EVALUATION OF HABITAT SUITABILITY MODELS FOR ELK AND CATTLE

By

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ABSTRACT

Managing elk (*Cervus elaphus nelsoni*) and cattle habitats in the western United States is confounded by the complex interactions of these species and by diverse private and public land management goals. Managers often use quantitative models as tools in land resource management yet many of these models have not been validated. I evaluated modified versions of existing elk and cattle habitat suitability index (HSI) models on four ranches in Montana and Wyoming to evaluate their ability to predict feeding site selections on non-forested habitats. Animal locations were determined from aerial surveys conducted 0.5 to 3.0 hours post-sunrise, and marked using GPS. The models were used to categorize landcover grids based on suitability for cattle and elk using data gathered from georeferenced spatial information on cover types, elevation, aspect, slope, distance from water, and roads. I hypothesized that elk and cattle feeding site selection would increase with increasing suitability levels. Chi-squared analyses were conducted on 1,076 independent elk group locations and 806 independent cattle group locations collected during 2001 and 2002. Selection ratios (S) determined selection (i.e., $S > 1.0$), avoidance (i.e., $S < 1.0$), or non-selection (i.e., $S = 1.0$) within a given habitat suitability category. Preference for specific habitat classes was determined using Bonferroni confidence intervals. I found little evidence that the modified elk model consistently predicted seasonal feeding site selection and failed to reject the null hypothesis. Elk selection during the fall season on one ranch satisfied my hypothesis, but the model performed poorly on the other ranches. The modified cattle HSI model was mostly a poor predictor of cattle use on all four ranches. Inaccuracies in the GIS-based data used in the models may have contributed to the failure of the models to predict elk and cattle use. Variables used in the models may have not accurately portrayed relationships among habitat variables and habitat use by cattle and elk. The poor performance of the elk and cattle models underscores the need to test habitat models before they are used in resource planning.

CHAPTER 1

INTRODUCTION

Elk (*Cervus elaphus nelsoni*) provide a myriad of values to humankind that includes ecological, aesthetic, consumptive and non-consumptive uses. The Rocky Mountain region is also host to beef cattle production, which represents a major activity in the economies of Wyoming and Montana. In Montana, 2002 cash receipts totaled 985 million dollars. In 2001, Wyoming cash receipts grossed 750 million dollars (National Agricultural Statistics Service 2004). Cattle ranching also contributes aesthetic and other non-market values. Despite the acknowledged values of elk and cattle, management issues remain complex because these species utilize many of the same forage species and foraging sites.

Many seasonal ranges historically used by elk are now privately owned and managed exclusively for agriculture, livestock management, and timber production (Vavra et al. 1989, Vavra 1992). Research conducted by Peek et al. (1982) and Thomas and Sirmon (1985) determined that more than 90 percent of the elk in the West used public land in the summer while the majority of winter range was on private land. Consequently, elk often damaged agricultural crops, ruined fences, and consumed forage allocated for cattle (Lacey et al. 1993, Irby et al. 1997).

Spatial and dietary selections overlap between elk and cattle and may provide an opportunity for competition. Frisina and Morin (1991) noted that habitat conflicts occurred when cattle and elk competed for forage on elk winter range. However, complementary interactions have been observed between elk and cattle. Moderate grazing by cattle removed dead plant material and stimulated regrowth within the growing season (Phillips et al. 1999). Elk that subsequently grazed land previously grazed by cattle may benefit from the vegetative regrowth. The Fleecer Coordinated Grazing Program in Montana illustrated how cattle grazing can enhance forage quality and quantity on elk winter range. Early spring cattle grazing and the applications of rest-rotation grazing strategies appeared to have increased elk use of these ranges (Frisina and Morin 1991). Research also suggested that elk winter forage can be enhanced by moderate cattle grazing (Clark et al. 2000).

Crane (2002) investigated how cattle grazing influenced subsequent feeding site selection by elk in fall, winter and spring seasons. According to Crane (2002), elk selected feeding sites in the winter and spring where forage residue was reduced by summer cattle grazing and avoided ungrazed sites in all three seasons.

Elk and cattle use similar resources and exhibit dietary and habitat overlap that varies spatially and temporally (Wisdom and Thomas 1996). Impacts from the combined and repeated habitat use by cattle and elk may lead to rangeland degradation. The restoration of damaged rangelands—or the sustainability of healthy rangelands—warrants the development of cooperative management strategies for elk and cattle. Habitat suitability index models are frequently used as decision-making tools in resource management, but many of these models have not been validated (Brooks 1997, Roloff and Kernohan 1999).

Several elk and cattle models have been developed for use in natural resource planning. Many of these models are too complex and may not always be appropriate to use in natural resource planning because of associated costs and time demands (REDSO Transboundary Workshop 1999, Childress et al. 2002, PHYGROW Forage Modeling System 2004). Because I was interested in practical management tools for natural resource managers, I used relatively parsimonious elk and cattle models to determine their efficacy in natural resource management. I evaluated a modified version of an elk habitat model (Arha 1997) developed for the Rocky Mountain region. Additionally, I evaluated a modified version of an existing cattle model described by Holechek (1988). Hence, the goal of my research was to evaluate modified versions of elk

(Arha 1997) and cattle (Holechek 1988) HSI models to determine the efficacy of these tools to predict elk and cattle feeding site selections.

