PREDICTING UTILIZATION OF FOOTHILL AND MOUNTAIN RANGELAND BY CATTLE IN SUMMER

A Dissertation Presented in Partial Fulfillment of the Requirements for the

Degree of Doctor of Philosophy

with a

Major in Natural Resources

in the

College of Graduate Studies

University of Idaho

by

Tracy K. Brewer

May 2004

Major Professor: Stephen C. Bunting, Ph.D.

AUTHORIZATION TO SUBMIT DISSERTATION

This dissertation of Tracy K. Brewer, submitted for the degree of Doctor of Philosophy with a major in Natural Resources and titled "Predicting Utilization of Foothill and Mountain Rangeland by Cattle in Summer", has been reviewed in final form. Permission, as indicated by the signatures and dates given below, is now granted to submit final copies to the College of Graduate Studies for approval.

Major Professor ________________________________ Date ______________
Stephen C. Bunting

Committee Members ________________________________Date ______________
Kenneth D. Sanders

________________________________Date ______________
Karen L. Launchbaugh

________________________________ Date ______________
Carl W. Hunt

Department
Administrator ________________________________ Date ______________
Karen L. Launchbaugh

Discipline's
College Dean ________________________________ Date ______________
Steven B. Daley Laursen

Final Approval and Acceptance by the College of Graduate Studies

_________________________ Date ______________
Katherine G. Aiken

ABSTRACT

Cattle grazing distribution on heterogeneous foothill and mountain rangeland is influenced by multiple, interrelated factors. The complexity of these interactions justifies efforts to assimilate knowledge of cattle habitat use patterns into mathematical models capable of predicting levels of utilization (e.g., Heavy, Moderate, Light, or Ungrazed).

Two cattle habitat use models for foothill and mountain rangeland were developed using discriminant analysis. Both models were developed and validated temporally from data in northwestern Wyoming and validated spatially from data in west-central Montana. The models incorporated readily available data from Geographic Information System (GIS) databases and other sources. Habitat variables included in the final models were herbaceous standing crop, slope, aspect, and two-dimensional distances to water, shade, and fence. Model 1 predicted cattle utilization into four classes: 1) Heavy (>60% utilization), 2) Moderate (31-60% utilization), 3) Light (11-31% utilization), and Ungrazed (<11% utilization). Model 2 predicted cattle utilization into three classes: 1) Heavy (<60% utilization), Moderate-Light (11-60% utilization), and Ungrazed (<11% utilization).

Classification accuracy of Model 1 was 32% in the model development stage. Temporal and spatial validation resulted in 39% and 49% classification accuracy, respectively. Cohen's weighted Kappa statistics for model development, temporal validation, and spatial validation were 0.11, 0.15, and 0.13, respectively ($P < 0.01$). Classification accuracy increased to 53% in the development stage of Model 2. Temporal and spatial model validation accuracies of Model 2 were 74% and 77%, respectively. Cohen's weighted Kappa statistics were 0.10, 0.20, and 0.05 for model development, temporal validation, and spatial validation, respectively ($P < 0.01$).

Model 1 and Model 2 were more rigorously tested and Model 2 was found to be much more accurate than previously published models of cattle utilization. Coupled with a natural resource manager’s local knowledge of the landscape, these models can serve as a simple, accurate tool for predicting cattle utilization on foothill and mountain rangeland. When used properly, predictions from these models can be used by land managers to develop or refine grazing strategies that are ecologically sustainable and compatible with wildlife and other resource uses and values.

ACKNOWLEDGEMENTS

The list of people that deserve recognition for their support during my doctoral program is lengthy, and undoubtedly Drs. Ken Sanders and Steve Bunting top the list. I would like to extend a sincere thank you to both of these gentlemen for their willingness to accept me into their graduate program and for believing in my abilities. Truly, I can never express how that selflessness has impacted me. Thank you.

I would also like to thank Drs. Karen Launchbaugh and Carl Hunt for serving on my committee and for being great mentors during my time at the University of Idaho. I would like to thank the faculty, staff, and students in the Department of Rangeland Ecology and Management at the University of Idaho for the support while I was completing my degree and for all of the memories I will take with me. I especially thank Rachel Frost for being a great friend and for helping me keep my sanity. I look forward to our careers together and our continued friendship.

My colleagues in the Department of Animal and Range Sciences at Montana State University deserve special recognition for the support that they have offered in data collection and field work necessary for this project and also in allowing me to pursue this degree while remaining employed. I genuinely appreciate the opportunity to continue my work at MSU while completing my Ph.D. program. I would especially like to thank Dr. Jeff Mosley for the encouragement to pursue my Ph.D. and the inspiration he has provided me throughout my graduate career.

I would like to thank Dr. Kelly Crane for all of the hours he spent horseback collecting data for this project. I won’t say he did all the “real work”, but his contributions deserve a great deal of recognition. I would like to thank Bob Snyder for the GIS support he provided for the successful completion of this project.

This research would not have been possible without the support of the owners, managers, and employees of the TE, Mooncrest, and Galt ranches. A genuine thank you goes out for the support from these ranches and to all who participated in some capacity.

Lastly, I would like to thank my family for the love, support, and encouragement they have extended to me throughout my Ph.D. program. I would especially like to thank my Dad and Mom for teaching me to challenge myself, believe in myself, and to follow my dreams. I also thank you for the values you have instilled in me and for the love of natural resources that I could only have gained through my upbringing.

To all who have touched my life throughout this period, thank you and God bless.

TABLE OF CONTENTS

LIST OF TABLES

CHAPTER 1

INTRODUCTION

Livestock distribution on heterogeneous landscapes and resource partitioning among ungulate grazers are two frequent challenges faced by natural resource managers on foothill and mountain rangeland. Resource partitioning and potential competition between cattle and wildlife species is of particular concern on Rocky Mountain foothill and mountain rangeland because these rangelands provide important seasonal habitat for many species of wildlife, such as elk (*Cervus elaphus*), mule deer (*Odocoileus hemionus hemionus*), white-tailed deer (*Odocoileus virginianus),* and pronghorn antelope (*Antilocapra americana*), as well as summer range for cattle (*Bos taurus*) (Berg and Hudson 1982, Hart et al. 1991, Sheehy and Vavra 1996, Selting and Irby 1997). Increased knowledge of cattle habitat selection patterns and the factors that influence them is needed to help resource managers develop strategies for effective resource partitioning and resolving cattle-wildlife conflicts.

Previous research has identified several variables that may influence habitat selection patterns of free-ranging cattle on foothill and mountain rangeland. Distance to water (Hart et al. 1991, Pinchak et al. 1991, Stewart et al. 2002) and slope (Mueggler 1965, Cook 1966, Roath and Kruger 1982, Gillen et al. 1984, Ganskopp and Vavra 1987, Stewart et al. 2002) have been identified as two primary determinants in cattle habitat selection. Habitat variables that are not directly controlled by managers that may influence cattle habitat selection patterns include forage abundance and nutritional quality (Bailey et al. 1989b, Pinchak et al. 1991, Bailey et al. 2001a), plant communities (Miller and Krueger 1976, Wade et al. 1998), elevation (Berg and Hudson 1982, Sheehy and Vavra 1996), aspect (Sheehy and

Vavra 1996), distance to adequate thermal cover (Beaver and Olson 1997), and range site (Hart et al. 1991, Pinchak et al. 1991). Additional non-habitat influences relatively uncontrollable by managers include social facilitation (Howery et al. 1998, Mosley 1999, Macdonald 2000), previous grazing experience (Bryant 1982), breed (Bailey et al. 2001a), and nutritional requirements (Bryant 1982). Physiological state (Bailey et al. 2001a), distance to salt, mineral, and supplemental feed (Gillen et al. 1984, Bailey et al. 2001b), timing of grazing (Marlow and Pogacnik 1986, Porath et al. 2002), and stocking rate and length of grazing period (Hart et al. 1991, Clary and Booth 1993) are other non-habitat factors that may influence cattle habitat selection and use patterns.

The complexity of cattle habitat selection justifies attempts to assimilate knowledge of cattle selection patterns into mathematical models that can aid natural resource management on foothill and mountain rangeland where cattle and wildlife cohabit. Researchers have identified abiotic landscape characteristics as the primary determinant of cattle distribution patterns and as the constraints under which biotic influences must operate (Pinchak et al. 1991, Bailey et al. 1996, Stewart et al. 2002). Current models simply predict areas to be either grazed or ungrazed and do not address the prediction of a level of use based on the combination of influential variables. A predictive model based on landscape variables that will aid in identification of areas with different levels of use by cattle may help resource managers identify opportunities for using management techniques to influence habitat use patterns of cattle.

Justification

Large herbivores, including cattle, play a major role in the dynamics and function of ecosystems via selective consumption of plants and plant communities in terrestrial biomes (Duncan and Gordon 1999). A decline in ecological (range) condition due to heavy, prolonged grazing on certain sites within a landscape may cause a shift in productivity and/or composition of most rangeland ecosystems (Pieper 1994). Similarly, lack of herbivory in patches located within communities can alter community processes to a great enough extent that negative consequences may result. Lack of herbivory and build-up of dead plant tissue can lead to an increase in fire frequency, which may lead to species composition changes within the community over time (Laycock 1994). Just as heavy and no grazing can contribute to decreased diversity, moderate levels of herbivory can contribute to greater species diversity than heavy or no grazing (Mueggler 1984, West 1993, Hart 2001).

Some level of patchiness is good for increased biodiversity of plants and animals at the landscape level (Laycock 1994). However, excessive use or lack of use of plants and patches across the landscape may be unfavorable to the overall sustainability of plant communities. Therefore, knowledge of cattle habitat use patterns and the influence habitat variables have on cattle distribution, combined with the ability to predict levels of cattle grazing utilization on landscapes, can help resource managers achieve desirable levels of landscape heterogeneity but minimize excessive selection and degradation of resource patches. Refined estimates of cattle habitat use patterns based on a tool that predicts excessive or lack of grazing by cattle can be utilized to more effectively manage for multiple uses. Implementation of a planning tool that can identify areas of complementarity and conflict between cattle grazing and other resource values, such as sage grouse (*Centrocercus* *urophasianus*) habitat, elk calving habitat, recreation areas, wild ungulate grazing habitat, riparian areas, can help to enhance the long-term sustainability of foothill and mountain rangeland.

This study utilized predictive modeling and model validation techniques to:

1. Develop a cattle habitat selection model for foothill and mountain rangeland that predicts a level of grazing utilization based on the influence of habitat variables.
2. Validate the cattle habitat selection model developed in Objective 1 by assessing: a) temporal variability and b) spatial variability.

CHAPTER 2

LITERATURE REVIEW

Cattle grazing distribution patterns on foothill and mountain rangeland in summer are a result of the influence of multiple factors, including physical landscape characteristics (Mueggler 1965, Cook 1966, Bailey et al. 1996), vegetative attributes (Pinchak et al. 1991, Smith et al. 1992, Sheehy and Vavra 1996), environmental factors (Stevens 1966, Bryant 1982), animal characteristics (Bryant 1982, Bennett et al. 1985), and management techniques (Hart et al. 1991). The abiotic, physical landscape characteristics, such as slope, elevation, and distance to water, are determinant features that generally cannot be easily altered by managers and often serve as the foundation for overall management decisions.

Mosaics of patches of vegetation that receive differential use by grazing livestock often characterize heterogeneous landscapes (Pieper 1994). Understanding the influence of physical landscape characteristics on cattle grazing distribution and subsequent utilization patterns on foothill and mountain rangeland in summer is an important initial step in making natural resource management decisions. Once these primary determinant factors are understood and accounted for, management decisions involving factors more directly controllable by resource managers, such as animal characteristics and management techniques, can be made effectively.

<u>Effects of Physical Habitat Characteristics on Cattle Habitat Use Patterns</u>

***Slope*.** Slope has been identified as an extremely important predictor of cattle habitat use patterns on foothill and mountain rangeland by many researchers, and various ranges of slope use by cattle have been documented in historic research. Percent slope is often negatively correlated with livestock use on mountain rangeland (Mueggler 1965, Cook 1966). It was shown to account for 51% of variability in relative grazing use by itself and 81% of variability in relative grazing use when combined with distance uphill from the base of the slope on foothill rangeland in southwestern Montana (Mueggler 1965). Steep side slopes were identified as a limiting factor of cattle use in a model developed in mountainous regions of Oregon and in the model's validation (Wade et al. 1998). In a model developed on the Starkey Experimental Forest and Range in northeastern Oregon, Stewart et al. (2002) found that percent slope was a significant factor in determining cattle distribution. In general, areas utilized by cattle had an average slope of 13.3%.

