GIS modeling of bison habitat in southwestern Montana : a study in ranch management and conservation
by Linda Bowers Phillips

A thesis submitted in partial fulfillment Of the requirements for the degree of Master of Science in Earth Sciences
Montana State University

Abstract:
Since the near extinction of American bison (Bison bison) at the turn of the century free-ranging herds exist in only a few locations. However, bison ranching has become increasingly common on fenced private lands. An example, is a privately owned bison ranch located in southwestern Montana that maintains their herd using a minimal management approach. The ranch manager's intent is to allow the bison operation to be largely defined by natural processes. Selective range utilization by bison, however, has affected range quality resulting in overutilization and underutilization. The objectives of this research were to determine if biophysical differences existed between areas of bison overutilization and underutilization, and to provide ranch managers with information regarding whether more intensive management could alleviate impacts associated with differential bison utilization. The methods employed were to (1) determine and collect data regarding bison utilization, (2) to develop a database of biophysical variables that could be measured and that might influence bison habitat selection, (3) to perform an exploratory data analysis using Classification and regression tree analysis, (4) to analyze nutritional, physical environmental, and behavioral variables independently using Bayesian probability analysis, and (5) to model the results of the analysis geographically for the ranch. Classification and regression tree analysis and Bayesian probability analysis were used to identify differences in biophysical variables and to produce bison habitat use models. Of the 14 variables studied, significant differences existed in areas underutilized and overutilized for 5 nutritional variables (forage type, forage productivity, soil mineralogy, soil pH, and soil salinity), 3 physical environmental variables (elevation, slope, and surface soil texture), and 2 behavioral variables (nearest neighbor distance and viewshed). The digital database, analysis and results were intended to provide ranch managers with information regarding the characteristics of the sites utilized and not utilized by bison throughout the ranch.

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APPROVAL

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Linda Bowers Phillips

This thesis has been read by each member of the thesis committee and has been found to be satisfactory regarding content, English usage, format, citations, bibliographic style, and consistency, and is ready for submission to the College of Graduate Studies.

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ABSTRACT

Since the near extinction of American bison (*Bison bison*) at the turn of the century free-ranging herds exist in only a few locations. However, bison ranching has become increasingly common on fenced private lands. An example, is a privately owned bison ranch located in southwestern Montana that maintains their herd using a minimal management approach. The ranch manager's intent is to allow the bison operation to be largely defined by natural processes. Selective range utilization by bison, however, has affected range quality resulting in overutilization and underutilization. The objectives of this research were to determine if biophysical differences existed between areas of bison overutilization and underutilization, and to provide ranch managers with information regarding whether more intensive management could alleviate impacts associated with differential bison utilization. The methods employed were to (1) determine and collect data regarding bison utilization, (2) to develop a database of biophysical variables that could be measured and that might influence bison habitat selection, (3) to perform an exploratory data analysis using Classification and regression tree analysis, (4) to analyze nutritional, physical environmental, and behavioral variables independently using Bayesian probability analysis, and (5) to model the results of the analysis geographically for the ranch. Classification and regression tree analysis and Bayesian probability analysis were used to identify differences in biophysical variables and to produce bison habitat use models. Of the 14 variables studied, significant differences existed in areas underutilized and overutilized for 5 nutritional variables (forage type, forage productivity, soil mineralogy, soil pH, and soil salinity), 3 physical environmental variables (elevation, slope, and surface soil texture), and 2 behavioral variables (nearest neighbor distance and viewshed). The digital database, analysis and results were intended to provide ranch managers with information regarding the characteristics of the sites utilized and not utilized by bison throughout the ranch.

Chapter 1

INTRODUCTION

American bison (*Bison bison*) historically occupied a variety of habitats from prairies to upland mountains (Roe 1972). Since their near extinction at the turn of the century, however, free-ranging herds exist on just a few locations in the U.S. and Canada. Cattle have been introduced and have occupied most historical bison rangelands, except where bison populations have since been restored on public and private lands. Bison herds on private lands are managed on fenced ranges. While efforts to sustain bison populations have been successful, having this species on fenced ranges can create ecological problems associated with overgrazing, overrest, overuse, bison-elk conflict, bison health, and noxious weeds (Sindelar and Ayers 1999).