To sample animal locations, biweekly aerial surveys were conducted 0.5 to 3.0 hours post sunrise, a period of time generally thought to be prime feeding times (Craighead et al. 1973, Arnold and Dudzinski 1978, Green and Bear 1990). Cattle feed almost exclusively in non-forested habitats. Elk feed in forested and non-forested habitats, but accurately detecting elk presence in forested habitats would be difficult (e.g., visibility bias). Thus, only animal group locations on non-forested vegetative types were used in the HSI models. I tested the hypothesis that elk and cattle feeding site selection were positively related to HSI suitability levels. I predicted that elk and cattle would avoid the unsuitable class (e.g., HSI = 0) but incrementally increase selection of the higher suitability classes: low (e.g., HSI = 1), medium (e.g., HSI = 2) and high (e.g., HSI = 3.0).

CHAPTER 2

LITERATURE REVIEW

Deductive and Inductive Modeling

Researchers use computer simulation models to better understand complex biological systems. Krebs (1980) stated that models are not meant to represent the complexity of nature but to capture the essence of the phenomenon. Egler (1977) provided a brief but insightful view about modeling biological systems. He remarked that ecosystems are not only more complex than we think, they are more complex than we can think.

Models are said to be mechanistic in nature when they depict causal relationships between variables. Mechanistic modeling is characteristically deductive and moves from a general idea (i.e., a theory) towards a more narrow idea (i.e., a hypothesis). According to Whittemore (1986), deductive modeling is an essential part of the scientific method because the primary objective for deductive modelers is to formulate hypotheses about the nature of life. Observations and specific data are subsequently collected and used to test hypotheses. From these hypotheses, modelers may postulate ideas about which mechanisms caused the phenomenon. Furthermore, Whittemore (1986) stated that the goal for modelers was not to find the right answer, but, to identify the right question. Hence, biologists do not construct conclusions from data; they construct hypotheses that are tested with data (Murphey and Noon 1991).

Inductive reasoning complements deductive reasoning and is also necessary for hypothesis confirmation in biological modeling (Williams et al. 2002). Inductive reasoning is built upon a foundation of empirical observations acquired from our natural world. Models that incorporate an inductive reasoning approach begin with specific observations and subsequently detect patterns from which general inferences or conclusions are derived. Inferences based on inductive reasoning may lead to erroneous conclusions because biological investigations are open to natural variation and sampling error.

Models have predictive qualities that provide insight to potentially different management scenarios. Thomas (1986) noted that models provide resource managers with a formalized method of guiding adaptive management of natural resources. Additionally, models may be considered complementary to science and resource planning because they effectively bridge the gap between these two fields. Namely, models play key roles in both the science and management of biological systems, as expressions of biological understanding, as engines for deductive inference, and as articulations of biological response to management and environmental change (Williams et al. 2002).

Habitat Concepts and Standard Terminology

Murphey and Noon (1991) argued that the rigorous application of scientific methods and the development of clear operational definitions for terminology were central to producing solid, credible, and defendable science. Results gathered from biological research are often applied to land use planning, livestock grazing management, and wildlife management. Because value systems vary greatly with regard to land resource management, researchers and their scientific works have come under scrutiny by various interest groups. In the western United States, natural resource managers are not only challenged to manage for healthy, sustainable rangelands, but they must meet management goals for livestock grazing, wildlife habitat, recreation, and other resource uses. Furthermore, real or perceived interspecific competition between wild and domestic ungulates, combined with public/private land management practices contribute to the complexity of wildlife/livestock issues. Therefore, researchers who investigate biological processes must perform rigorous science structured with unambiguous, unequivocal terminology.

Hall et al. (1997) reviewed 50 habitat papers published between 1980 and 1994 in various wildlife and ecology journals and books. They reported that habitat terminology was imprecisely used in 82 percent of the papers reviewed. If different researchers were to make similar measurements of like entities, then standardized, operational definitions are necessary (Morrison and Hall 2002). Important habitat terms are subsequently defined below.

"Habitats" are the resources and conditions present in an area that promote occupancy, including survival and reproduction, by a given organism (Hall et al. 1997). Habitat components include food, cover (security and thermal), water, temperature, precipitation, topography, and other species (e.g., the presence or absence of predators, prey, competitors), special factors (e.g., mineral licks, dusting areas), and other components unidentified by managers (Krausman 1999).

The term "habitat type" is often used erroneously to characterize features of particular habitats. In Daubenmire's (1984) classic definition, he stated that habitat type was a "term for all parts of the earth's surface that support or are capable of supporting the same kind of plant association, i.e., the same "climax." Hence, this term describes the biological potential of a given site to support a specific plant community.

"Habitat use" was defined by Hall et al. (1997) as the way an animal used a collection of physical and biological resources in its habitat. An animal may use a variety of habitats for foraging, nesting, and movement corridors. Use may vary according to season, animal age, sex or a combination thereof.

"Habitat/resource selection" comprises a hierarchical process that involves a series of intrinsic and learned behavioral decisions made by an animal about which habitats it would use at different spatial scales of the environment (Hutto 1985). It is imperative for researchers to recognize that animal-habitat relationships are scale-dependent and subsequently tailor their habitat studies to the specific scale of selection (Hall et al. 1997).

Johnson (1980) described four naturally ordered habitat selection processes. "First-order selection" occurred at the physical or geographical range of a species (i.e., macrohabitat). "Second-order selection" occurred at the home range of an individual or social group within their geographical range. "Third-order selection" pertained to how the habitat components within the home range are used (e.g., areas used for foraging). "Fourth-order selection" signified how components of the habitat are used. If third-order selection determined a foraging site, then fourth-order selection would be the actual procurement of food items from those available at that site. Understanding these different levels of selection should be useful in habitat management.