Pinchak et al. (1991), in a study in south-central Wyoming, documented more than 90% of cattle observations in areas with less than 7% slope when, overall, cattle utilized slopes ranging from 0 to 40%. Similarly, cattle grazing in southeastern Oregon in the summer were observed 99.5% of the time on slopes <40% and 94% of the time on slopes between 0 and 19%. These cattle preferred slopes from 0 to 9%, were indifferent to 10-19% slopes, and avoided slopes of 20% or greater (Ganskopp and Vavra 1987). It was documented in this study, however, that cattle in pastures with more rugged terrain exhibited use on a wider range of slopes than cattle in pastures with less terrain variability. Researchers in north-central Oregon showed that cattle preferred slopes less than 10% and avoided areas with slopes greater than 20% under continuous summer grazing, early summer grazing, and late summer grazing (Gillen et al. 1984). In the Henry Mountains, Utah, cattle were observed using slopes less than 25% ninety percent of the time (Van Vuren 1982). Cattle grazing in the Rocky Mountain foothills of southwestern Alberta were observed 71%

of the time on areas with less than 10% slope (Berg and Hudson 1982) and mature cows and yearlings grazing in the Blue Mountains of Oregon used 41% of the available area, characterized by ≤ 35% slope, 78% of the time (Bryant 1982). In contrast to many of the above findings, Sheehy and Vavra (1996) observed that cattle did not exhibit preference or avoidance of any slopes ≤ 50% in the Blue Mountains, Oregon. The lack of preference exhibited by these cattle is likely due to the study being conducted within a relatively small area compared to other studies.

Slope has been used as a primary factor in stocking and cattle grazing utilization guidelines. Scientists on the Charles M. Russell National Wildlife Refuge used the following guidelines to set stocking rates in areas where wildlife and cattle cohabited. As slopes on the refuge increased, forage allocation declined as follows: areas with slopes >35º were available to cattle 1%, areas from 26-35º were available 5%, areas from 11-25º were available 18%, and areas with slopes less than or equal to 10º were available 100% of the time (Hedrick and Dailey 1982). Holechek (1988) suggested a 100% reduction in grazing capacity for areas over 60% slope, a 60% reduction for areas from 31-60% slope, a 30% reduction for areas from 11-30% slope, and no reduction for areas with 0-10% slope.

Distance to Water. Distance to water sources has been identified by numerous researchers as another important influence of cattle distribution patterns and landscape use. Distance to water is generally negatively correlated with cattle use (Cook 1966), the grazing capacity of an area (Valentine 1947), and the amount of forage harvested from a community (Miller and Krueger 1976). It has been shown to be the primary determinant in cattle distribution and habitat use in the summer in various areas of the semiarid West (Roath and Krueger 1982, Pinchak et al. 1991, Howery et al. 1998).

Varying landscape use patterns by domestic livestock have been attributed to animals grazing outward from watering points and returning at regular intervals to drink (Valentine 1947, Pickup 1994). Cattle in the southern Blue Mountains of Oregon were observed utilizing portions of a pasture in a wetter year that remained unused in a dry year, as a result of increased availability of water sources in the wet year (Roath and Krueger 1982). Porath et al. (2002), in a study conducted in the foothills of the Wallowa Mountains in northeastern Oregon, determined that whether cattle were offered off-stream water or not, the animals tended to conduct their activities in the afternoon hours at or near the location where they consumed water in late morning or early afternoon. Stewart et al. (2002), in a model developed on the Starkey Experimental Forest and Range, determined that distance to permanent water strongly influenced cattle distribution patterns and that animal locations averaged 358 m from water sources.

Pinchak et al. (1991) observed cattle on foothill rangeland in south-central Wyoming using areas within 366 m of water 66% more than they were expected to throughout their study and used areas beyond 732 m, which made up 65% of the study area, only 12% of the time. In the Henry Mountains of Utah, cattle were observed within 200 m of water 48% of the time and within 100 vertical m of water 97% of the time (Van Vuren 1982). In the southern Blue Mountains of Oregon, utilization by cattle in the summer reached zero in areas with 80 m of vertical rise above a stream (Roath and Krueger 1982). Cattle grazing under continuous grazing during the summer on mountain rangeland in north-central Oregon preferred grazing within 600 m of water (Gillen et al. 1984). Cattle under continuous grazing in a foothill rangeland pasture in south-central Wyoming exhibited a preference for areas within 3,000 m of water (Hart et al. 1993). In contrast to these findings, Bryant (1982) concluded that off-stream water availability was ineffective when attempting to minimize riparian use and increase use of upland slopes in a study conducted on the Starkey Experimental Forest and Range.

Similar to percent slope, distance to water has been used to set guidelines for stocking and grazing utilization of heterogeneous landscapes. Valentine (1947) suggested water location as a major factor in setting stocking rates and determining grazing capacity of rangelands. Holechek (1988) recommended a 100% reduction in grazing capacity for areas greater than 3.2 km from water, a 50% reduction for areas between 1.6 and 3.2 km from water, and no reduction for areas less than 1.6 km from water. On the Charles M. Russell National Wildlife Refuge in Montana, scientists suggested that areas within 0.4 km of water would be used by cattle 100% of the time, areas between 0.4 and 0.8 km of water would be used 63% of the time, areas between 0.8 and 1.2 km of water would be used 41% of the time, areas between 1.2 and 1.6 km would be used 21% of the time, and areas between 1.6 and 3.2 km would be used only 10% of the time by cattle (Hedrick and Dailey 1982).

Elevation. The influence of elevation on cattle habitat use patterns has been researched to a limited extent on foothill and mountain rangeland and mixed results have been documented. Foraging distribution of cattle in the Henry Mountains of Utah was not correlated to elevation (Van Vuren 1982). In a model developed in northeastern Oregon, elevation was found to slightly influence cattle habitat selection, but not strongly enough to be included in a predictive logistic regression model (Stewart et al. 2002). In southwestern Alberta, Berg and

Hudson (1982) identified 84% of cattle observations in locations below 1490 m in an area that ranged from 1370 to 1675 m. In northeastern Oregon, moderate elevations were preferred and/or desirable to cattle while high and low elevations were undesirable and/or avoided (Sheehy and Vavra 1996).

Distance to Fence. The influence of distance to fence on cattle habitat use patterns has not been researched much in foothill and mountain rangeland areas and only minimally elsewhere. Stewart et al. (2002), in a project designed to produce a predictive model for cattle distribution on foothill rangeland, determined that cattle distribution was not influenced by distance to fence and that animal observations averaged 582 m from fences in pastures located in the Starkey Experimental Forest and Range.

Research conducted in other regions of the country has produced varied results regarding the influence of distance to fence on cattle grazing distribution. On shortgrass prairie in northern Colorado, cattle were influenced by fences and tended to focus their grazing activity around fences in pastures 23 and 10 ha in size (Dean and Rice 1974). In a study conducted in mixed-brush vegetation with grass understory in southwestern Texas, researchers determined that distance to fence influenced utilization patterns of cattle when forage availability was limited, but had no effect when abundant forage was available (Owens et al. 1991).

Effects of Vegetative Attributes on Cattle Habitat Use Patterns

Vegetation Type/Plant Community Type. Presence of various plant communities and vegetation types has been documented to influence cattle habitat use patterns on foothill and mountain rangeland. Miller and Krueger (1976) determined that differential use of plant communities in the foothills of the Wallowa Mountains confirmed that animal preferences for communities make uniform grazing distribution difficult to obtain. Similarly, the plant communities present in the Blue Mountains (Sheehy and Vavra 1996) and vegetation types present in the Elkhorn Mountain Range in central Montana (Stevens 1966) were found to influence cattle habitat selection and grazing patterns.

In two separate modeling efforts, results regarding the influence of vegetation type and plant communities differed. Wade et al. (1998) found that vegetation type was the primary determinant of cattle grazing potential of a site in their model developed for mountainous regions of Oregon, while Stewart et al. (2002) found that plant communities present did not influence cattle distribution on foothill rangeland on the Starkey Experimental Forest and Range in Oregon. These differing results may have been due to the much smaller scale, restriction of the study to the summer grazing season, and only having four vegetation types within the study area in the Stewart et al. (2002) model compared to Wade et al. (1998), where the model was developed for the entire state of Oregon throughout the year and included 133 community types.

Cattle at the Red Bluff Research Ranch in southwestern Montana differentially utilized vegetation types in the summer and were observed in riparian, mountain grassland, sagebrush steppe, limber pine savannah, and coniferous forest types 38%, 27%, 18%, 17%, and 0% of the time, respectively, when they were available 12, 11, 21, 42, and 14% on the study area, respectively (Macdonald 2000). Cattle grazing in mountainous rangeland in north-central Oregon from June to mid-October utilized meadow communities 47% of the time and grassland communities 18% of the time when they comprised 5% and 6% of the study area, respectively. They utilized forested communities proportionally or less than their availability (Gillen et al. 1984). In the foothills of southwestern Alberta, 86% of cattle grazing observations occurred in grassland and grassland-conifer (open limber pine (*Pinus flexilus* James) and Douglas fir {*Pseudotsuga menziesii* (Mirbel) Franco}) vegetation types when mixed forest, low shrub, and mixed deciduous forest types were also available (Berg and Hudson 1982).

Habitat Type and Range Site. Limited research has been done in foothill and mountain rangeland documenting the influence of habitat type or range site on the habitat use patterns of cattle. In a study conducted in south-central Wyoming, cattle displayed preferences for loamy, wetland/subirrigated, and grazeable woodland range sites and concurrently avoided coarse upland, shallow loamy, and very shallow range sites when all were available within pastures (Pinchak et al. 1991).

Forage Quality and Quantity. Bailey and Sims (1998), in a study conducted in a radial maze, documented that cattle exhibited the ability to remember the forage nutritive quality at various spatial locations and return to the highest quality forage. However, these researchers concluded that the strength of the association between forage quality and location decreases over time. In a study conducted in southern Wyoming, cattle exhibited a repeated preference for range sites with forages containing higher percent crude protein (CP) than other sites (Pinchak et al. 1991).

Bailey et al. (1996) demonstrated that cattle have the ability to associate food quantity with spatial locations in a parallel-arm maze when steers were observed returning to areas where the largest availability of feed reward was located (Bailey et al. 1989b). In addition to their findings regarding forage quality, Pinchak et al. (1991) also concluded that cattle grazing on diverse foothill rangeland preferred range sites that had the greatest amount of standing crop (kg/ha) of preferred forages available. In contrast, Van Vuren (1982) found amount of preferred forage present on a site in the Henry Mountains was not significantly correlated with cattle distribution. Cattle not grazing in areas of abundant, preferred forage was attributed to a significant and positive correlation between amount of preferred forage and percent slope.

Patchiness. Plant community distribution on the landscape can be described as patchy, with patches of one type of vegetation embedded in a mosaic pattern in a more dominant type that surrounds it (Pieper 1994). Although research regarding cattle grazing response to patches on the landscape is limited for foothill and mountain rangeland situations, Bailey et al. (1989b, 1996) and Bailey and Sims (1998) contended that cattle select patches of higher forage quality and quantity on the landscape more frequently than less productive, nutrient-poor patches via spatial memory mechanisms. Bailey (1995) found that steers in northwestern Oklahoma exposed to heterogeneous areas selected patches within pastures that had higher crude protein levels than other patches present. Steers exposed to homogeneous areas displayed no preferences for areas within a pasture. Pickup and Bastin (1997) attempted to model cattle distribution in arid Australian rangelands as affected by changes in vegetative cover over time. They concluded patch surroundings could reasonably be eliminated from models used to predict cattle distribution because landscape types adjacent to preferred patches did not influence the rate of cover change in the preferred patches.

Effects of Environmental Factors on Cattle Habitat Use Patterns

Aspect. Aspect, or exposure, has not been determined as a dominant factor influencing cattle habitat use patterns on foothill and mountain rangeland. Cattle grazing seasonal rangeland in the Blue Mountains utilized all aspects proportionally to availability and did not exhibit preference for or avoidance of any aspects (Sheehy and Vavra 1996). In southwestern Alberta, cattle utilized areas with east, south, and west exposure equally. These researchers suggested that a higher probability of sighting animals in open grassland areas on these exposures, as compared to forested north exposures, might have influenced their results (Berg and Hudson 1982). Stewart et al. (2002) determined that aspect did not influence cattle distribution. Mean animal locations were found on east exposures at 119° from north.

Distance to Shade. An animal’s ability and tendency to seek shade to improve its microclimate is an important consideration for summer cattle grazing and animal production and must be balanced with grazing time (Bennett et al. 1985). Research regarding the influence of distance to shade on cattle habitat use patterns is limited in foothill and mountain rangeland and is restricted to more tropical environments. However, Howery et al. (1998) suggested the development of shade in upland areas in south-central Idaho to attract cattle into uplands and decrease use of riparian areas for shade. Porath et al. (2002) suggested cattle in the Wallowa Mountains not offered off-stream water tended to seek shade during hot afternoon periods in riparian areas near where they drank water in the middle of the day.