In 1989 the Flying D Ranch (FDR), a 53,825 ha (133,000 acre) ranch located in southwestern Montana, began bison ranching using a minimal management approach. This approach included the removal of internal fences, allowing bison to range freely within the confines of the fenced FDR exterior boundary (pers comm Bud Griffith, FDR manager). The intent was to allow the bison operation to be largely defined by natural processes. Over the years, FDR personnel and range habitat assessors observed that bison utilized certain areas of the FDR intensively, while other areas were unutilized. This pattern of use has affected range quality, resulting in poor habitat where parts of the FDR were being overgrazed and less than ideal habitat in areas characterized by severe underutilization (Sindelar 1997). Recently, FDR managers have questioned whether more intensive management could promote a more widespread distribution of bison on the range and thus alleviate problems resulting from this selective grazing behavior.

Objectives

The overall objective of this research was to determine if Geographic Information Systems (GIS) are useful for ranch management activities on the FDR. The first part of the research entailed a GIS User Needs Assessment (Aspinall and Phillips 1998). The assessment and discussions with ranch employees indicated the need to explore the geography of bison habitat of the FDR bison herd. The specific objectives of the bison investigation were:

(a) to identify biophysical differences, if any, between areas receiving different levels of utilization; and

(b) to explore the physical geography of bison habitat so to better understand how management might result in better bison distribution on the FDR.

GIS and spatial analysis techniques allow quantitative analysis of spatial use patterns over large areas (Herr and Queen 1993, Hepinstall *et al.* 1996, Bian and West 1997, Pearson *et al.* 1995, Turner *et al.* 1994). These techniques were used to assess bison habitat requirements and apply this knowledge to understanding bison spatial patterns of use to facilitate management and conservation of bison rangeland for the FDR.

Bison habitat use has been studied extensively (Reynolds *et al.* 1978, Meagher and Shaw 1999, Meagher 1973), and reliable knowledge of habitat requirements is necessary for development of successful conservation and management strategies (Otis 1998). Two general approaches to study habitat use by wildlife have been used, depending on the objectives and data availability (Stoms *et al.* 1992). The first, a deductive approach, determines geographic areas used by a species based on rules applied to biophysical characteristics of an area. These rules are derived from known general relationships and data overlay techniques, and the approach is ultimately descriptive (Aspinall 1992). The second, an inductive approach, is used when specific biophysical characteristics are not known, and a GIS and spatial analysis are used to induce the characteristics from known animal species' locations. More recently the inductive approach has been used for wildlife habitat studies (Aspinall 1992, Walker and Moore 1998).

Habitat Variable Selection

Based on previous literature and discussions with bison ecologists, biophysical variables that were directly or indirectly associated with bison habitat selection were identified and a digital database was created. While many aspects of bison ecology have been studied, bison research conducted in other geographic areas or research conducted on herds subject to different management strategies does not necessarily apply to the FDR. As a result, this research employs the inductive approach to habitat variable selection to account for differences in habitat requirements from one geographic area to another.

Knowledge of bison ecology allows for an investigation of bison habitat selection on a specific study area, incorporating biophysical variables.

Previous Literature

Male and female bison select similar foraging sites (Larter and Gates 1991), however the composition of their diets shows significant differences. This suggests that males and females use their habitat in different ways, choosing different plants or plant parts, the females being more selective than the males (Larter 1988).