Resource selection can be determined by the amount of resource used compared to the amount of resource available (Alldredge et al. 1998). Hence, if resources are used disproportionately to their availability, use is characterized as selective (Johnson 1980). Resource availability implies that an animal has access to a specific resource.

Most species-habitat studies attempt to evaluate habitat preference based upon habitat suitability (i.e., quality) for a given animal population (Garshelis 2000). Rosenzweig and Abramsky (1986) classified preferred habitats as those that would confer higher levels of fitness (e.g., individual survival and reproduction) over lesser preferred habitats. Habitat preference identifies non-random use of a particular type of habitat when all other factors influencing habitat use are controlled. Under controlled experimental conditions, preference may be determined by offering equal portions of differing resources and observing the choices made (Elston et al. 1996).

After reviewing the literature, it appears researchers remain polarized over "selection" inferring "preference". Some researchers argue that habitat preference may be inferred from patterns of observed use if habitat use resulted from selection (Garshelis 2000). Because habitat selection was considered a hierarchical process based on decisions, Hall et al. (1997) proposed that preference was the consequence of habitat selection. Johnson (1980) reasoned that preference was reflected in selection, but only if the resource was relatively scarce. Litvaitis et al. (1996) countered that caution must be applied when inferring preference from use because biological needs cannot always be determined from these patterns.

Elk Habitat Selection

Free-ranging elk populations are found primarily in coniferous forests associated with mountain, foothill, or canyon rangelands. Elk habitat use is conditioned by topography, weather, cover, predator avoidance, biting insects, hunters, and biological factors—such as forage quality and cover quantity (Skovlin et al. 2002).

Knowledge and understanding of elk food habits are important to interpret elk behavior and ecology (Cook 2002). Elk are considered intermediate feeders and dietary opportunists because they consume diets with more equal portions of grass, forbs, and browse than grazers or browsers (Wisdom and Cook 2000). Kufeld (1973) noted that, as intermediate feeders, elk were capable of adjusting their feeding habits to available forage. Throughout the U. S. and Canada, food habits of elk can vary seasonally, among years, and among ranges, but tend to be strongly linked to availability and plant phenology (Cook 2002).

Seasonal changes in plant nutritive quality and availability were also associated with elk diet selection (Skovlin 1982). Various grasses, forbs, and shrubs were consumed during early spring and summer when these forages were highly nutritious and abundant (Wisdom and Thomas 1996). In early summer and late fall, elk diets shifted to forbs and shrubs, respectively (Wisdom and Cook 2000). Grasses were also included in early fall diets whenever "green up" occurred on the rangeland (Bryant 1993). Kufeld (1973) determined elk winter diets were proportionately higher in grasses but winter conditions, such as snow depth, largely controlled diet selection as elk consumed forage that was readily available. During winter in Montana, elk primarily consumed grasses (Cook 2002).

Proximity to water may also influence where elk select resources (Thomas et. al 1976). Marcum (1975) documented that approximately 80 percent of elk use was within 400-m of water when on summer range. Conversely, Jones (1997) stated that water was not a significant predictor for winter elk habitat selection.

Topographical features, such as elevation, slope, and aspect affect local vegetation and, consequently, patterns of elk use (Skovlin et al. 2002). Elevation is a decisive topographical feature influencing elk habitat selection because precipitation, snow accumulation, and plant phylogeny are related directly to elevation (Skovlin et al. 2002).

Elk use of slope and aspect varied among seasons and years, and even among sexes. In western Montana, Marcum (1975) documented that elk used moderately steep slopes of 27 to 58 percent for bedding and feeding during the summer and fall. Mackie (1970) examined elk use of slopes in the Missouri Breaks region of Montana. During spring and fall, approximately 50 percent of elk use was on slopes of 0 to 18 percent, but during summer and winter, elk use on these slopes increased to nearly 65 percent (Mackie 1970). During the winter and spring, elk primarily selected southern to southwestern exposures because of wind, sun angle, and the propensity of these areas to lose snow-cover sooner. North-facing slopes provided cooler temperatures in the summer and offered high quality forages in early autumn (Skovlin 1982). Marcum (1975) noted that bull elk in Montana selected southerly to easterly exposures on summer range compared to female elk that selected southwesterly through northwesterly and northeasterly exposures.

Elk tend to select habitats that provide security or a means of escape from the threat of predators or harassment (Lyon and Christensen 1992). These habitats are often dense stands of vegetative cover but might also include rough terrain such as ridges or canyons. During hunting season, elk may also select a mixture of habitat patterns, especially if chances of survival might be increased (Wisdom and Cook 2000). During spring migration, elk seldom use security cover and can be seen using exposed grassland openings when spring green-up occurs (Wisdom et al. 1986).

Human disturbance can greatly influence elk use of habitats (Lyon 1983). Elk consistently avoided open roads across a variety of seasons, landscape conditions, and geographic regions (Marcum 1975, Morgantini et al. 1979, Wisdom and Thomas 1996). Lyon (1983) demonstrated that elk use of roads was approximately 50 percent in areas where densities were 1.3 km/km^2. Elk use decreased to approximately 30 percent when road densities were 2.5 km/km^2.

Cattle Habitat Selection

Cattle are classified as roughage grazers because they primarily consume diets dominated by grasses (Vallentine 2000). Several environmental factors may also influence where cattle select their food resources. Knowledge of the mechanisms that influence livestock distribution and habitat selection are important for successful livestock grazing management.

