in Table 11. This diversity could have affected the animals' searching behavior, causing turning paths along the entire scale. As the cattle responded to this diversity, their movement paths changed with scales changes. A sudden change in the fractal dimension at a certain spatial scale, suggests animals change the way they view the landscape, indicating that paths or pattern of movements are influenced by the landscape (Sugihara and May 1990).

The summer season shows a continually decrease in path movement, showing the animals' path became much more heterogeneity. This could be a result of fewer forage choices but also possible movement under the canopy cover due to thermal discomfort.

Forbes 2 also displayed a similar pattern of patch size as in Forbes 1. We see the patch size occurring approximately at 30 meters. As the scale becomes bigger, the path increased in heterogeneity. This may be a result of a more diverse array of forage species as Forbes 2 has the least amount of canopy cover. The reduced canopy cover could impact the amount and type of forage present to the animals, increasing potential forage diversity.

Correlation of Cosine

Correlation of cosine further defined the degree of landscape heterogeneity. In Forbes 1, the patch size varied from approximately 10 meters in late spring to 30 meters in summer (Figure 28). This would indicate there is more heterogeneity in late spring, due to increased vegetation in spring than in summer. In Forbes 2 the patch size was similar in early spring, late spring and winter but differed in summer, 10 meter patches as opposed to 30 meters, respectively. This could be related to vegetation but also canopy cover. Forbes 2 has the least complexity canopy cover and could have affected patchiness. The Haworth pasture had patch sizes similar across seasons with much larger patch sizes, 30 to 40 meters, than Forbes 1 and Forbes 2. . Porter had similar patch sizes as Haworth which relate back to the pasture complexity (Table 11). These results were similar to the D (Table 11). Nams (2005) simulated animal movement in a heterogeneous movement path and detected patch sizes. Correlation of cosine can detect patch sizes along the animal movement path, or in other words, a heterogeneous movement path. A change in correlation between positive and negative was seen (Figure 26), indicating a change in patch size. Domains of scale were also seen in the D analysis but D might be considered a conservative tool for detecting transitions within domains of scale Nams (2005).

Cows live in an environment that is patchy and patches reside within patches (hierarchy). Cows perceive and react to this structure at several scales as they select habitats and seek forage. The analysis of fractal dimension and correlation cosine for cow positions across the scale of 0 to 300 meters reveals the small scale patches and larger scale patches that are influencing movement paths within the four study pastures.

Landscape Attributes & Animal Activity

The interactions strengthen our understanding of slope effects on grazing activity. For grazing activity there were significant negative interactions between slope and each of elevation, distance to water, canopy cover and vegetation height because grazing use increases on gentle slopes that tend to be at lower elevations with lower canopy cover and stock water is usually located on and surrounded by gentle slopes. Because these areas receive greater grazing activity it is reasonable to expect lower vegetation height.

Similar interactions were found for slope and each of elevation and distance to water reaffirming the earlier statement that rest areas and grazing areas are frequently the same or closely adjacent areas.

Temperature positively affects grazing activity but not resting activity. The interactions of temperature with each of canopy cover, pre-grazing standing crop and Medusahead positively influence grazing and resting activity. As temperature increases through the growing season pre-grazing standing crop increases and Medusahead cover increases. Because resting activity often occurs near grazing activity it also is influenced by these interactions that are positive for grazing activity. The positive interaction of canopy cover and temperature with grazing and resting activity is more complex. During hot weather grazing activity may increase under canopy cover as the temperature increases. However, in colder seasons grazing under canopy cover tends to decrease as cows seek sunny aspects.

Feeding bout activities, such as selecting for palatable species and against unpalatable species, occur at this smaller scale (< 40 m). Patches of unpalatable grasses often occur at this smaller scale. Cruising activity is influenced by larger scale (> 40 m) movements that may be tortuous when searching between patches greater than 40 meters, traversing steep slopes or circumnavigating dense canopy cover to move toward water or canopy cover for shade.

Cattle moment patterns could have been affected by breeding status, competition, and/or spatial memory. Webb et al. (2009) found male deer displaying a less tortuous movement path than females. Female deer also had a different movement pattern during parturition, their D was greatest during parturition possibly due to restricted movements in smaller areas or increased searching pattern for forage. The cattle in our study all had calves with them during the winter, early spring and late spring seasons but not during the summer. Our research found no differences in animal movement due to parturition.

CONCLUSIONS

Fractal analyses provided a means of quantifying animal movements, detecting change in patterns, and tested managerial processes. Our research found that fractal dimension could be used to analyze animal movement and determining how animals respond to small and large scale landscape attributes. Fractal analysis of movement patterns provided a means to identify the spatial scales at which an animal responds to the landscape and its associated attributes. Path tortuousity differed between pastures, seasons and vegetation cycles. Fractal analysis can also detect landscape heterogeneity. Fractal analysis revealed that slope and canopy cover complexity differed between pastures, seasons and vegetation cycles and could be interpreted to influence path tortuousity.

Fractal dimension further showed that animal perceived their environments at different scales. The biggest range of scales or “domains” was seen at less than 40 meters and between 40 to 200 meters. Movement at the smaller scale is less tortuous than at the larger scale suggesting searching for patches at the larger scale.

Further analysis of the correlation of cosine detected heterogenic patches which further defined the scale at which cattle perceived their landscape. Analysis showed cattle movement paths in regards to patch sizes were affected by different pastures and during different seasons.

Animal activities (grazing resting and cruising), were also affected by landscape attributes. Grazing activity was positively related to small scale attributes of vegetation such as percent of forbs, palatable grasses and height of vegetation. It was negatively associated with unpalatable grasses and medusahead. Several of the significant influences on grazing activity were also found for resting activity probably because resting and grazing activity often occur in the same or nearly the same place. Cruising was shown to be directed movement, influenced by larger scale attributes such as canopy cover, temperature, distance to water and slope that are associated with patch, feeding site, and camp scales.

Our research produced results that fulfilled our original objectives and lead us to a better understanding on how cattle perceive and move in heterogeneous landscapes. The integration of global positioning technology and geographic information systems allowed us to analyze data in new and innovative ways. The use of fractal analysis enabled us to accurately quantify cattle movement paths and the landscape attributes that effect their paths. Our research showed the possibilities and capabilities of our techniques in creating a new understanding of animal distribution. This research provided an understanding of how to develop spatial models for managerial decisions that could affect livestock distribution. Similar studies on other landscapes will enable land managers and livestock producers to greatly improve rangeland management for long term ecological benefits. Having the ability to apply models, given the known landscapes attributes, would aid in managing cattle distribution. Understanding how the ecological attributes and managerial options can affect distribution can lead to a better understanding of methods to manipulate cattle movement.

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