Male and female bison repeat similar movements between summer and winter ranges (Meagher 1986, Van Vuren 1983), using mostly open rangelands and sometimes using wooded areas when available (Fuller 1960, McHugh 1958). Bison are large mammals, females averaging 1760 kg and males averaging 4400 kg (Meagher 1973), requiring large quantities of forage (Houston 1982). Bison have adapted to a diet of low quality and high quantity forage (Houston 1982). They are generalist foragers and eat grasses and sedges proportionate to their availability in some habitats (Reynolds *et al.* 1978). The diet of bison in the Henry Mountains, Utah consisted of approximately 90% grasses and sedges, 5% forbs, and 1% browse (VanVuren 1979). The food habits in the Yellowstone National Park bison herd were found by Meagher (1973) to be similar to those in the Henry Mountains. Grasses and grass-like plants composed 91-99% of their diet, sedges constituted more than half of the main food source for all seasons, forbs constituted 3% and browse constituted 1% of their diet (Meagher 1973). It has been suggested that soil salinity and soil pH (pers comm Dennis Cash) might influence plant absorption of minerals that subsequently become available to bison during digestion.

Bison are strongly attracted to recently burned areas (Shaw and Carter 1990, Turner *et al.* 1994), possibly resulting from the short-term increase in forage quality (Coppock *et al.* 1986) and quantity (Wallace *et al.* 1995). When bison were allowed access to an area that was previously unavailable and recently burned , females over two years old tend to consistently move on to the area in winter and repeat that movement in subsequent years (Shaw and Carter 1990).

Since cattle replaced bison throughout much of North America over the last century, comparative studies between domestic cattle and bison have been conducted. In the shortgrass plains of Colorado, cattle prefer foraging in swales and shallow depressions, whereas bison prefer foraging in upland areas (Peden *et al.* 1974). Bison spent an average of 1.9 days at any location in the Henry Mountains, Utah (Van Vuren 1981). The foraging behavior resulted in a more uniform distribution of grazing pressure by bison than by cattle in the Henry Mountains.

In the Henry Mountains of Utah, bison have been observed grazing at elevations greater than 3080 m, frequently at elevations up to 3260 m, and almost half of all bison observations were recorded above 3000 m (Van Vuren 1979). In another study, bison typically spent summer months at elevations of 2500-3500 m and spent winter months at elevations of 1700-2100 m (Van Vuren and Bray 1986). Comparative studies have been conducted on bison foraging behavior at various elevations and slopes in the Henry Mountains of Utah (Van Vuren 1983), and bison utilized areas at higher elevations than cattle. Bison were observed grazing on slopes exceeding 25 degrees frequently, one third of slopes in the area exceeded 25 degrees (Van Vuren 1979) and bison consistently utilized steeper slopes than cattle (Peden *et al.* 1974). Distance to water was not important for bison habitat selection in bison herds in the Henry Mountains of Utah (VanVuren 1983). Bison preferred grazing at a farther distance to a water source than cattle, with only 18% of bison observations located within 200 m of a water source (Van Vuren 1979).

Bison wallows are prevalent in areas of bison use and are often permanent features in the landscape that are used year after year (Meagher 1973). Wallows are created most commonly by bulls, and wallowing increases during the rut (Meagher 1986).

Bison are gregarious animals (Roe 1970), and therefore bison habitat selection studies must incorporate habitat variables that allow bison to maintain required natural behaviors. Bison herds are fluid aggregations. Individuals and juvenile groups change membership frequently and group size varies from a few to hundreds of animals (Van Vuren 1983, Lott and Minta 1983). These mixed groups maintained closer contact in smaller groups than when they are farther from neighboring groups (Green 1992). Non-mother females are more often found in adult groups containing males. These adult groups more often occur before the rut (Komers *et al.* 1993, Fuller 1960, Reynolds *et al.* 1982).

Females appear to have larger home ranges than males, and larger groups are found in more open habitats (Van Vuren 1981) and on more gentle slopes (Rutberg 1984). This may result from a larger foraging area required for the larger number of animals (Larter and Gates 1990).

Forested areas are not used frequently for foraging (Meagher 1973) and wooded areas are used only to seek relief from the sun, during rutting activity, travel, and escape from insects (Robert Garrott pers comm, Meagher 1973). It has been theorized (pers comm Margie Taylor) that more convoluted patch shapes might minimize bison comfort as a result of of historic gray wolf (*Canis lupus*) predation of bison (Fuller 1960). Bison are gregarious animals, forming herds according to sex, age, season, foraging conditions and habitat (Meagher 1986). Travel routes are usually well defined in mountainous areas, and travel is usually in a line lead by an adult female (McHugh 1958). Bison principally utilize open areas and prefer to maintain visual contact for communication.