Grazing distribution patterns of large herbivores are affected by abiotic factors (e.g., slope and proximity to water) and biotic factors (e.g., forage quality and quantity) (Bailey 1996). Based upon the available literature, Holechek et al. (1998) concluded several generalizations regarding cattle habitat selection based on proximity to water and percent slope.

Areas closest to water sources were classified as highly suitable and expected to receive greater utilization (Table 1). In a study conducted in Wyoming, Hart et al. (1989) noted that 60 percent of use by cattle was less than 1.6-km from water but decreased to less than 30 percent on areas greater than 4-km from water.

Table 1. Suggested reductions in cattle grazing capacity with respect to distance from water.

Distance from Water (km)	Reduction in grazing capacity (%)
0 - 1.6	0
1.6 - 3.2	50
> 3.2	100

Source: Holechek et al. 1998

Likewise, Holechek et al. (1998) predicted that areas with gentle slopes were highly suitable for cattle utilization (Table 2). Mueggler (1965) determined that on a 10 percent slope, 75 percent of cattle use was within 740-m of the foot of the hill. Conversely, on a 60 percent slope, 75 percent of cattle use was within 32-m of the foot of the hill.

Table 2. Suggested reductions in cattle grazing capacity for different slopes.

Percent slope	Reduction in grazing capacity (%)
0 - 10	0
11 - 30	30
31 - 60	60
> 60	100

Source: Holechek et al. 1998

Several studies have investigated grazing habits of cattle and cattle distribution. Arnold and Dudzinski (1978) reported that cattle foraged most actively from 0.5 hours before sunrise until approximately 3 hours after sunrise and from 3 hours before sunset to 0.5 hour after sunset. Low et al. (1981) reported that in large pastures, the location of cattle near sunrise was indicative of where they would do most of their selection during a 24-hour period.

Effects of animal age and physiological status may affect grazing distribution. Yearling heifers, yearling steers, and non-lactating cows used pastures more extensively than cow-calf pairs (Bell 1973). Cows with young calves appeared more reluctant to graze steep slopes or travel far from water (Bailey 1999). Cows with older calves, however, used steeper slopes and higher elevations than cows with younger calves (Bailey et al. 1996). First-calf heifers appeared to use gentler slopes and lower elevations more than older cows with calves (Bailey 1999).

Moorefield and Hopkins (1951) described cattle activities in pastures in Kansas. They reported that in early spring (i.e., April), 59 percent of the herd was distributed in lowland areas dominated primarily by western wheatgrass (*Pascopyrum smithii* Rydberg). Six percent of the herd was distributed on the hillsides, and 35 percent was distributed on the uplands. During spring (i.e., June), 19 percent of the herd utilized hillsides more extensively as forage became more available. Dominant grasses included buffalo grass (*Buchloë dactyloides* (Nutt.) Engelm.) and blue grama (*Bouteloua gracilis* (Willd. ex Kunth) Lag. ex Griffiths). Fifty percent of the cattle herd grazed the lowland areas in June. By July, forty-six percent of the cattle herd used the upland compared to 16 percent in June. Moorefield and Hopkins (1951) noted that cattle grazing was largely restricted to areas where vegetation was most succulent and had greater forage production (e.g., the lowlands).

Gillen et al. (1984) investigated habitat variables that influenced cattle distribution on mountain rangeland in northeastern Oregon. They reported that small riparian meadows (3 to 5 percent of the total study area) were the most preferred plant community with 24 to 47 percent of the cattle utilizing these areas.

Pinchak et al. (1991) investigated beef cattle distribution patterns on range sites located on summer foothill ranges in southeastern Wyoming. They concluded that 77 percent of observed use was within 366-m of water. Only 12 percent of cattle use was beyond 723-m from water, approximately 65 percent of the land area. Cattle also preferentially selected slopes less than 4 percent across three grazing seasons.

Habitat Models

Several important environmental legislative acts were passed between the late 1960s and the 1970s. Among these acts were the National Environmental Policy Act (NEPA) of 1969, the Forest and Rangelands Renewable Resources Planning Act (FRRRPA) of 1976, and the Endangered Species Act (ESA) of 1973. These acts prompted federal and state management agencies to develop simple but reliable management strategies designed to monitor animal populations and habitat quality (Berry 1986.) These acts were effective catalysts that created a new paradigm in natural resource management: species-habitat modeling.

Various types of habitat models exist and may be considered valuable tools in research and management planning. When used in research, models provide a framework in which qualitative habitat characteristics and quantitative relationships are integrated into testable hypotheses (Schamberger and O'Neil 1986, Van Horne 2002).

Computer simulation habitat models are used as tools to predict a species' response and occurrence in its environment. Characterization of habitats and resources selected by animals provides researchers with knowledge about the nature of the animal and key understanding about the requisites needed for survival (Manly et al. 1993). The ability to effectively manage and conserve animal populations and their habitats depends largely on our ability to understand and predict species-habitat relationships.

Complex ecosystem models are often developed to examine species-habitat relationships. These models may include mechanistic processes such as climatic inputs, soil water and nutrient dynamics, plant uptake and growth by species, herbivory, fire, complex animal communities, and animal diseases (REDSO Transboundary Workshop 1999, Childress et al. 2002, PHYGROW Forage Modeling System 2004). The Ecological Dynamics Systems (EDYS), one of several complex species-habitat models, has been developed for use as a management tool (Childress et al. 2002). To use this model, managers must conduct measurements to obtain data for the complex input variables (i.e., climate data, soil water and nutrient dynamics). Hence, using these complex models in natural resource planning may not always be cost-effective. Most land managers must contend with time and budgetary constraints. Thus, parsimonious models may be more appropriate to use as management tools rather than complex ecosystem models.