Steers grazing in Queensland, Australia were observed spending more time in the shade as mean radiant temperature and air temperature increased (Bennett et al. 1985). McIlvain and Shoop (1971) observed cattle in the southern plains of Oklahoma with access to shade using the shade consistently while animals without access to shade lingered around water sources in the hot portion of the day. These behaviors were true even when the shade was 1.6 km from water. They suggested that placement of shade in relation to over- and underused areas within a pasture can increase uniformity of use of pastures.

Temperature and Relative Humidity. The influences of temperature and relative humidity on cattle habitat use patterns are difficult to separate. Cattle grazing in northeastern Oregon moved from upslope positions to riparian bottoms when mean ambient temperatures were relatively high and relative humidity was low. They also moved to upslope positions when temperatures in riparian zones decreased and relative humidity increased (Bryant 1982). Mean percent relative humidity appeared to have a greater influence on cattle distribution than temperature and was displayed by cattle preferring areas where relative humidity was between 60 and 70 percent, regardless of temperature. In a two-year study in southwestern Montana, cattle grazing on foothill rangeland used a wider range of slopes and traveled further from water in a hot, dry year compared to a cool, wet year (Macdonald 2000). Cattle displayed differential use of vegetation types in central Montana as a result of changing temperatures. They used upland sites in cooler mornings and evenings, tree and shrub types near water during mid-day when temperatures were hot, and upland sites during mid-day in more moderate temperatures (Stevens 1966).

Effects of Animal Characteristics on Cattle Habitat Use Patterns

Age and Body Size. Few studies have focused directly on the influences of age and body size on landscape-level resource selection patterns by cattle. Because age and body size are directly related, differences in grazing behavior between age classes of cattle may be confounded with differences in body size and the effects it has on the spatial scale within which an animal operates.

In limited studies conducted in foothill and mountain rangeland, researchers have included observations between age classes of animals and their relationship to habitat use patterns. In a study of cattle habitat use patterns in relation to riparian fencing, Bryant (1982) observed that mature cows utilized a wider range of slope classes and selectively grazed areas of higher forage productivity within a pasture than yearlings. These findings, as they relate to animal age, may be somewhat confounded with the effects of previous grazing experience in the pasture by the mature cows. Howery et al. (1998) explained differential use patterns by mature cows and yearlings as a result of yearling grazing habits being directly influenced by peer facilitation whereas older cows tended to graze areas they had previously experienced.

Physiological State and Nutritional Requirements. Cattle in differing physiological conditions and with different nutritional requirements have been documented utilizing foothill and mountain rangeland landscapes differently. In north-central Montana, non-lactating cows generally used higher terrain and steeper slopes than lactating cows in the summer (Bailey et al. 2001a). The tendency for lactating animals to use lower, gentler areas of the pasture in this study was attributed to higher water requirements of the lactating cows, which required them to remain near water sources, and the hindered ability of calves to traverse more rugged terrain. Similarly, Bryant (1982) attributed cows with calves exhibiting greater tendency than yearlings to select the most productive plant community types to greater energy needs and expenditures of the lactating animals.

Breed. Bailey et al. (2001a) have conducted the only research in foothill and mountain rangeland that has focused on the influence of cattle breed on habitat use patterns. Differences in terrain use were evaluated between Hereford (HH), Tarentaise (TT), and Hereford-Tarentaise (3H1T, HT, and 1H3T) cross cows in north-central Montana in summer. Tarentaise and 1H3T cows climbed higher vertically above water than Hereford cows in both years of the study and used areas with steeper slopes in one of two years of the study. The authors speculated that Tarentaise cattle utilized more difficult terrain because the breed originated in rugged terrain in the Alps of Western Europe.

Bennett et al. (1985) studied the differences in the amount of time different breeds of cattle spent in the shade and grazing in a rangeland situation in Australia. Shorthorn steers spent 3.48 h per day in the shade compared to 2.25 h spent by Brahman x Hereford-Shorthorn cross steers and 1.64 h per day spent by Brahman steers. Consequently, Shorthorn cattle spent only 7.46 h per day grazing compared to 8.20 and 8.24 h for Brahman x Hereford-Shorthorn cross steers and Brahman steers, respectively. The origination of the Brahman breed in the tropics resulted in greater heat tolerance and less need for shade.

Herbel and Nelson (1966) observed differences in the amount of time Hereford and Santa Gertrudis cows spent grazing and walking on the Jornada Experimental Range. Herefords spent 42% of a twenty-four hour period grazing while Santa Gertrudis cows spent only 12.1% annually. The greatest seasonal differences in time spent grazing was seen in the summer when Herefords grazed 40.8% and Santa Gertrudis cows only grazed 31.8% of the time. Santa Gertrudis cows spent 12.1% walking while Herefords spent only 6.5% on a yearlong basis. These differences were maximized in summer and fall when Santa Gertrudis spent 8.6% and 7.3% more time walking than Herefords, respectively. Santa Gertrudis cattle spent twice as much time walking and traveled nearly 3 miles more per day than Hereford cows.

Previous Experience and Memory. Previous grazing experience and spatial memory in cattle can influence cattle habitat use patterns. Although there is limited information directly linking these factors to use patterns in landscape situations, researchers have historically attributed portions of their results of cattle distribution studies to previous experience and spatial memory. Bryant (1982) concluded that the wider distribution of mature cows than yearlings across the landscape was a result of the mature animals having previous grazing experience and familiarity with that particular pasture. Similarly, Beaver and Olson (1997) attributed 3-year old cows using unprotected areas of a pasture in southwestern Montana in the winter in greater quantities than their availability, and subsequent loss of back fat compared to mature cows, to the lack of experience in the pasture and low resource use efficiency of the younger cattle.

Bailey et al. (1989a, 1989b) tested the hypothesis that cattle can utilize spatial memory to return to locations of abundant feed. After some level of training, heifers exposed to radial- and parallel-arm mazes and steers exposed to a radial-arm maze exhibited the ability to associate locations with availability of feed resources and to remember locations for up to 8 hours. Bailey and Sims (1998) concluded that cattle also have the ability to associate food locations with feed quality after observing steers returning to arms within an 8-arm radial maze that contained the highest quality feed. The strength of these associations, however, weakened over time (Bailey et al. 1989a, 1989b; Bailey and Sims 1998). Based on these studies, Bailey et al. (1996) hypothesized that cattle utilize spatial memory to make grazing decisions at a landscape level as a result of previous grazing experience and spatial memory of food locations.

Learned Behavior and Social Interaction. Learned behaviors, both individual and those prompted by social facilitation, influence cattle habitat selection patterns on the landscape. Calves are most influenced by their dam when they are young. This effect weakens as calves become yearlings, and peer influences become the strongest. Ultimately, as cattle mature, individual experiences become the strongest influence of behaviors that dictate habitat use patterns. Howery et al. (1998) observed that calves in south-central Idaho grazed in upland areas where they were reared when they returned to pastures as adults. However, as they aged and the number of individual experiences increased, cattle use shifted from uplands to riparian areas, despite more exposure to uplands at a young age.

Cattle that exhibit intraspecific dominance within a herd, in general, are able to select areas for feed, shade, and supplement over subordinate animals (Mosley 1999). Macdonald (2000) observed that social rank affected habitat use patterns in southwestern Montana. When forage quantity and quality were limited in a hot, dry year, high-ranked cows competitively excluded low-ranked cows from higher quality feeding sites. However, cattle with high and low social rank did not use slope classes or areas at various distances to water and shade differently.

Effects of Management Practices on Cattle Habitat Use Patterns

Grazing System and Stocking Rate. Type of grazing system and associated stocking rates have the potential to influence cattle habitat use patterns on foothill and mountain rangeland. Clary and Booth (1993) demonstrated that cattle grazing in early summer in central Idaho utilized meadows adjacent to riparian areas more equally to riparian areas when pastures were moderately stocked. Riparian areas were used more heavily when pastures were lightly stocked. In the foothills of southwestern Alberta, Willms (1990) observed that as stocking rate increased, variability of use among different slope classes decreased.

Hart et al. (1993) found that stocking rate influenced cattle habitat use patterns in south-central Wyoming, but the type of grazing system did not. They found that 90% of use on foothill rangeland occurred within 460 m of water (35% of the land area) under very light stocking while only 63% of use occurred within 460 m of water under moderate stocking. Under the heavier stocking rate, cattle were forced to graze further from water as a result of increased competition for resources. They concluded that type of grazing system did not affect habitat use patterns. Uniformity of grazing by cattle was similar under time-controlled, rotational grazing vs. continuous grazing when pastures were similar in size and shape, and cattle exhibited comparable maximum grazing distances from water.

Season of Use. Cattle grazing on foothill and mountain rangeland alter habitat use behaviors seasonally as a result of changing forage conditions. Cattle grazing from June 15 to October 15 in south-central Wyoming utilized areas of the landscape further from water more frequently late in the grazing season than early (Pinchak et al. 1991). Similarly, Porath et al. (2002) found that cattle without access to off-stream water and supplement spent more time in riparian areas early in the grazing period, until they depleted riparian resources, then shifted their use to the uplands later in the grazing period. Cattle with access to off-stream water and supplement utilized portions of a pasture away from the riparian area more regularly early in the grazing season (July) and shifted use to riparian areas later in the grazing season (August). The shift was attributed to the presence of more desirable forage near the stream later in the season as upland resources near off-stream water and supplement became progressively more depleted.

Supplement. Strategic placement of supplement has long been recognized as a tool to alter grazing distribution and habitat use on foothill and mountain rangeland. However, the effectiveness of different supplement types used specifically for this purpose has been varied. Mature cow and yearling distribution was unaffected by salt location in the summer grazing season in the Blue Mountains and, overall, salt was ineffective at increasing livestock distribution and decreasing cattle concentrations in riparian areas (Bryant 1982). Cattle grazing in mountainous rangeland in north-central Oregon, however, prefered areas within a pasture located within 600 m of salt throughout the grazing season (Gillen et al. 1984).

Bailey and Welling (1999) and Bailey et al. (2001b) conducted studies on foothill rangeland in Montana, to determine the effects of a 30% crude protein, dehydrated molasses supplement on cattle distribution during periods of low forage quality (late summer, fall, winter). Bailey and Welling (1999) observed 32% of the herd in areas containing dehydrated molasses supplement and only 3% of the herd in areas without the supplement. Results also indicated the supplement was effective at attracting cattle to areas of moderate and difficult terrain, but salt placement did not affect grazing distribution. Bailey et al. (2001b) observed

18% of cows within 200 m of the 30% crude protein, dehydrated molasses supplement in north-central Montana. Additionally, 58% and 33% of cattle were observed within 600 m of supplement in two separate pastures, which corresponded to 38% and 26% of those pasture areas, respectively.

Cattle Habitat Selection Modeling

Attempts have been made to model habitat use patterns of cattle on landscapes utilizing regression analysis (Senft et al. 1983, 1985, Owens et al. 1991, Pinchak et al. 1991, Stewart et al. 2002). Incorporation of Geographic Information Systems (GIS) into modeling efforts has recently introduced an efficient mechanism by which cattle habitat selection and use modeling can be accomplished. Assimilation of readily available, meaningful information into efficient spatial and temporal models has been recognized as a cost-effective method for natural resource management and has been attempted for cattle habitat use prediction at the landscape level by researchers in various regions (Wade et al. 1998, Brock and Owensby 2000).

Brock and Owensby (2000) created two separate models to predict grazing distribution and forage removal by cattle in tallgrass prairie vegetation in the Flint Hills region of Kansas, incorporating both biotic and abiotic factors. They found 19 significant variables in predicting grazing distribution and 18 significant variables in predicting forage removal. Grazing treatment had the largest effect in both models. When the models were evaluated, grazing distribution (R^2=0.98) was predicted better than forage removal (R^2=0.07). The poor predictive ability of the forage removal model was attributed to the degree of use within grazed areas being dependent upon descriptive plant community variables, which they did not include in their model. They advocated models that contain information that is easy to derive for management over large areas.

Animal distribution models used in Australia have operated under the premise that distance to water and preferred forage types are the factors having the most influence on animal distribution. Pickup and Bastin (1997) attempted to create a landscape-level cattle distribution model from remotely sensed data. They found that distribution was unaffected by paddock shape and size, water source location, and vegetative patches within paddocks.