Thesis Structure

The remainder of this thesis is structured with 6 chapters and 4 appendices. Chapter 2 describes the physical geography of the study area. Chapter 3 describes the methodology employed, including the specifics of the biophysical data, and a description and justification of the statistical analysis and sensitivity analysis. Chapter 4 explains the results of the

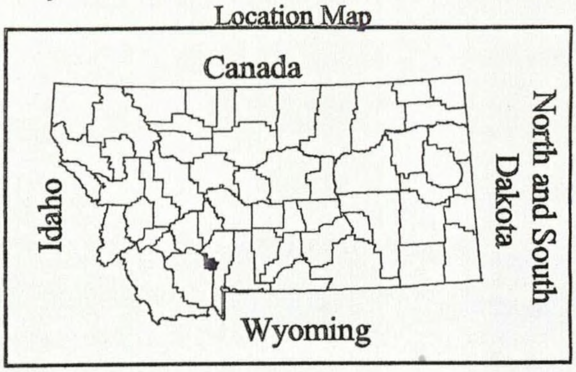
statistical analysis and sensitivity analysis, from both a statistical and geographical perspective. Chapter 5 discusses the inferences drawn from the statistical and sensitivity analysis. Chapter 6 discusses implications of the research for FDR management activities and suggestions for future research.

Chapter 2

STUDY AREA

The research was conducted on the FDR, located in southwestern Montana. southwest of Bozeman, MT (Figure 1). The FDR is 53,825 ha (133,179 acres) in area and supports approximately 3000 bison. The FDR is within the Madison River basin and the Gallatin River basin, north of the Spanish Peak Mountains on the Madison Range, and south of Gallatin Gateway, MT .

The FDR consists of open rangeland, foothills, and mountains ranging in elevation from approximately 1300 m to 2590 m. The lower elevations are found along the Madison River basin and the higher elevations are in the southern portion of the FDR approaching the Spanish Peak Mountains. Slopes range from 0 degrees to 46 degrees with the flatter areas in the northwestern region along the Madison River. Precipitation ranges from 356 mm/year (14 inches/year) in the lower elevations to 1524 mm/year (60 inches/year) in the higher elevation southern region (The Nature Conservancy 1989). Geologically, the lower elevations are on a syncline composed of gently folded sedimentary rocks (The Nature Conservancy 1989). Soils in this region are deep and consist mostly of silty and clayey loams. The mountains in the southern region of the FDR are uplifted metamorphic rocks