Habitat Suitability Index Models

Habitat suitability index (HSI) models are species-specific habitat models used in research and management to predict an animal species' occurrence over time (USFWS 1981). Modelers develop and use HSI models for land-use management plans because they are simple to use and the outputs are easy to understand. Habitat suitability index models are also favored because they may be applied in an efficient manner and are relatively inexpensive to operate (Schamberger and O'Neil 1986).

Habitat suitability index models are comprised of four primary factors: assumptions, input variables, variable relationships, and model output (Schamberger and O'Neil 1986). These models integrate topographical attributes such as percent slope, elevation, and aspect and biotic information to methodically evaluate seasonal habitat criteria, such as food, water, and cover for an animal species.

To determine habitat suitability (e.g., quality), suitability index (SI) scores are assigned to each variable to represent the degree in which the variable may contribute to the species life requisites. An SI score ranges between 0.0 (least suitable habitat) and 1.0 (optimum habitat) and is based upon a mixture of empirical data, professional wisdom, and at times, inspired guesses (USFWS 1981). Consequently, SI scores reflect the relative probability that a given habitat will be selected and indicate habitat preferences.

Resource managers use HSI models to predict future changes in habitat use when land management alternatives are expected. Oftentimes, HSI models are constructed during the development of Environmental Impact Statements (EIS), which are required by NEPA (Stauffer 2002). Despite the increased use of these models, the predictions seldom have been tested and have unknown levels of accuracy (Brooks 1997). Hence, application of HSI models in resource management planning can draw heavy criticism.

Elk Habitat Suitability Models

Located in the Blue Mountains of northeastern Oregon, the Starkey Project compiled a habitat database and used geographical information systems (GIS) to examine relationships of environmental variables for elk, mule deer (*Odocoileus hemionus*), and cattle in relation to animal distribution and habitat use (Rowland et al. 1998). An HSI was constructed using habitat variables that were expected to influence resource use. Variables included vegetative types, abiotic characteristics (e.g., slope, aspect, elevation), proximity to water, and distance from disturbance factors (e.g., roads, humans). These variables were further divided into specific, quantified categories (e.g., percent slopes of 0-15%, 16-35%, and > 35%). Each category received a habitat SI score between 0.0 (least suitable habitat) and 1.0 (optimum habitat) based on published studies for cattle, elk, and deer. A habitat database containing the environmental variables was queried to create unique combinations of habitat suitability categories for each ungulate species. According to the HSI models, cattle, mule deer and elk grazed in the highly suitable areas.

A winter habitat suitability model for elk was developed and tested by Jones (1997) in west-central Alberta, Canada. Habitat selection was examined on three spatial scales using 12 radio-collared elk. The sample consisted of nine adult cows, one yearling cow and two mature bulls. Jones (1997) reported that the food and cover components of the model did not perform significantly better between use and availability data (i.e., selection did not occur). Several factors may have contributed to the lack of the model's predictability. The study was based only upon one winter season (111 days) and all elk were considered equivalent. Cow and bull elk do not always use habitats in a similar manner so including both sexes into the sample may have increased error in the model (Unsworth et al. 1998, Wisdom and Cook 2000).

Roloff et al. (2001) tested a seasonal elk habitat effectiveness model on five female sub-herds in Custer State Park, South Dakota. The model emphasized forage quality, forage quantity, and the effects of vegetative security cover (i. e., forage potential) to determine suitable elk habitat. Roloff et al. (2001) proposed that previous habitat models had diminished the importance of forage quality and quantity. Forage potential is fundamental to elk fitness (Irwin and Peek 1983, Hobbs and Swift 1985). Hence, this component should be integrated into elk habitat models. The authors tested their models using the Volume of Intersection test statistic. The elk model did not consistently predict summer elk use but performed more consistently during the fall. Roloff et al. (2001) reported that cover, which was incorporated into the elk model, may have been the over-riding factor influencing elk use in the fall. The authors reported that elk used topographic barriers for cover during the summer months, but this feature was not incorporated into the model.

Arha (1997) developed a comprehensive elk HSI model for the eastern foothill ranges of the Rocky Mountains. This model was developed to predict seasonal habitat use by elk (winter, spring, summer, and fall). Habitat classes, interspersion, and disturbance were the primary factors used to determine habitat suitability. For every season, two initial elk habitat suitability scores were assigned separately for forage value and cover value for every 90-m pixel in the GIS map output (Arha 1997). One pixel represented 8,100-m^2 of a cover type and contained spatial location (e.g., x, y coordinates) and the initial assigned value. Initial forage and cover values were rated high, medium, low, or unsuitable (3.0, 2.0, 1.0, and 0.0, respectively). At this point, these values represented the maximum degree of habitat suitability without regard to spatial relationships or other (a)biotic features. The model subsequently adjusted the maximum forage and cover value based on the values assigned to topographical features, habitat interspersion, and disturbance factors (Arha 1997). The greater value of the two adjusted suitability scores (i.e., forage or cover) was the final index value assigned to each grid cell.