Pinchak et al. (1991) developed regression models for cattle summer use of foothill and mountain rangeland in south-central Wyoming. Their model was based on abiotic landscape characteristics and biotic forage characteristics on preferred range sites. Forage characteristics included crude protein content, standing crop, and leaf-stem ratio of tufted and rhizomatous grass species. Water distribution was the primary determinant of cattle distribution, with other abiotic factors of slope and range site contributing. They also found the relationships present between site use and associated forage characteristics were dynamic throughout the grazing season. As forage characteristics across sites became more similar toward mid- to late-grazing season, relationships weakened and the predictability of site use based on these characteristics declined.

Senft et al. (1983, 1985) developed models on shortgrass steppe in northeastern Colorado to predict cattle distribution patterns. Models were developed in 11- and 22-ha pastures with 2-6 animals per pasture and were validated in a 125-ha pasture (Senft et al. 1983). Sixty potential variables were screened for inclusion in the models using stepwise multiple regression, resulting in the use of seven {elevation, slope, aspect, cactus (*Opuntia polyacantha* Haw.) frequency, and distances from water, fence, and pasture corners}. They concluded: 1) the resulting regression equations and successful validation indicated that topographic features largely influenced cattle distribution with minimal input from vegetative attributes, 2) the models may have limited applicability in other vegetation types and terrain types, and 3) grazing patterns may be influenced differently when social interactions of an entire herd of cattle are introduced. Senft et al. (1985) developed regression models to determine the spatial landscape features that influenced cattle distribution during the growing and dormant seasons and to determine if selection of grazing areas was related to nutritional properties of available forage. Results indicated that selection for each grazing period was influenced by different variables except proximity to water and spreading buckwheat (*Eriogonum effusum* Nutt.) frequency. Cattle distribution in the growing season (R^2=0.46) was more accurately predicted than in the dormant season (R^2=0.27). Additionally, they concluded that both forage quality and quantity were important in predicting plant community use. However, because these values varied so widely and changed so dynamically throughout the study period, models of this nature were considered narrowly applicable.

Wade et al. (1998) used a GIS to model the spatial distribution of cattle across Oregon. Two models were developed to predict: 1) areas in Oregon that cattle would potentially graze or not graze, based on vegetative preference, slope, and cost distance to water, and 2) the relative probability that areas identified as grazeable in the first model would be utilized by cattle, based on values computed from the variables in the first model. The models were evaluated by comparing predictions to the presence of cattle in counties across Oregon, obtained from existing county beef cattle density census data. Vegetation type was the primary determinant factor influencing cattle distribution in these models, with steep slopes and distance to water contributing minimally. They concluded that, although the validation process was successful, data collected at a larger scale might have increased the utility of the models. They recommend using these models for management and land use planning tools.

Owens et al. (1991) conducted a study near Uvalde, Texas to determine if pasture characteristics controllable by managers influenced forage utilization in homogeneous pastures. This study included conditions of abundant and limited forage availability. Factor analysis was used to derive influential factors and regression equations were created to describe the relative influence of each factor. They found when forage was plentiful, green herbage availability, grass quantity, brush abundance, remoteness from roads, and water availability explained 54% of the variation in utilization patterns. When forage was limited, brush abundance, grass quantity, green forb frequency, road location, fence proximity, and water availability accounted for 45% of the variation in utilization patterns.

Stewart et al. (2002) used stepwise logistic regression to characterize habitats that were selected or avoided by cattle on the Starkey Experimental Forest and Range. They determined that cattle habitat use patterns were significantly different from random points. Habitat variables that had the greatest influence on cattle distribution were percent slope and distance to permanent water. Plant community, elevation, aspect, terrain diversity and distances to fence, intermittent water, and roads did not contribute significantly.

CHAPTER 3

MATERIALS AND METHODS

Study Area Description

The study was conducted within three study sites on two cattle ranches in northwestern Wyoming and two study sites on one cattle ranch in west-central Montana. In Wyoming, the Rattlesnake study site was approximately 24,000 ha in size, the Rock Creek study site was approximately 11,000 ha, and the Diamond Bar study site was approximately 8,000 ha. These study sites were located 19 km northwest, 60 km southwest, and 50 km southwest of Cody, Wyoming, respectively. In Montana, the Lingshire study site was approximately 13,500 ha in size and the Birch Creek study site was approximately 8,000 ha. These study sites were located 72 km northwest and 12 km west of White Sulphur Springs, Montana, respectively. Each of these five study sites was managed as an independent unit with separate herds of cattle. In general, grazing and cattle management strategies on the study area were typical of many western ranches. The summer cattle grazing season extended from approximately June 1 to October 1. Cattle in the study area were primarily cow/calf pairs and rotational cattle grazing was used throughout the study area in the summer. Moderate stocking rates were implemented with 2.8 ha/AUM (Animal Unit Month) across the Wyoming study sites and 1.8 ha/AUM across the Montana study sites. Elk, mule deer, white-tailed deer, and pronghorn antelope were present on all study sites throughout a majority of the year, however, large numbers of wild ungulates were present only during late fall, winter, and spring.

Topography on the study area was highly variable with plains and rolling foothills at lower elevations subtending rock outcrops and steep mountains at high elevations. Elevations on the study sites ranged from 1650 to 3700 m on the Wyoming sites and from 1280 to 2600 m on the Montana sites. Mean annual precipitation on the Wyoming and Montana study sites was 28 cm and 37 cm, respectively (Western Regional Climate Center 2003). A diversity of plant communities existed from foothill sagebrush grassland to mountain grasslands and subalpine forests. Although forested plant communities were relatively common at the higher elevations of the study area, non-forested habitats provided the majority of summer foraging sites for cattle in foothill and mountain rangeland (Macdonald 2000). This research focused exclusively on non-forested, sagebrush grassland and mountain grassland plant communities occupying foothill and mountain rangeland in the Absaroka Mountains in Wyoming and the Big Belt Mountains in Montana. The non-forested areas included in this research were 30,180 and 28,860 ha in size in Wyoming and Montana, respectively.

Major plant species present in the sagebrush grassland communities included mountain big sagebrush (*Artemisia tridentata* ssp. *vaseyana* Beetle), Wyoming big sagebrush (*A. t.* ssp. *wyomingensis* Beetle), bluebunch wheatgrass (*Agropyron spicatum* (Pursh) Scribn.), Idaho fescue (*Festuca idahoensis* Elmer), Sandberg bluegrass (*Poa secunda* Presl.), Hood's phlox (*Phlox hoodii* Richardson), rose pussy-toes (*Antennaria rosea* Greene), and western yarrow (*Achillea millefolium* L.). Major species present in the mountain grassland communities included Idaho fescue, Sandberg bluegrass, Columbia needlegrass (*Stipa nelsonii* Scribn.), needleandthread (*Stipa comata* Vasey), timber oatgrass (*Danthonia intermedia* Vasey), lupine (*Lupinus* spp. Kell.), and milkvetch (*Astragalus* spp. L).

Procedures

A model based on landscape habitat variables was developed to predict the spatial distribution of forage utilization by cattle on foothill and mountain rangeland. The model was developed from spatial information and actual cattle utilization measurements obtained at the end of the summer grazing season from the three Wyoming sites in 1999 and 2000. The model was then validated temporally using data from the Wyoming sites in 2001 and 2002 and spatially using data from the Montana sites in 2001 and 2002. Spatial validation in this study refers to the evaluation of the model on similar foothill and mountain rangeland landscapes located in a different area (Montana) than where the model was developed (Wyoming).

Characterization of Habitat Available to Cattle in Summer. Ten habitat variables that influence cattle habitat selection were identified from previous research and included in the initial analysis. The ten variables selected to describe the foothill and mountain summer cattle range included: percent slope, aspect, elevation, herbaceous standing crop, two-dimensional distance to water (horizontal), three-dimensional distance to water (vertical and horizontal combined), two-dimensional distance to shade, three-dimensional distance to shade, two-dimensional distance to fence, and three-dimensional distance to fence.

For model development, one hundred random points were generated on each of the three study sites in Wyoming in 1999 and 2000 (n=594) and values for each of the chosen variables were obtained to characterize the sites (Edge et al. 1988). Similarly, one hundred points were generated on each of the three study sites in Wyoming in 2001 and 2002 (n=600) for temporal model validation and on the two study sites in Montana in 2001 and 2002 (n=400) for spatial model validation. The random samples of points used to characterize habitats on the study area were stratified to include only sagebrush grassland and mountain grassland habitats in pastures where cattle had been present during the grazing season in the summers of 1999, 2000, 2001, and 2002. The random points were also stratified to include equal representation of each of the four *a priori* utilization classes used in the model (i.e, 25% of random points per utilization class). Random points were restricted to being located $\geq$ 60 m from one another in order to ensure independence. Random points were generated using the Random function in Arc Macro Language (AML) in Workstation Arc/Info (ESRI 2002).

Values for slope, aspect, herbaceous standing crop, elevation, two- and three-dimensional distance to water, two- and three-dimensional distance to shade, and two- and three-dimensional distance to fence used in both the model development and validation steps were obtained using a Geographic Information System (GIS) and individual, easily-queried raster layers were created for each variable. A raster layer of the 1992 National Land Cover Database (NLCD) (Vogelmann et al. 2001) was used to determine the vegetation type for each random point. Random points were restricted to either sagebrush grassland (NLCD classification 51, Shrubland), or mountain grassland (NLCD classification 71, Grassland/Herbaceous) types. Herbaceous standing crop for each of the two vegetation types was calculated from the oven-dried weights of current-year's growth clipped to ground level from a 50 x 50-cm quadrat inside a 2.5-m^2 grazing exclosure at the end of the grazing season. Each vegetation type was sampled with nine exclosures across study sites in Wyoming in 1999 and 2000 (9 exclosures x 2 vegetation types x 2 years = 36 exclosures) and ten exclosures per vegetation type in Wyoming and Montana in 2001 and 2002 (10 exclosures x

2 vegetation types x 2 years = 40 exclosures per state). Exclosures were randomly located within each of the vegetation types and were moved to new locations within the vegetation type each year.

Digital Elevation Models (DEMs) (USGS 1999, 2002) for the Wyoming and Montana sites were used to obtain the values for slope, aspect, elevation, two- and three-dimensional distance to water, two- and three-dimensional distance to shade, and two- and three-dimensional distance to fence. The elevation of each random point corresponded to the elevation value of the 30 x 30-m cell located at that point on the DEM. Aspect and percent slope were calculated for each random point using the elevation values of surrounding cells. Percent slope was calculated with an algorithm and identified as the maximum rate of change in value from its neighbors in a 3 x 3-cell area and aspect was determined to be the direction of the maximum downhill slope gradient. Aspect was reported in degrees clockwise from due north and then transformed using a cosine transformation.

Two-dimensional (horizontal) distances to landscape features were determined to be the straight-line distances from a random point to a point feature, to the nearest point on a linear feature, or to the nearest point within a polygon. Point features included developed water, linear features included perennial streams and fences, and polygon features included perennial ponds and springs and forested cover (shade). Areas of shade were defined as raster cells that had NLCD land cover values corresponding to deciduous forest, evergreen forest, or mixed forest (NLCD classifications 41, 42, and 43, respectively). These cells were assigned values of 1 with all other cells receiving a nodata value and distance to shade was determined to be the straight-line distance from a random point to the nearest shade cell. Spring and pond polygons were treated similarly to shade polygons and the smallest distance to developed water, a stream, a spring, or a pond was chosen as the value to represent distance to water.

Three-dimensional (vertical and horizontal combined) distances from random points to landscape features were defined as the shortest straight-line distance from the random point to the feature and also included the additional distance accrued by following the ups and downs of the undulating terrain along the way. Distance measurements were obtained by summing three-dimensional distance values obtained for each 30-m section of a line between the random point and the nearest landscape feature across the undulating terrain using the Surfacexsection function in Arc Macro Language (AML) in Workstation Arc/Info (ESRI 2002).

Characterization of Forage Utilization by Cattle in Summer. In addition to the habitat variables described above, each random point was also classified within one of four cattle utilization classes based on field inventories taken at the end of the summer grazing season each year. Forage utilization by cattle was inventoried on each study site in Wyoming in 1999 and 2000 for model development, in 2001 and 2002 in Wyoming for temporal model validation, and in 2001 and 2002 in Montana for spatial model validation. Utilization was inventoried following the protocol described by Anderson and Currier (1973) and Crane (2002). Summer cattle grazing intensity was inventoried after the grazing season via horseback and all-terrain vehicle and was characterized as Ungrazed (<11% utilization), Light (11-30% utilization), Moderate (31-60% utilization), or Heavy (>60% utilization) using landscape appearance guidelines presented in USDA-USDI (1996). A minimum mapping unit of 20 ha was used for delineating different levels of forage utilization. Utilization categories were documented on 1:24,000 topographic quadrants during the ocular sampling. Through this process, a complete map was produced of each study site for each year that depicted the distribution of the four different forage utilization classes across the landscape.