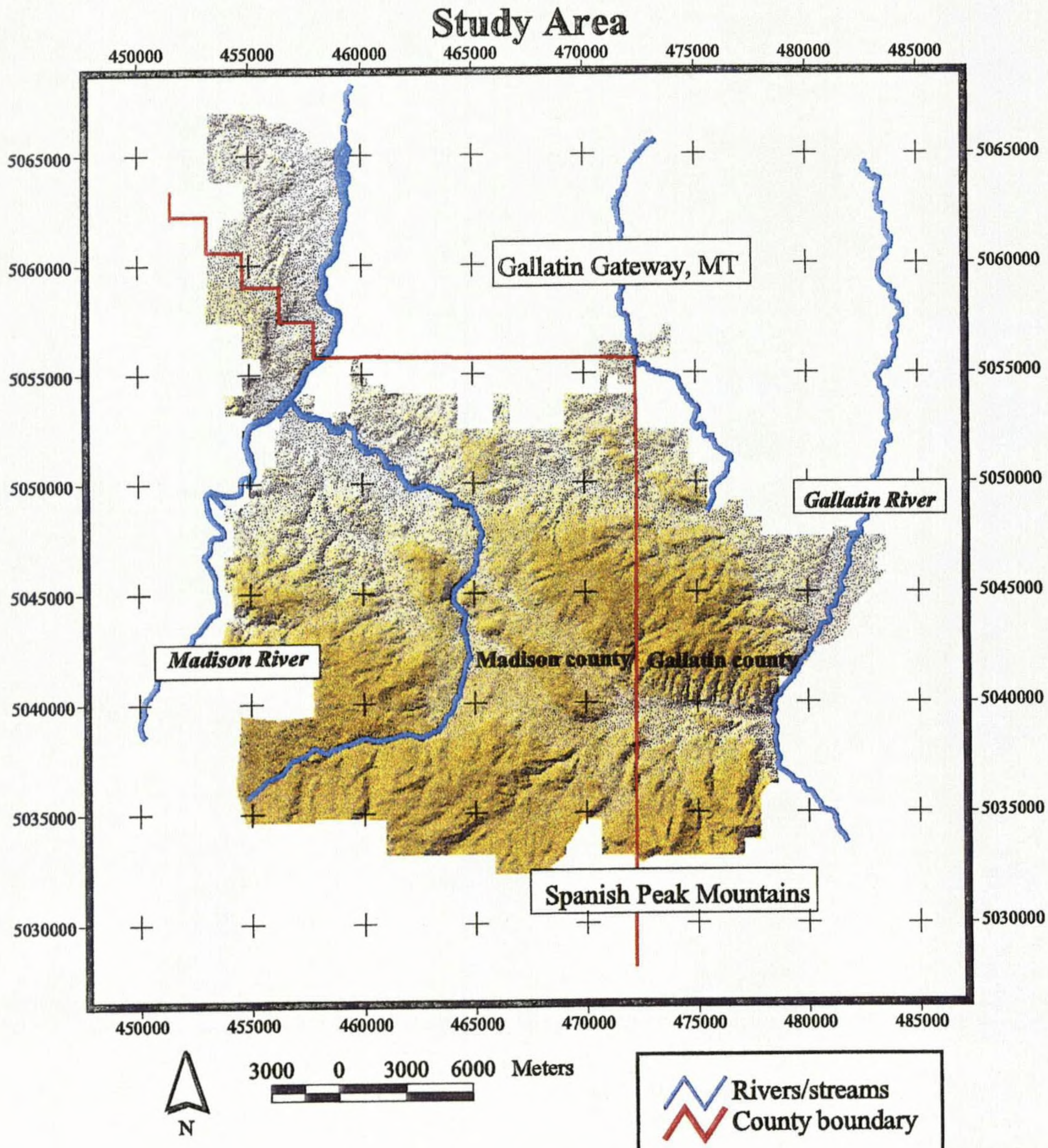


Figure 1. Location of the study area.

with many outcrops (Nature Conservancy 1989). Soils in these upper elevations are shallow and derived from granite and gneiss.

soil pH of the rangelands averaged 7.3, and soil pH of the southeastern and northeastern areas of the FDR is 7.8. The lower elevations along the Madison River and lower Cherry Creek have the highest soil pH levels of 8.4. The mineralogy of the soil within the rangelands is mixed. Areas in the central and southeastern corner are carbonatic while montmorillonitic soils are prevalent in the large basin area in the central region.

The southern portion of the FDR is largely covered by conifer forest. This is predominantly lodgepole pine (*Pinus contorta*), Douglas-fir (*Pseudotsuga menziesii*), and subalpine fir (*Abies lasiocarpa*). The ranch has nine distinct bison foraging areas that have been defined by a range consulting firm (Sindlear and Ayers 1989). Thirteen forage types have been mapped, and documented in the Grazing Plan and Resource Base for the FDR (Sindelar and Ayers 1999). Individual species composition for these forage types is not known, as a consensus view of forage types was employed. These forage types are deep upland bench grass, moist foothills grass, wet meadow grass, dry meadow grass, improved pasture, basin timothy, dry foothills grass, shallow upland bench grass, moist mountain browse, dry mountain browse, aspen woodland, willow riparian, and conifer forest.

Chapter 3

METHODS

Database Development

A database was developed to analyze variables that could reasonably be measured and related to bison range utilization. The landscape variables were represented in the database by biophysical variables that were collected and converted to digital format, acquired in digital format, or derived in a GIS from an existing spatial dataset.