Grover and Thompson (1986) described a spring feeding site selection model for elk in southwestern Montana. The explanatory variables used were previous cattle grazing (i.e., estimated percent of plants grazed), proximity to cover and roads (i.e., visible and concealed), and topographical features such as elevation, aspect and percent slope. Using multiple regression techniques, the best model identified four variables that accounted for 65 percent of the variation in elk feeding distribution: cattle use (partial $r = 0.59$, $P < 0.001$); distance from the nearest visible road (partial $r = 0.53$, $P <0.001$); density of bunchgrass plants (partial $r = 0.47$, $P <0.001$); and distance to cover (partial $r = -0.39$, $P < 0.004$). Grover and Thompson (1986) concluded that because cattle grazing was the easiest variable to manipulate, moderate cattle grazing may be an effective tool to enhance spring elk feeding sites but only within the limits imposed by distance to cover, distance to nearest visible road, and forage density.

Cattle Habitat Suitability Models

Holechek (1988) described a parsimonious HSI model for cattle in which steepness of slope and/or proximity to water influenced cattle habitat selection. Based on these topographical features of rangelands, managers can expect potential grazing reductions and must adjust stocking rates accordingly (Mueggler 1965, Holechek 1988). If managers fail to adjust stocking rates for percent slope and distance from water, over-grazing may consequently cause deterioration on valley bottoms, ridgetops and riparian bottoms. Additionally, heavy stocking rates are economically unfeasible and may result in reduced calf crops, reduced calf weaning weights, and higher death losses (Sims et al. 1976, Holechek et al. 1998).

Holechek and Pieper (1992) tested a quantitative stocking rate model as described by Holechek (1988) on two study sites located in the Chihuahuan desert and shortgrass prairie in New Mexico. The stocking rate model integrated total usable forage, forage intake, influences of slope, and proximity to water (Holechek 1988). Holechek and Pieper (1992) reported that stocking rates unadjusted for steepness of slope or proximity to water could result in stocking rate estimates heavier than the ranges could actually support.

The stocking rate procedure tested by Holechek and Pieper (1992) underestimated actual stocking rate by an average of 10%. They concluded that underestimating stocking rate by 10% was acceptable for most western U.S. rangelands provided that reliable data were available on standing crop of the key forage species.

Bailey et al. (1996) developed a conceptual model that focused on cognitive foraging mechanisms combined with abiotic factors in order to predict feeding site selection of large herbivores. Feeding site selection was defined as a collection of patches in a contiguous spatial area that animals grazed during a foraging bout (Bailey et al. 1996). Potential selection criteria included topography, distance from water, forage quality, forage abundance, plant phenology, cover, thermoregulation, and competition.

Senft et al. (1985) examined patterns of cattle use on shortgrass steppe of northeastern Colorado. Regression models were used to determine growing and dormant-season grazing patterns. They reported that grazing distribution of cattle was correlated with proximity to water. Grazing patterns were consistent across seasons. During the growing season, percent frequency of western wheatgrass was also a significant predictor of selection. Senft et al. (1985) concluded that selection of grazing areas was correlated to nutritional properties of vegetation.

Wade et al. (1998) used GIS to model potential beef cattle distribution for the entire state of Oregon. Percent slope was derived from 1:250,000-scale Digital Elevation Models (DEM), an extremely coarse resolution. One pixel (i.e., 500-m cell) corresponded to one land unit equal to 250,000-m^2. Wade et al. (1998) were unable to obtain digital data on water sources and were forced to make several assumptions regarding probable water points. The authors integrated layers of digital vegetation data, percent slope, and proximity to water to produce raster-based maps (e.g., a matrix of cells) of cattle grazing site potential. Grazing potential was characterized by four classes: 0.0 (unlikely grazing potential); 1.0 (low grazing potential); 2.0 (moderate grazing potential); and 3.0 (high grazing potential). The final pixel value was 107-m on a side. Hence, these maps remained at a coarse resolution.

The model was tested by comparing the proportion of grazing potential classes to the density of beef cattle in December 1992 (Wade et al. 1998). Class 0 was negatively correlated with cattle density (Spearman rank correlation, $r_s = -0.061$, $P < 0.0001$). Classes 1, 2, and 3 were positively correlated to cattle density ($r_s = 0.47\text{-}0.53$, P's < 0.005). Standard errors were not reported in this paper. Areas that were considered ungrazable may not have been accurately estimated because of the coarse scale of the input data (Roloff and Kernohan 1999). Small scale/low resolution (1:250,000) elevation data smoothes terrain because of larger sampling distance between elevation measures, and likely resulted in gentler slopes (Walsh et al. 1987). Wade et al. (1998) argued that use of a finer scale (e.g., 1:24,000) would have been cumbersome to use for the entire state of Oregon.

Testing Habitat Suitability Index Models

Habitat suitability index models represent hypotheses about species-habitat relationships. According to Morrison et al. (1992), wildlife-habitat models are based on ecological theories related to habitat selection, niche partitioning, and limiting factors. Despite this fact, models usually prove to be "legacies of failure."

Application of HSI models in resource management has drawn heavy criticism because they frequently have been implemented before validation. Testing HSI models is essential before application in management decisions because an untested model only serves as the basis of faith rather than evidence. Evaluating models also helps provide information about performance and reliability. Additionally, these tests provide data that may lead to model improvement (Schamberger and O'Neil 1986).