To enhance the accuracy of ocular estimates, the Paired-Plot Method (USDA-USDI 1996) was used to determine percent utilization using the grazing exclosures described previously. Prior to initiation of ocular inventories, utilization was calculated at each exclosure site by comparing the oven-dried weights of herbage from one, 50 x 50-cm quadrat inside each grazing exclosure with herbage from one, 50 x 50-cm quadrat outside each grazing exclosure (USDA-USDI 1996). The general location of grazing exclosures was determined subjectively to ensure representative sites, but individual quadrat locations were randomly selected. Ocular estimates were then calibrated with these utilization measurements prior to the initiation of ocular surveys during all years of the study.

Statistical Analyses

Summer cattle utilization was mapped and random points were located on three sites (Rattlesnake, Rock Creek, Diamond Bar) for two years (1999, 2000) in Wyoming for model development. Temporal model validation was completed with data from three sites (Rattlesnake, Rock Creek, Diamond Bar) for two years (2001, 2002) in Wyoming and spatial model validation was completed with data from two sites (Lingshire, Birch Creek) for two years (2001, 2002) in Montana. Data from the three study sites and two years (1999, 2000) in Wyoming were combined in model development and data from the three sites and two years (2001, 2002) in Wyoming and two sites and two years (2001, 2002) in Montana were combined in temporal and spatial model validation, respectively.

Model Development. Discriminant analysis procedures in SAS (2003) were used to predict group membership of random points from 1999 and 2000 on the Wyoming study sites into the four *a priori* utilization classes (Heavy, Moderate, Light, Ungrazed) based on the best combination of discriminant variables. Potential discriminant variables included: slope, aspect, elevation, herbaceous standing crop, and two- and three-dimensional distances to water, shade, and fence.

The list of potential discriminant variables was screened for multicollinearity between variables prior to performing the discriminant analysis. To control for multicollinearity among discriminant variables (Bowyer et al. 1998, 1999; Stewart et al. 2002), one of any pair of variables with $|r| \geq 0.45$ in the correlation matrix was eliminated (Bowyer et al. 1998). The variable within the correlated pair that was most related to the remaining discriminant variables was eliminated.

The remaining variables were entered into discriminant analysis. Those variables with a probability value > 0.30 were deemed to have little influence on cattle utilization patterns on the landscape and were eliminated from the model. Next, unstandardized and standardized discriminant functions containing the remaining variables were obtained for each of the four utilization classes. Wilk's Λ was used to test for model significance and the model was significant at $P \leq 0.05$. For each random point, corresponding values for each remaining variable were inserted into the unstandardized discriminant functions, resulting in a numeric value for each class. Each randomly located point was then classified into the utilization class (group) having the largest discriminant score. The data were standardized to evaluate the relative influence of the variables on utilization level.

Model accuracy was evaluated by comparing the actual classification values (mapped value) to the predicted utilization classification derived from the discriminant analysis (Tabachnick and Fidell 1989). In addition, Cohen's weighted Kappa statistic was used to describe the chance-corrected agreement between actual and predicted values (Titus et al. 1984).

Model Validation. Once discriminant functions were obtained in model development, values of randomly located points from the Wyoming study sites in 2001 and 2002 were applied to the unstandardized equations to evaluate the temporal variability of the model. Similarly, values of randomly located points from the Montana study sites in 2001 and 2002 were applied to these equations to evaluate the spatial variability of the model. Again, each randomly located point was classified into the utilization class that had the largest discriminant score.

Temporal and spatial accuracies of the model were evaluated for the Wyoming and Montana study sites, respectively, in 2001 and 2002 by comparing the actual classification values (mapped value) to the predicted utilization classification derived from the discriminant analysis (Tabachnick and Fidell 1989). In addition, Cohen's weighted Kappa statistic was used to describe the chance-corrected agreement between actual and predicted values (Titus et al. 1984).

Means Comparisons. Analysis of variance (ANOVA) was used to test for differences between means of the six habitat descriptor variables between four classes of cattle utilization from 1999, 2000, 2001, and 2002 in northwestern Wyoming and west-central

Montana. Means comparisons were made using Fisher's Protected LSD test (SAS 2003). Differences were considered significant at $P \leq 0.01$.

Additional Procedures

Due to poor predictive accuracy and low Kappa statistics of the model (hereafter referred to as Model 1) in both the model development and validation stages, another model (hereafter referred to as Model 2) was developed and evaluated. Model 2 had three utilization classes rather than four, with the Moderate and Light classes combined (11-60% utilization). These two classes were combined for two reasons. First, in general, natural resource managers strive for light to moderate grazing utilization and manage to minimize heavily grazed and ungrazed areas within a pasture. Second, mean values of most of the habitat variables did not differ between the Moderate and Light utilization classes (data reported in Table 7 in Results chapter), suggesting that areas grazed moderately and lightly were relatively similar. The resulting model consisted of three utilization classes, Heavy, Moderate-Light, and Ungrazed, characterized by >60%, 11-60%, and <11% utilization, respectively.

Model 2 was also based on landscape habitat variables and was developed to predict the spatial distribution of forage utilization by cattle on foothill and mountain rangeland. As in Model 1, Model 2 was developed from spatial information and actual cattle utilization measurements obtained at the end of the summer grazing season from the three Wyoming sites in 1999 and 2000. This model was then validated temporally using data from the Wyoming sites in 2001 and 2002 and spatially using data from the Montana sites in 2001 and

2002. All procedures and statistical analyses were conducted the same for Model 2 as they were for Model 1, but with only three utilization classes instead of four.

CHAPTER 4

RESULTS

Correlation Analysis

Five pairs of the original ten habitat variables were significantly correlated ($P < 0.01$) with $|r| > 0.45$ (Table 1). Elevation was negatively correlated ($P < 0.01$) with both two- and three-dimensional distance to shade (r = -0.57 and r = -0.57, respectively). In addition, two- and three-dimensional distances to water (r = 1.0), two- and three-dimensional distances to shade (r = 1.0), and two- and three-dimensional distances to fence (r = 1.0) were perfectly correlated ($P < 0.01$). Elevation and three-dimensional distances to water, shade, and fences were eliminated due to high correlations with other variables. The remaining six variables (i.e., slope, aspect, herbaceous standing crop, and two-dimensional distances to water, shade, and fence) were retained for inclusion in the discriminant analysis.

Model 1 – Four Utilization Classes

Model Development. Discriminant analysis procedures resulted in four discriminant classification equations ($P < 0.01$; Table 2, Table 3) for the Heavy, Moderate, Light, and Ungrazed utilization classes, based on six significant variables: slope ($P < 0.01$), aspect ($P = 0.21$), herbaceous standing crop ($P < 0.01$), and two-dimensional distances to water ($P < 0.01$), shade ($P = 0.01$), and fence ($P < 0.01$). Heavy utilization was most influenced by slope and distance to water (discriminant coefficients = -0.42 and -0.33, respectively), moderate utilization by slope and distance to shade (discriminant coefficients = -0.20 and

-0.18, respectively), light utilization by distance to fence (discriminant coefficient = 0.27), and ungrazed areas by slope (discriminant coefficient = 0.60) (Table 3).

When the model development data from northwestern Wyoming (1999, 2000) was applied to the unstandardized equations, overall classification accuracy of the model was 32%, with only 192 of the 594 random points correctly classified (Table 4). Classification accuracy was 0% for the Heavy utilization class, 76% for the Moderate class, 15% for the Light class, and 39% for the Ungrazed class (Table 4). Cohen's weighted Kappa statistic for model development was 0.11 ($P < 0.01$; Table 5).

Temporal Validation. When data from northwestern Wyoming in 2001 and 2002 were applied to the four unstandardized discriminant classification equations, overall classification accuracy for temporal model validation was 39%, with 236 of the 600 random points classified correctly (Table 6). Cohen's weighted Kappa statistic was 0.15 ($P < 0.01$; Table 5). Classification accuracies into the Heavy, Moderate, Light, and Ungrazed classes were 0, 69, 16, and 42%, respectively (Table 6).

Spatial Validation. Spatial validation of Model 1 resulted in 49% accuracy overall (198 of 400 points classified correctly) when data from west-central Montana in 2001 and 2002 were applied to the four unstandardized discriminant classification equations (Table 7). The Heavy class had zero points classified correctly, the Moderate class had 85%, the Light class had 3%, and the Ungrazed class had 25% of points classified correctly (Table 7). Cohen's weighted Kappa statistic was 0.03 ($P = 0.06$; Table 5).

Means of Habitat Descriptor Variables. Mean values for herbaceous standing crop, slope, aspect and two-dimensional distances to water, shade, and fence all differed between the four utilization classes across the Wyoming and Montana study sites ($P < 0.01$; Table 8). Herbaceous standing crop in the Moderate, Light, and Ungrazed utilization classes averaged 1,281 kg/ha and did not differ ($P > 0.05$) from each other, but were lower than the 1,512 kg/ha that characterized the Heavy utilization class ($P \leq 0.05$). Percent slope differed between all four utilization classes ($P \leq 0.05$) with averages of 17%, 20%, 23%, and 30% characterizing the Heavy, Moderate, Light, and Ungrazed utilization classes, respectively (Table 8).

Aspect in the Ungrazed utilization class differed ($P \leq 0.05$) from the Heavy and Moderate utilization classes at –0.18 vs. 0.02 and 0.02, respectively (cosine of degrees). Aspect in the Light utilization class (-0.08) did not differ ($P > 0.05$) from the Heavy, Moderate, or Ungrazed utilization classes (0.02, 0.02, and –0.18, respectively) ($P \leq 0.05$; Table 8).

Two-dimensional distance to water did not differ ($P > 0.05$) between the Moderate and Light utilization classes, averaging 355 m, or between the Heavy and Ungrazed utilization classes, averaging 237 m. However, two-dimensional distance to water differed ($P \leq 0.05$) between the Heavy and Ungrazed and the Moderate and Light utilization classes (237 m vs. 355 m, respectively) (Table 8).

Two-dimensional distance to shade differed ($P \leq 0.05$) between the Heavy (562 m) utilization class and the Moderate and Light utilization classes, which averaged 391 m. Two-dimensional distance to shade in the Ungrazed utilization class (448 m) did not differ ($P >$

0.05) from the Heavy, Moderate, or Light utilization classes, which averaged 562, 418, and 364 m, respectively (Table 8).

Two-dimensional distance to fence differed ($P \leq 0.05$) between the Light (558 m) utilization class and the Heavy, Moderate, and Ungrazed utilization classes, which were characterized by averages of 397, 468, and 353 m, respectively. Two-dimensional distance to fence did not differ ($P > 0.05$) between the Heavy (397 m) utilization class and the Moderate (468 m) and Ungrazed (353 m) utilization classes (Table 8).

Model 2 – Three Utilization Classes

Model Development. Discriminant analysis procedures resulted in three discriminant classification equations ($P < 0.01$; Table 9, Table 10) for the Heavy, Moderate-Light, and Ungrazed utilization classes. Slope ($P < 0.01$), aspect ($P = 0.30$), herbaceous standing crop ($P < 0.01$), and two-dimensional distances to water ($P < 0.01$), shade ($P < 0.01$), and fence ($P < 0.01$) were significant in the model. Heavy utilization was most influenced by slope and distance to water (discriminant coefficients = -0.42 and -0.33, respectively), moderate-light utilization by distance to fence (discriminant coefficient = 0.20), and ungrazed areas by slope (discriminant coefficient = 0.60) (Table 10).

Model accuracy was 53% overall (315 of 594 points classified correctly) when data from northwestern Wyoming in 1999 and 2000 were applied to the three unstandardized classification equations (Table 11). Cohen’s weighted Kappa statistic for model development was 0.10 ($P < 0.01$; Table 12). Classification accuracies for the Heavy, Moderate-Light, and Ungrazed utilization classes were 0%, 97%, and 18%, respectively (Table 11).

Temporal Validation. Overall accuracy of Model 2 was 74% when Wyoming data in 2001 and 2002 were applied to the three unstandardized discriminant classification equations, with 444 of 600 random points correctly classified (Table 13). Cohen's weighted Kappa statistic was 0.20 ($P < 0.01$) for temporal model validation (Table 12). Classification accuracy for the Heavy utilization class was 0%, 94% for the Moderate-Light class, and 23% for the Ungrazed class (Table 13).

Spatial Validation. When data from west-central Montana in 2001 and 2002 were applied to the three unstandardized discriminant classification equations, overall classification accuracy for spatial model validation was 77%, with 307 of 400 random points correctly classified (Table 14). Cohen's weighted Kappa statistic for spatial model validation was 0.05 ($P = 0.08$; Table 12). Classification accuracies in the Heavy, Moderate-Light, and Ungrazed utilization classes were 0%, 91%, and 15%, respectively (Table 14).