The database consisted of 14 biophysical variables and one response variable. These variables representing the biophysical landscape, were grouped into three categories: 1) nutritional variables, 2) physical environmental variables, and 3) social/behavioral variables. The response variable was the level of bison utilization. Database details regarding data source, method of derivation, and data values are provided in Appendix A.

Biophysical Variable Selection/Representation

Nutritional Variables. Nutritional variables were included because they contribute calories and minerals to bison through forage and soils. The 5 nutritional variables selected based on previous literature included:

(1) forage productivity (forage quantity and species composition),

(2) forage type (forage quality),

(3) soil mineralogy (trace minerals),

(4) soil pH (potential mineral absorption), and

(5) soil salinity (potential mineral absorption).

Forage productivity represented the forage quantity and forage type represented forage quality and species composition. Soil salinity and soil pH were included because they dictate plant composition and might influence mineral absorption through plants during digestion. The FDR bison herd might be deficient in trace minerals so the herd is supplemented with mineral blocks (pers comm Bud Griffith). Therefore mineralogy was included to represent availability of trace minerals.

Physical Environmental Variables. Physical environmental variables were included because they can limit bison utilization (i.e., physical barriers) of range. The 4 physical environmental variables were chosen based on previous literature and included:

(6) distance from water,

(7) elevation,

(8) slope, and

(9) surface soil texture.

Distance to water is important during the summer months. Bison do not obtain sufficient amounts of water from vegetation in the summer months and, thus must have drinking water available (pers comm Mary Meagher). Bison use of habitat as it relates to elevation and slope has not been studied for the FDR bison herd, so elevation and slope were included as potential contributors to bison habitat selection. The creation of wallows has been noted (Meagher 1986, Meagher 1973), although research on wallowing has not been extensively studied. Surface soil texture was included as a measure of potential for bison to create wallows; relationships between wallow sites and soil texture have not previously been reported.

Social/Behavioral Variables. Biophysical variables representing aspects of bison social behavior were included in the study. Five datasets representing bison social behavior attempted to incorporate bison behavior with digital landscape representation. These 5 datasets based on previous literature included:

(10) nearest neighbor distance (forage area connectivity),

(11) patch area (forage area size),

(12) patch shape (forage area shape),

(13) proximity (forage area connectivity), and

(14) viewshed (visual contact).

Four of these datasets were generated by performing a spatial pattern analysis of the FDR. The spatial objects (patches) in this research were the generalized vegetation types: wet grassland, dry grassland, riparian vegetation, conifer forest and non-vegetation.

Patch connectivity was addressed due to the need for an appropriate level of comfort for animals traveling from patch to patch. Nearest neighbor distance and proximity were included to represent the connectivity of patches as foraging areas that are insufficiently connected within the landscape since these might influence bison utilization of these areas. Nearest neighbor distance indicates the similarity of forage types next to, and adjacent to, one another. Proximity indicates the similarity of forage types at a smaller scale, and incorporates the size of the neighboring forage patch. The size of foraging areas is represented by patch area, as the size of foraging areas is potentially important due to the social group requirements of bison. Areas that are not of adequate size to enable the social group to forage might be avoided.

Patch shape was included to represent the potential importance of the shape of the foraging area.

The fifth dataset that represented bison sociality was viewshed. A viewshed analysis was performed to address the need for bison to maintain visual contact with other bison.

Response Variable – Bison Utilization. The response variable was the historic pattern of utilization by bison on specific areas throughout the FDR during the months of April through September. A range assessment of the FDR categorized utilization into three distinct levels of use (Sindelar and Ayers 1999): overgrazed, moderately utilized, and underutilized. This pattern of utilization has been collected as expert knowledge by the ranch manager (pers comm Bud Griffith). The bison utilization observations by the ranch manager were independently confirmed by a range consulting firm (pers comm Brian Sindelar). Bison utilization of the range was known for 19 specific grazing sites, represented in the GIS by 19 polygons (Figure 2).

The 19 areas of known utilization constituted 18,267 ha (45,138 acres). Areas were noted overgrazed when foraging plants were regrazed before they recovered from a