Recognizing that a consistent framework was lacking to validate HSI models, Roloff and Kernohan (1999) developed seven criteria for application in HSI model validation studies. Using their criteria, they evaluated and scored 17 studies that tested the reliability of 58 HSI models. A maximum score of 7.0 was possible, but the maximum score was 4.05 (mean = 2.10). Their guidelines are described below.

Model Components Evaluated

Because models are usually constructed using assumptions and subjective knowledge, Roloff and Kernohan (1999) recommended that the components of the model (i.e., the variables) be evaluated in a step-wise manner. The mechanistic relationships of the input variables are meant to represent overall habitat suitability, and the product of these relationships must be sensitive to changes in the input variables (Roloff and Kernohan 1999). Finally, the authors suggest that the accuracy of model predictions should be validated.

Input Data Variability

Habitat suitability models build on the relationships between vegetative structures and spatial features. Nevertheless, the manner in which input data are described may be a frequent source of poor model performance. Habitat models may be prone to two types of error associated with the input data. For example, when assigning averaged values to vegetative polygons, sampling error may have profound consequences in model interpretation. Secondly, vegetative polygons must be accurately mapped in order to depict spatial relationships. Otherwise, model outputs may not be precise. Roloff and Kernohan (1999) recommend application of statistical tests to HSI scores to reflect vegetation sampling error of the mapped polygons.

Validity of Comparative Test(s) Used

Roloff and Kernohan (1999) recommended that modelers evaluate the statistical power of the HSI models *a priori*. Researchers must also explicitly define the animal response replicates and quantify the adequacy of their sample (Roloff and Kernohan 1999). Furthermore, the authors recognize that statistical tests were preferred over subjective tests, but the statistical tests should focus on statistical power, assumptions, and correct interpretation.

Scale

Consideration of the appropriate spatial scale is warranted in HSI validation tests. Oftentimes, a species' home range is used as a basis of scale, but Roloff and Kernohan (1999) point out that home range estimates can vary depending on estimation techniques, environmental conditions, and sample size. A more consistent approach is using allometric equations as the basis of scale in HSI models (Calder 1984). Roloff and Kernohan (1999) cautioned that allometric equations may not adequately describe home ranges of species that exhibit pronounced inter- or intra specific interactions that influence their use of space.

Range of HSI

To ensure the HSI model is robust, Roloff and Kernohan (1999) recommend that the model's predictive power should be evaluated across the entire range of habitat quality. Additionally, Bender et al. (1996) demonstrated that a narrow range of habitat scores may unjustly imply that real differences in habitat quality exist, when in fact the scores do not differ significantly. Roloff and Kernohan (1999) stated that if studies captured the full potential range of HSI scores (e.g., 0.00-1.00), they were considered more robust than those studies that only captured a fraction of the range. Roloff and Kernohan (1999) also evaluated the distribution of the HSI scores to detect if the continuous gradient of the habitat variables were sampled.

Population Index

Most validation studies incorporate measures of abundance or density as indicators of population response to habitat quality. These measures are relatively easy to obtain, but density and abundance are misleading factors of habitat quality (Van Horne 1983). Instead, Roloff and Kernohan (1999) recommend measuring surrogates of fitness (e.g., reproductive rate, fecundity, survival, and mortality) in conjunction with HSI models.

Duration of Population Data Collection

Variability in population density and animal distribution affect the ability to demonstrate habitat quality and population index relationships (Roloff and Kernohan 1999). Changes in demographics can result from shifts in numerous variables, making sources of error likely (Van Horne 1983). To minimize this variation, Roloff and Kernohan (1999) recommend that the duration of population data collection should correspond to the breeding cycle of the target species. Furthermore, it was recommended that if the target species exhibited an annual reproductive cycle, a minimum of three years of data were necessary. The authors also recommended that researchers needed to be in tune with environmental variability. During periods of drought, data collected on population demographics may be poorly represented.

Manly et al. (1993) proposed several methods to collect data for studies of resource selection in animals. One crucial step was to determine the scale of the selection study. They suggested that selection should be studied at more than one scale. For example, research was conducted by Danell et al. (1991) to determine whether moose select forage at the individual tree level or on patches of trees. If field studies cannot be manipulated in this way, Manly et al. (1993) recommended measuring availabilities at various distances from used sites.

Manly et al. (1993) described a sampling design called "Design I." The principles of this design stated that measurements may be made at the population level. Hence, individual animals are not identified. Furthermore, resource units (e.g., used, unused, or available) may be sampled or censused in the study area. Classification of animal locations may be obtained using aerial surveys. Maps or aerial photography are used to determine availability of resources. Animal locations within the resource units determine use or non-use. Selection may be determined by comparing percentage use to respective availability.

Land managers accept HSI models that can predict animal responses with 60 percent reliability (Roloff 1994). Researchers, however, criticize the utility of a tool that cannot consistently describe animal responses at a statistical level of significance (Brooks 1997). Nevertheless, statistical procedures may be too conservative, especially in landscape-scale studies. Roscoe and Byars (1971) reviewed the use of the Chi-squared statistic and pointed out that textbook authors indicated that a satisfying approximation was achieved when expected frequencies were restricted to values of 5 or more. This restriction appeared more arbitrary and was not based on mathematical or empirical evidence (Roscoe and Byars 1971). The authors suggested that at a 0.05 significant level, the average expected cell frequency should be at least 1.0 when the expected cell frequencies were close to equal.