CHAPTER 5

DISCUSSION AND CONCLUSIONS

Cattle Habitat Use Patterns

Cattle habitat utilization patterns on foothill and mountain rangeland in northwestern Wyoming and west-central Montana were influenced by slope, herbaceous standing crop, aspect, and distances to water, shade, and fence. Heavily utilized sites were influenced greatly by percent slope and distance to water in both models. The negative relationship between both of these variables and heavily used sites supports historic findings that cattle utilization increases as slope and distance to water decrease (Mueggler 1965, Cook 1966, Miller and Krueger 1976). Ungrazed sites were influenced dominantly by percent slope in both models. Similar to other findings, as percent slope increased on the study area, cattle presence decreased and sites remained ungrazed (Gillen et al. 1984, Ganskopp and Vavra 1987). In Model 1, moderately grazed sites were characterized by lower percent slopes and lower distance to shade than lightly grazed or ungrazed sites and lightly grazed sites were characterized by greater distances from fence. In Model 2, when the moderate and light utilization classes from Model 1 were combined, the moderately-lightly grazed sites were largely influenced by distance to pasture fence. Overall, the strength of the influence of habitat variables on moderately and moderately-lightly utilized sites was less than the relationships exhibited between habitat variables and heavily grazed or ungrazed sites.

As percent slope on the study area increased, cattle grazing utilization decreased. Areas with slopes averaging 17% were grazed heavily, those with slopes averaging 20% were grazed moderately, areas with slopes averaging 23% were grazed lightly, and areas with slopes averaging 30% remained ungrazed. Stewart et al. (2002) documented cattle utilizing slightly gentler slopes in the Blue Mountains of Oregon than the average slope grazed by cattle in this study (13% vs. 20%, respectively). Cattle grazed on slopes ranging from 0.2% to 83%, but, in general, restricted their grazing activity to slopes less than 23%. This supports other findings that cattle favor gentle slopes (Bryant 1982, Van Vuren 1982, Gillen et al. 1984), however, the range of slope use by cattle in this study was larger than the 0-40% slope use observed by Pinchak et al. (1991) in south-central Wyoming

Results from this study suggest that grazing guidelines, such as those available from Holechek (1988), may need refined for foothill and mountain rangeland landscapes. Holechek (1988) suggests a 100% reduction in grazing capacity for areas with >60% slope, and suggests a 60% reduction for areas with slopes from 31-60%. In this study, polygons ≥20 ha in size were heavily grazed on slopes up to 69%, with moderate utilization on slopes up to 73%, and light utilization on slopes up to 83%. These results suggest that on foothill and mountain rangeland, Holechek's guidelines are extremely conservative and that, perhaps, grazing capacity should not be reduced on slopes <60% and that a 100% reduction in grazing capacity may not be appropriate until slopes reach 80%. Cattle inhabiting more rugged terrain have been documented utilizing steeper slopes than cattle inhabiting more moderate terrain (Ganskopp and Vavra 1987). Because the foothill and mountain rangeland sites in this study were rugged and diverse, grazing guidelines specific for these heterogeneous landscapes may be more appropriate than general guidelines used elsewhere.

Heavy utilization by cattle occurred within areas that averaged 206 m from water, while moderate and light cattle utilization occurred an average of 360 m and 349 m from water, respectively. These results are similar to the findings of Pinchak et al. (1991), when they observed cattle grazing within 366 m of water 77% of the time on foothill rangeland in south-central Wyoming. The observed grazing distances from water in this study tended to be shorter than findings from some research. Cattle grazing in mountain rangeland in north-central Oregon preferred areas within 600 m of water (Gillen et al. 1984), while cattle grazing in foothill rangeland in south-central Wyoming preferred areas within 3,000 m of water (Hart et al. 1993). These different findings may be due to ample availability of water on the study sites in northwestern Wyoming and west-central Montana, as indicated by the 318 m average distance from water across the study area.

Holechek (1988) suggests that areas >3,200 m from water should be considered ungrazable by cattle (i.e., a 100% reduction in grazing capacity) and that grazing capacity in areas between 1,600 and 3,200 m from water should be reduced by 50%. Results from this study indicated that the maximum distance that cattle on these foothill and mountain rangeland landscapes grazed from water was 2,829 m when water was readily available across the study area. Based on this information, a refined grazing guideline specifically for foothill and mountain rangeland may be warranted. In foothill and mountain rangeland areas where water is readily available to cattle, grazing capacity should be reduced by 100% in areas located >2,829 m from water.

Cattle heavily utilized areas of greater forage availability, whereas areas with less available herbaceous standing crop were grazed moderately, lightly, or remained ungrazed. Heavily grazed areas averaged 1,512 kg/ha of available herbaceous standing crop vs. a 1,281-kg/ha average in moderate, light, and ungrazed areas. Similar to these findings, cattle grazing on diverse foothill rangeland in southern Wyoming selected range sites with the greatest amount of standing crop of preferred forages available (Pinchak et al. 1991).

However, cattle grazing in the Henry Mountains did not selectively graze areas of abundant forage (Van Vuren 1982). Cattle generally grazed on gentle slopes near water sources, despite deterioration of forage on those sites.

Cattle heavily grazed areas that averaged 562 m from shade, whereas areas averaging 391 m from shade were grazed moderately or lightly. Ungrazed areas averaged 448 m from shade. Sites that were far from shade may have been heavily grazed in response to increased forage availability, as plants in full sunlight are more productive than shaded plants (Larcher 1983). Research regarding the influence of shade on cattle grazing patterns on foothill and mountain rangeland is limited. Research suggests that cattle tend to rest in areas where water was consumed mid-day (Porath et al. 2002) and that development of shade in upland areas may decrease the use of riparian areas (Howery et al. 1998). However, no other literature was found specifically regarding the relationship between shade and grazing activity.

Results regarding the influence of distance to fence were mixed in this study. Areas the furthest from fences (558 m) were grazed lightly, areas closest to fences remained ungrazed (353 m), and areas that averaged 468 m were grazed moderately. Heavily grazed sites were at similar distances as those areas that were either moderately grazed or remained ungrazed. Although distance to fence was a significant variable in the discriminant analysis, the results may support the findings of Stewart et al. (2002) that cattle distribution was not influenced by distance to fence on large pastures in the Starkey Experimental Forest and Range.

While aspect remained a significant variable in both models, it exhibited less influence on cattle distribution patterns than the other five variables. Cattle utilization was greater on sites with slightly northerly vs. slightly southerly aspects (0.02 vs. –0.18 cosine of degrees, respectively). In addition, 18% of the grazed area (i.e., heavy, moderate, or light utilization) was located on west-facing slopes vs. 31% on east-facing slopes. Overall, although differences were minimal, cattle grazed more heavily on slightly northerly and easterly slopes. Research for foothill and mountain rangeland, in general, has indicated aspect is not a dominant factor influencing cattle habitat use patterns (Sheehy and Vavra 1996, Stewart et al. 2002).

Cattle Utilization Models

The correlation analysis that was performed prior to model development resulted in five pairs of variables that were significantly correlated. Of those variables, elevation and three-dimensional distances to water, shade, and fence were the four variables eliminated. Three-dimensional distances were eliminated to increase the practical applicability of the model for future users because two-dimensional distances are much easier to attain. Elevation also was eliminated from the model due to its high correlation with distance to shade and because it likely played a very small role in cattle utilization pattern differences within any given pasture.

The ability of Model 1 to classify sites accurately increased from 32% in model development to 39% in temporal validation and 49% in spatial validation. Model 1 classified points into the Moderate utilization class particularly well, averaging 76% through the development and validation stages. Sites in the Ungrazed and Light classes were classified less accurately (35 and 11%, respectively) and Model 1 did not classify any points into the Heavy utilization class in the development, temporal validation, or spatial validation stages.

The weighted Kappa coefficients in the development and validation stages for Model 1 were significant, but the coefficients were small. Model 1 was able to classify points into the correct utilization class significantly better than chance, but only 11% better than chance in the development stage, 15% better in the temporal validation stage, and 3% better in the spatial validation stage.

Combining Moderate and Light utilization classes in Model 2 increased the classification accuracy of the model compared to Model 1. Classification accuracy for model development was 53%, which was 21 percentage points higher than Model 1. Classification accuracy for the Ungrazed class increased by 8 percentage points between Model 1 and Model 2 and averaged 19% in Model 2. Correct classification into the Moderate-Light utilization class was exceptional, averaging 94% in Model 2 compared to 76 and 11% for Moderate and Light utilization, respectively, in Model 1. As in Model 1, Model 2 did not classify any points into the Heavy utilization class. In general, areas that were characterized by Heavy utilization were very limited, representing only 4% of the study area.

The weighted Kappa coefficients for the Model 2 development and validation stages were significant, indicating that Model 2 was able to predict points into the correct utilization class significantly better than chance. The weighted Kappa in the model development stage for Model 2 was slightly less than Model 1 (0.10 vs. 0.11, respectively), but the weighted Kappa values increased between Model 1 and Model 2 in both temporal (0.15 vs. 0.20, respectively) and spatial validation (0.03 vs. 0.05, respectively).

In comparison, Model 2 was more successful at correctly classifying points across all utilization classes than Model 1 (75% and 44% classification accuracy for model validation, respectively). Model 2 was better at correctly predicting points into the Moderate-Light category (92.5%) in the validation stages than Model 1 correctly predicted Moderate (76.9%) or Light (9.3%) utilization in the validation stages. Model 1, however, was able to correctly predict points into the Ungrazed class (33.5%) in validation stages better than Model 2 (19%). Both models were unable to correctly predict sites into the Heavy utilization class. The ability of the models to predict Moderate and Moderate-Light utilization relatively well may be attributed to the large proportion of the study area characterized by moderately-lightly grazed sites and the increased range of variability of the habitat variables that characterize those sites.

Published models of cattle habitat use have not been validated temporally or spatially, but instead, have either been published without validation or have been validated using data from the same sites for the same years of study. Stewart et al. (2002) created a logistic model for cattle on foothill rangeland in northeastern Oregon by comparing areas actually used by cattle to random locations to determine what habitat variables were selected for or avoided. Their logistic model was not tested beyond the model development stage, however, the model correctly classified 66% of the study sites as grazed or ungrazed by cattle. In comparison, Model 2 had greater classification accuracy in both the temporal validation stage (74%) and the spatial validation stage (77%). The greater classification accuracies are also notable given that Model 2 classifies levels of cattle utilization rather than merely grazed or ungrazed.

Senft et al. (1983) developed models to predict cattle behavior patterns on shortgrass prairie in northeastern Colorado. The models were developed to predict areas where cattle would spend time grazing and traveling, resting in the summer, resting in the winter, and bedding and had R^2 values of 0.50, 0.34, 0.25, and 0.20, respectively. All of these values indicate lower predictive accuracy than Model 2. Senft et al. (1985) developed two separate models to predict seasonal patterns of cattle grazing. The growing season model had an R^2

value of 0.46 and the dormant season model had an R^2 value of 0.27. Their correlations between observed and predicted grazing patterns on shortgrass prairie were also much lower than the ability of Model 2 in this study to predict a level of cattle grazing utilization on foothill and mountain rangeland (75% predictive accuracy in temporal and spatial validations combined).

In foothill rangeland of south-central Wyoming, Pinchak et al. (1991) developed multiple regression equations that accounted for up to 79% of the variation in cattle locations across the landscape. The independent variables in these models described the growth form composition and nutritive quality of the vegetative standing crop. Not only are the attributes of forage vegetation more difficult to obtain than the data incorporated into Model 2, but they are highly dynamic throughout the grazing season, thus limiting the applicability of the models (Senft et al. 1985).

Brock and Owensby (2000) developed two separate models, one to identify grazed vs. ungrazed sites and the other to predict forage removal by cattle in tallgrass prairie. The models were evaluated by withholding 20% of the original data and had R^2 values of 0.98 and 0.07 for predicting grazed vs. ungrazed sites and forage removal, respectively. The R^2 values indicate grazed sites were readily predicted, but forage removal was not. In contrast, Model 2 in this study correctly classified forage utilization on 75% of sites.

In summary, Models 1 and 2 were more rigorously tested and Model 2 was found to be much more accurate than previously published models of cattle utilization. Predictive accuracy was especially high for sites receiving moderate utilization in Model 1 and moderate-light utilization in Model 2. Additionally, the information required for implementation of these models by resource managers is accessible from existing sources and is easily attainable. Their user-friendly nature can help increase the effectiveness and efficiency of natural resource management on foothill and mountain rangeland.

Management Implications

Predictions from Models 1 and 2, when used in conjunction with a resource manager's personal knowledge of the landscape, provide a useful tool when managing for multiple uses across large landscapes on foothill and mountain rangeland. Proper implementation and appropriate use of this tool is essential to its effectiveness.

The intended use of these models is as a planning tool to help natural resource managers identify areas of potential conflict and complementarity between cattle grazing and other resource uses and values. These models should not be used to set stocking rates or as a substitute for monitoring grazing utilization by cattle. The applicability of these models is limited to foothill and mountain rangeland that is grazed in summer at moderate stocking levels under extensive, rotational grazing systems.

These models can be used to effectively identify portions of foothill and mountain rangeland landscapes that will receive moderate or moderate-light grazing utilization by cattle. This information, coupled with previous knowledge of cattle grazing distribution patterns, habitat variables that influence these patterns, and specific details about a pasture or landscape, provide an effective tool for identifying areas that may need revised management strategies to achieve management goals. Ultimately, these models can be used to help resource managers sustain the ecological integrity of foothill and mountain rangeland.

CHAPTER 6

LITERATURE CITED

Anderson, E.W., and W.F. Currier. 1973. Evaluating zones of utilization. J. Range Manage. 26:87-89.

Bailey, D.W. 1995. Daily selection of feeding areas by cattle in homogeneous and heterogeneous environments. Appl. Anim. Behav. Sci. 45:183-200.

Bailey, D.W., J.E. Gross, E.A. Laca, L.R. Rittenhouse, M.B. Coughenour, D.M. Swift, and P.L. Sims. 1996. Mechanisms that result in large herbivore grazing distribution patterns. J. Range Manage. 49:386-400.

Bailey, D.W., D.D. Kress, D.C. Anderson, D.L. Boss, and E.T. Miller. 2001a. Relationship between terrain use and performance of beef cows grazing foothill rangeland. J. Anim. Sci. 79:1883-1891.

Bailey, D.W., L.R. Rittenhouse, R.H. Hart, and R.W. Richards. 1989a. Characteristics of spatial memory in cattle. Appl. Anim. Behav. Sci. 23:331-340.

Bailey, D.W., L.R. Rittenhouse, R.H. Hart, D.M. Swift, and R.W. Richards. 1989b. Association of relative food availabilities and locations by cattle. J. Range Manage. 42:480-482.

Bailey, D.W., and P.L. Sims. 1998. Association of food quality and locations by cattle. J. Range Manage. 51:2-8.

Bailey, D.W., and G.R. Welling. 1999. Modification of cattle grazing distribution with dehydrated molasses supplement. J. Range Manage. 52:575-582.

Bailey, D.W., G.R. Welling, and E.T. Miller. 2001b. Cattle use of foothills rangeland near dehydrated molasses supplement. J. Range Manage. 54:338-347.

Beaver, J.M., and B.E. Olson. 1997. Winter range use by cattle of different ages in southwestern Montana. Appl. Anim. Behav. Sci. 51:1-13.

Bennett, I.L., V.A. Finch, and C.R. Holmes. 1985. Time spent in shade and its relationship with physiological factors of thermoregulation in three breeds of cattle. Appl. Anim. Behav. Sci. 13:227-236.

Berg, B.P., and R.J. Hudson. 1982. Elk, mule deer and cattle: functional interactions on foothills range in southwestern Alberta, p. 509-519. *In*: J.M. Peek and P.D. Dalke (eds.), Proc. Wildlife-Livestock Relationships Symp., Idaho For., Wildl., and Range Exp. Sta., Univ. of Idaho, Moscow.

Bowyer, R.T., J.G. Kie, and V. VanBallenberghe. 1998. Habitat selection by neonatal black-tailed deer: climate, forage, or risk of predation? J. Mammal. 79:415-425.

Bowyer, R.T., V. VanBallenberghe, J.G. Kie, and J.A.K. Meier. 1999. Birth-site selection in Alaskan moose: maternal strategies for coping with a risky environment. J. Mammal. 80:1070-1081.

Brock, B.L., and C.E. Owensby. 2000. Predictive models for grazing distribution: a GIS approach. J. Range Manage. 53:39-46.

Bryant, L.D. 1982. Response of livestock to riparian zone exclusion. J. Range Manage. 35:780-785.

Clary, W.P., and G.D. Booth. 1993. Early season utilization of mountain meadow riparian pastures. J. Range Manage. 46:493-497.

Cook, C.W. 1966. Factors affecting utilization of mountain slopes by cattle. J. Range Manage. 19:200-204.

Crane, K.K. 2002. Influence of cattle grazing on feeding site selection by Rocky Mountain elk. Ph.D. Diss., Univ. of Wyo., Laramie.

Dean, R.E., and R.W. Rice. 1974. Effects of fences and corrals on grazing behavior. Proc. West. Sec. Amer. Soc. Anim. Sci. 25:56-58.

Duncan, A.J., and I.J. Gordon. 1999. Habitat selection according to the ability of animals to eat, digest, and detoxify foods. Proc. Nutr. Soc. 58:799-805.

Edge, D.W., L.C. Marcum, and S.L. Olson-Edge. 1988. Summer forage and feeding site selection by elk. J. Wildl. Manage. 52:573-577.

Environmental Systems Research Institute, Inc. 2002. Workstation Arc/Info Version 8.3. Environmental Systems Research Institute, Redlands, Calif.

Ganskopp, D., and M. Vavra. 1987. Slope use by cattle, feral horses, deer, and bighorn sheep. Northw. Sci. 61:74-79.

Gillen, R.L., W.C. Krueger, and R.F. Miller. 1984. Cattle distribution on mountain rangeland in northeastern Oregon. J. Range Manage. 37:549-553.

Hart, R.H. 2001. Plant biodiversity on shortgrass steppe after 55 years of zero, light, moderate, or heavy cattle grazing. Plant Ecol. 155:111-118.

Hart, R.H., J. Bisso, M.J. Samuel, and J.W. Waggoner, Jr. 1993. Grazing systems, pasture size, and cattle grazing behavior, distribution and gains. J. Range Manage. 46:81-87.

Hart, R.H., K.W. Hepworth, M.A. Smith, and J.W. Waggoner, Jr. 1991. Cattle grazing behavior on a foothill elk winter range in southeastern Wyoming. J. Range Manage. 44:262-266.

Hedrick, M.B., and R.T. Dailey. 1982. A change in forage allocation on the Charles M. Russell National Wildlife Refuge, Montana, p. 529-536. *In*: J.M. Peek and P.D. Dalke (eds.), Proc. Wildlife-Livestock Relationships Symp., Idaho For., Wildl., and Range Exp. Sta., Univ. of Idaho, Moscow.

Herbel, C.H., and A.B. Nelson. 1966. Activities of Hereford and Santa Gertrudis cattle on a southern New Mexico range. J. Range Manage. 19:173-181.

Holechek, J.L. 1988. An approach for setting the stocking rate. Rangelands. 10:10-14.

Howery, L.D., F.D. Provenza, R.E. Banner, and C.B. Scott. 1998. Social and environmental factors influence cattle distribution on rangeland. Appl. Anim. Behav. Sci. 55:231-244.

Larcher, W. 1983. Physiological plant ecology. Springer – Verlag, Berlin.

Laycock, W.A. 1994. Implications of grazing vs. no grazing on today's rangelands. p. 250-280. *In*: M. Vavra, W.A. Laycock, and R.D. Pieper (eds.) Ecological implications of livestock herbivory in the west. Society for Range Management, Denver, CO.

Macdonald, B.R. 2000. Influence of social rank on habitat use and performance of free-ranging cattle. M.S. Thesis, Montana State Univ., Bozeman, Mont.

Marlow, C.B., and T.M. Pogacnik. 1986. Cattle feeding and resting patterns in a foothills riparian zone. J. Range Manage. 39:212-217.

McIlvain, E.H., and M.C. Shoop. 1971. Shade for improving cattle gains and rangeland use. J. Range Manage. 24:181-184.

Miller, R.F., and W.C. Krueger. 1976. Cattle use on summer foothill rangelands in northeastern Oregon. J. Range Manage. 29:367-371.

Mosley, J.C. 1999. Influence of social dominance on habitat selection by free-ranging ungulates, p. 109-118. *In*: K.L. Launchbaugh, K.D. Sanders, and J.C. Mosley (eds.), Proc. Grazing Behavior of Livestock and Wildlife, Univ. of Idaho For., Wildl., and Range Exp. Sta. Bull. 70.

Mueggler, W.F. 1965. Cattle distribution on steep slopes. J. Range Manage. 18:255-261.

Mueggler, W.F. 1984. Diversity of western rangelands, p. 211-217. *In*: J.L. Cooley and J.H Cooley (eds.), Natural Diversity in Forest Ecosystems. Univ. of Georgia, Athens.

Owens, K.M., K.L. Launchbaugh, and J.W. Holloway. 1991. Pasture characteristics affecting spatial distribution of utilization by cattle in mixed brush communities. J. Range Manage. 44:118-123.

Pickup, G. 1994. Modelling patterns of defoliation by grazing animals in rangelands. J. Appl. Ecol. 31:231-246.

Pickup, G., and G.N. Bastin. 1997. Spatial distribution of cattle in arid rangelands as detected by patterns of change in vegetation cover. J. Appl. Ecol. 34:657-667.

Pieper, R.D. 1994. Ecological implications of livestock grazing, p. 177-211. *In*: M. Vavra, W.A. Laycock, and R.D. Pieper (eds.) Ecological implications of livestock herbivory in the West. Society for Range Manage., Denver, Colo.

Pinchak, W.E., M.A. Smith, R.H. Hart, and J.W. Waggoner, Jr. 1991. Beef cattle distribution patterns on foothill range. J. Range Manage. 44:267-275.

Porath, M. L., P.A. Momont, T. DelCurto, N.R. Rimbey, J.A. Tanaka, and M. McInnis. 2002. Offstream water and trace mineral salt as management strategies for improved cattle distribution. J. Anim. Sci. 80:346-356.

Roath, L.R., and W.C. Krueger. 1982. Cattle grazing and behavior on a forested range. J. Range Manage. 35:332-338.

SAS Institute, Inc. 2003. SAS Version 9.0. SAS Institute, Cary, NC.

Selting, J.P., and L.R. Irby. 1997. Agricultural land use patterns of native ungulates in southeastern Montana. J. Range Manage. 50:338-345.

Senft, R.L., L.R. Rittenhouse, and R.G. Woodmansee. 1983. The use of regression models to predict spatial patterns of cattle behavior. J. Range Manage. 36:553-557.

Senft, R.L., L.R. Rittenhouse, and R.G. Woodmansee. 1985. Factors influencing patterns of cattle grazing behavior on shortgrass steppe. J. Range Manage. 38:82-87.

Sheehy, D.P., and M. Vavra. 1996. Ungulate foraging areas on seasonal rangeland in northeastern Oregon. J. Range Manage. 49:16-21.

Smith, M.A., J.D. Rodgers, J.L. Dodd, and Q.D. Skinner. 1992. Habitat selection by cattle along an ephemeral channel. J. Range Manage. 45:385-390.

Stevens, D.R. 1966. Range relationships of elk and livestock, Crow Creek drainage, Montana. J. Wildl. Manage. 30:349-363.

Stewart, K.M., R.T. Bowyer, J.G. Kie, N.J. Cimon, and B.K. Johnson. 2002. Temporospatial distributions of elk, mule deer, and cattle: Resource partitioning and competitive displacement. J. Mammal. 83:229-244.

Tabachnick, B.G., and L.S. Fidell. 1989. Using multivariate statistics, 2nd ed. Harper and Row, New York.

Titus, K., J.A. Mosher, and B.K. Williams. 1984. Chance-corrected classification for use in discriminant analysis: ecological applications. Amer. Midl. Natur. 111:1-7.

U.S. Department of Agriculture – U.S. Department of Interior. 1996. Utilization studies and residual measurements. Interagency Tech. Reference BLM/RS/ST-96/004+1730, Bur. of Land Manage., Denver, Colo.

U.S. Geological Survey. 1999. 30 meter National Elevation Dataset (tiled for Wyoming). Available at: http://www.sdvc.uwyo.edu/24k/dem.html.

U.S. Geological Survey. 2002. National Elevation Dataset for Montana. Available at: http://nris.state.mt.us/nsdi/nris/el10/dems.html.

Valentine, K.A. 1947. Distance from water as a factor in grazing capacity of rangeland. J. For. 45:749-754.

Van Vuren, D. 1982. Comparative ecology of bison and cattle in the Henry Mountains, Utah. p. 449-457. *In*: J.M. Peek and P.D. Dalke (eds.), Proc. Wildlife-Livestock Relationships Symp., Idaho For., Wildl., and Range Exp. Sta., Univ. of Idaho, Moscow.

Vogelmann, J.E., S.M. Howard, L. Yang, C.R. Larson, B.K. Wylie, N. and Van Driel. 2001. Completion of the 1990s National Land Cover Data Set for the conterminous United States from Landsat Thematic Mapper data and ancillary data sources. Photogr. Eng. Rem. Sens. 67:650-652.

Wade, T.G., B.W. Schultz, J.D. Wickham, and D.F. Bradford. 1998. Modeling the potential spatial distribution of beef cattle grazing using a Geographic Information System. J. Arid Environ. 38:325-334.

West, N.E. 1993. Biodiversity of rangelands. J. Range Manage. 46:2-13.

Western Regional Climate Center. 2003. Cody, Wyoming (481840), Cody 21SW, Wyoming (481855), White Sulphur Springs 2, Montana (248930), and White Sulphur Springs 24, Montana (248936). Available at: http://www.wrcc.dri.edu/.

Willms, W.D. 1990. Distribution of cattle on slope without water restrictions. Can. J. Anim. Sci. 70:1-8.

Table 1. Pairwise correlation coefficients (r) between 10 habitat descriptor variables from foothill and mountain rangeland in northwestern Wyoming (n=594 random points).

	Habitat Variables									
	Herbaceous Standing Crop	**Slope**	**Aspect**	**Elevation**	**2-D Distance to Water**	**3-D Distance to Water**	**2-D Distance to Shade**	**3-D Distance to Shade**	**2-D Distance to Fence**	**3-D Distance to Fence**
Herbaceous Standing Crop		-0.03	0.05	0.21	0.10	0.10	-0.20	-0.21	0.09	0.09
Slope			-0.20	0.33	-0.01	0.01	-0.34	-0.33	0.03	0.05
Aspect				-0.09	0.02	0.02	0.19	0.19	-0.08	-0.09
Elevation					0.23	0.24	-0.57*[1]	-0.57*	0.32	0.33
2-Dimensional Distance to Water						1.00*	-0.09	-0.09	-0.06	-0.05
3-Dimensional Distance to Water							-0.10	-0.10	-0.06	-0.05
2-Dimensional Distance to Shade								1.00*	-0.20	-0.21
3-Dimensional Distance to Shade									-0.20	-0.21
2-Dimensional Distance to Fence										1.00*
3-Dimensional Distance to Fence										

[1]* = $|r| \geq 0.45$

Table 2. Unstandardized discriminant functions for classifying non-forested foothill and mountain rangeland into four utilization classes. Equations based on data from 1999 and 2000 in northwestern Wyoming.

Utilization Class	Classification Equations
Heavy	S_H = -11.83206 + 0.00581y_1+ 0.16559y_2 + -0.22899 y_3 + 0.00522y_4 + 0.00511y_5 + 0.00266y_6
Moderate	S_M = -10.23696 + 0.00578y_1+ 0.18149y_2 + -0.20917 y_3 + 0.00771y_4 + 0.00484y_5 + 0.00330y_6
Light	S_L = -11.13243 + 0.00586y_1+ 0.19572y_2 + -0.40452 y_3 + 0.00715y_4 + 0.00504y_5 + 0.00366y_6
Ungrazed	S_U = -11.78782 + 0.00533y_1+ 0.23748y_2 + -0.30148 y_3 + 0.00841y_4 + 0.00569y_5 + 0.00238y_6

y_1 = herbaceous standing crop; y_2 = slope; y_3 = aspect; y_4 = 2-dimensional distance to water; y_5 = 2-dimensional distance to shade; y_6 = 2-dimensional distance to fence.

Table 3. Standardized discriminant functions for classifying non-forested foothill and mountain rangeland into four utilization classes. Equations based on data from 1999 and 2000 in northwestern Wyoming.

Utilization Class	Classification Equations
Heavy	S_H = -3.39589 + 0.06745y_1+ -0.42046y_2 + 0.04126 y_3 + -0.32760y_4 + -0.03387y_5 + -0.13697y_6
Moderate	S_M = -0.90653 + 0.04843y_1+ -0.19548y_2 + 0.05543y_3 + 0.09861y_4 + -0.18338y_5 + 0.12259y_6
Light	S_L = -1.20294 + 0.09408y_1+ 0.00577y_2 + -0.08427 y_3 + 0.00309y_4 + -0.07114y_5 + 0.26628y_6
Ungrazed	S_U = -1.72610 + -0.20752y_1+ 0.59635y_2 + -0.01058 y_3 + 0.21848y_4 + 0.28504y_5 + -0.25392y_6

y_1 = herbaceous standing crop; y_2 = slope; y_3 = aspect; y_4 = 2-dimensional distance to water; y_5 = 2-dimensional distance to shade; y_6 = 2-dimensional distance to fence.

Table 4. Classification of four cattle utilization levels in northwestern Wyoming during 1999 and 2000 based on discriminant analysis from 1999 and 2000 data.

Actual Utilization Class	**Cattle Utilization Levels Classified by Discriminant Functions**				**Classification Accuracy**
	Heavy	**Moderate**	**Light**	**Ungrazed**	
	--------------------- number of sites ---------------------				------ % ------
Heavy (n=146)	0	117	14	15	0.0
Moderate (n=148)	0	112	19	17	75.7
Light (n=150)	0	108	22	20	14.7
Ungrazed (n=150)	0	88	4	58	38.7
Total (n=594)	0	425	59	110	32.3

Table 5. Weighted Kappa coefficients and their probability values for the classifications of four cattle utilization levels based on discriminant functions developed from 1999 and 2000 data from northwestern Wyoming.

Study Area and Years					
Wyoming 1999-2000		**Wyoming 2001-2002**		**Montana 2001-2002**	
Weighted Kappa Coefficient	***P***	**Weighted Kappa Coefficient**	***P***	**Weighted Kappa Coefficient**	***P***
0.11	<0.01	0.15	<0.01	0.03	0.06

Table 6. Classification of four cattle utilization levels in northwestern Wyoming during 2001 and 2002 based on discriminant functions developed from 1999 and 2000 data.

	Cattle Utilization Levels Classified by Discriminant Functions				
Actual Utilization Class	**Heavy**	**Moderate**	**Light**	**Ungrazed**	**Classification Accuracy**
	--------------------- number of sites --------------------				------ % ------
Heavy (n=12)	0	6	2	4	0.0
Moderate (n=193)	0	133	21	**39**	68.9
Light (n=243)	0	168	39	36	16.0
Ungrazed (n=152)	0	75	13	64	42.1
Total (n=600)	0	382	75	143	39.3

Table 7. Classification of four cattle utilization levels in west-central Montana during 2001 and 2002 based on discriminant functions developed from 1999 and 2000 data from northwestern Wyoming.

Actual Utilization Class	**Cattle Utilization Levels Classified by Discriminant Functions**				**Classification Accuracy**
	Heavy	**Moderate**	**Light**	**Ungrazed**	
	-------------------- number of sites --------------------				------ % ------
Heavy (n=30)	0	28	1	1	0.0
Moderate (n=218)	**0**	185	7	26	84.9
Light (n=112)	0	90	3	19	2.7
Ungrazed (n=40)	0	29	1	10	25.0
Total (n=400)	0	332	12	56	49.5

Table 8. Means (± SE) of habitat descriptor variables between four classes of cattle utilization and weighted means (± SE) for the study area from 1999, 2000, 2001, and 2002 in northwestern Wyoming and west-central Montana.

Habitat Variable	*P*	Cattle Utilization Levels				Study Area (n=1594)
		Heavy (n=188)	Moderate (n=559)	Light (n=505)	Ungrazed (n=342)	
Herbaceous Standing Crop (kg/ha)	<0.01	1512(43)a[1]	1297(19)b	1302(22)b	1244(26)b	1312(12)
Slope (%)	<0.01	16.7(0.8)a	20.1(0.5)b	22.8(0.5)c	29.6(1.0)d	22.6(0.3)
Aspect (cosine of degrees)	<0.01	0.02(0.05)a	0.02(0.03)a	-0.08(0.03)ab	-0.18(0.04)b	-0.05(0.02)
2-Dimensional Distance to Water (m)	<0.01	206(21)a	360(17)b	349(20)b	268(15)a	318(10)
2-Dimensional Distance to Shade (m)	<0.01	562(38)a	418(21)b	364(20)b	448(30)ab	425(13)
2-Dimensional Distance to Fence (m)	<0.01	397(34)ab	468(19)a	558(22)c	353(18)b	463(11)

[1]Means within rows followed by the same letter are not different (*P* > 0.01).

Table 9. Unstandardized discriminant functions for classifying non-forested foothill and mountain rangeland into three utilization classes. Equations based on data from 1999 and 2000 in northwestern Wyoming.

Utilization Class	Classification Equations
Heavy	S_H = -11.82868 + 0.00582y_1+ 0.16492y_2 + -0.21630 y_3 + 0.00526y_4 + 0.00511y_5 + 0.00264y_6
Moderate-Light	S_{M-L} = -9.96496 + 0.00582y_1+ 0.18789y_2 + -0.29314 y_3 + 0.00748y_4 + 0.00494y_5 + 0.00346y_6
Ungrazed	S_U = -11.77962 + 0.00533y_1+ 0.23675y_2 + -0.28635 y_3 + 0.00847y_4 + 0.00568y_5 + 0.00235y_6

y_1 = herbaceous standing crop; y_2 = slope; y_3 = aspect; y_4 = 2-dimensional distance to water; y_5 = 2-dimensional distance to shade; y_6 = 2-dimensional distance to fence.

Table 10. Standardized discriminant functions for classifying non-forested foothill and mountain rangeland into three utilization classes. Equations based on data from 1999 and 2000 in northwestern Wyoming.
y_1 = herbaceous standing crop; y_2 = slope; y_3 = aspect; y_4 = 2-dimensional distance to water;

Utilization Class	Classification Equations
Heavy	S_H = -3.39586 + 0.06793y_1+ -0.41957y_2 + 0.04021 y_3 + -0.32892y_4 + -0.03304y_5 + -0.13605y_6
Moderate-Light	S_{M-L} = -0.33988 + 0.07147y_1+ -0.09460y_2 + -0.01473 y_3 + 0.05074y_4 + -0.12724y_5 + 0.19506y_6
Ungrazed	S_U = -1.72637 + -0.20810y_1+ 0.59632y_2 + -0.00988 y_3 + 0.21935y_4 + 0.28495y_5 + -0.25509y_6

y_5 = 2-dimensional distance to shade; y_6 = 2-dimensional distance to fence.

Table 11. Classification of three cattle utilization levels in northwestern Wyoming during 1999 and 2000 based on discriminant analysis from 1999 and 2000 data.

Actual Utilization Class	**Cattle Utilization Levels Classified by Discriminant Functions**			**Classification Accuracy**
	Heavy	**Moderate-Light**	**Ungrazed**	
	----------------- number of sites -----------------			------ % ------
Heavy (n=146)	0	141	5	0.0
Moderate-Light (n=298)	0	288	10	96.6
Ungrazed (n=150)	0	123	27	18.0
Total (n=594)	0	552	42	53.0

Table 12. Weighted Kappa coefficients and their probability values for the classifications of three cattle utilization levels based on discriminant functions developed from 1999 and 2000 data from northwestern Wyoming.

Study Area and Years					
Wyoming 1999-2000		**Wyoming 2001-2002**		**Montana 2001-2002**	
Weighted Kappa Coefficient	***P***	**Weighted Kappa Coefficient**	***P***	**Weighted Kappa Coefficient**	***P***
0.10	<0.01	0.20	<0.01	0.05	0.08

Table 13. Classification of three cattle utilization levels in northwestern Wyoming during 2001 and 2002 based on discriminant functions developed from 1999 and 2000 data.

Actual Utilization Class	**Cattle Utilization Levels Classified by Discriminant Functions**			
	Heavy	**Moderate-Light**	**Ungrazed**	**Classification Accuracy**
	---------------- number of sites ----------------			------ % ------
Heavy (n=12)	0	12	0	0.0
Moderate-Light (n=436)	0	409	27	93.8
None (n=152)	0	117	35	23.0
Total (n=600)	0	538	62	74.0

Table 14. Classification of three cattle utilization levels in west-central Montana during 2001 and 2002 based on discriminant functions developed from 1999 and 2000 data from northwestern Wyoming.

Actual Utilization Class	**Cattle Utilization Levels Classified by Discriminant Functions**			**Classification Accuracy**
	Heavy	**Moderate-Light**	**Ungrazed**	
	----------------- number of sites	-----------------	-----------------	------ % ------
Heavy (n=30)	0	29	1	0
Moderate-Light (n=330)	0	301	29	91.2
Ungrazed (n=40)	0	34	6	15.0
Total (n=400)	0	364	36	76.8