CHAPTER 3

MATERIALS AND METHODS

Description of Study Areas

Montana

Data were collected from two cooperating beef cattle ranches in southwestern Montana. Situated in the Little Belt mountains 6-km west of White Sulphur Springs, the BCR Ranch (46.5330°N, -111.4073°W) is divided into 2 sub-units with a combined area of approximately 40,010 ha (Figure 1). The STR Ranch (46.5271°W, -110.8660°N) is located in the foothills of the Castle Mountains, approximately 3-km southeast of White Sulphur Springs (Figure 2). This ranch is approximately 3,481 ha in area. Both ranches represent a combination of public and private land.

Mean annual precipitation at White Sulphur Springs (elev. 1579-m) was documented at 34-cm from data collected since 1978 (Western Regional Climate Center 2003). Precipitation averages were highest during May, June, and July, receiving 2.31-cm, 2.33-cm, and 1.77-cm, respectively. Elevation ranged from 1545-m to 2500-m.

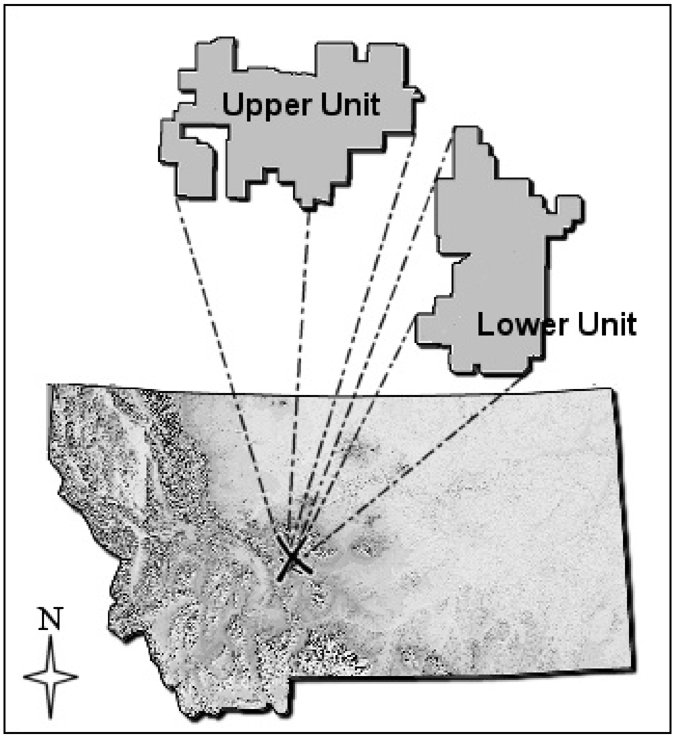

Figure 1. The BCR Ranch, White Sulphur Springs, Montana.

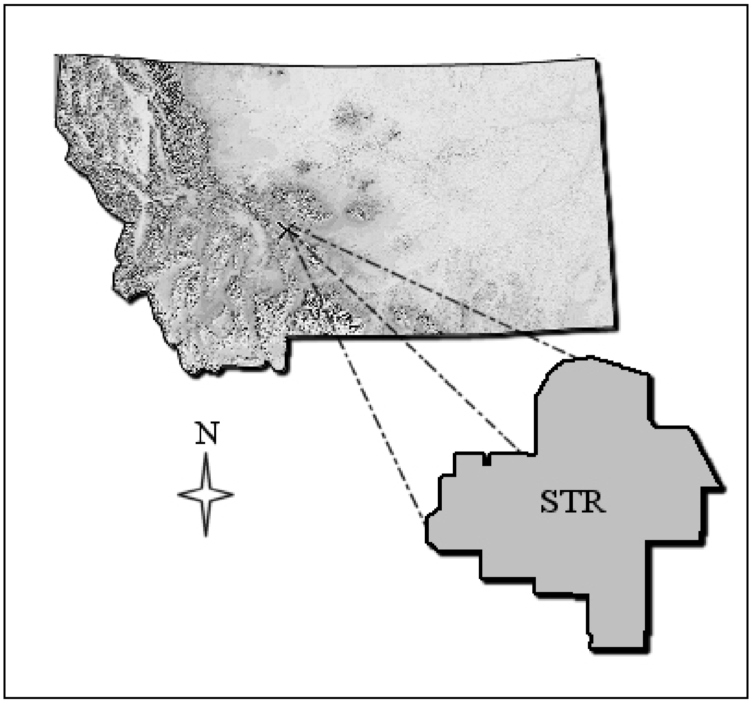

Figure 2. The STR Ranch, White Sulphur Springs, Montana.

Argiborolls-lithic soils dominate the study area's semiarid rangeland. Cryochrept soils are found extensively on mountain slopes in forested rangelands. To a much lesser extent, loamy Haploborolls are found on glacial till plains, outwash terraces, sedimentary bedrock plains, and foothills (Montagne et al. 1982).

Plant communities on these ranches included lowland sagebrush communities, mountain grasslands, and coniferous forests. Coniferous forests are primarily dominated by Douglas fir (*Pseudotsuga menziesii* (Mirbel) Franco). Dominant perennial graminoids include Columbia needlegrass (*Stipa nelsonii* Scribner), needleandthread (*Stipa comata* Trin. & Rupr.), Idaho fescue (*Festuca idahoensis* Elmer), western wheatgrass (*Pascopyrum smithii* (Rydberg) Love), and bluebunch wheatgrass (*Pseudoroegneria spicata* (Pursh) Love).

Common deciduous trees found in riparian areas are quaking aspen (*Populus tremuloides* Michaux) and black cottonwood (*Populus trichocarpa* Torr. & A.Gray). Associated riparian shrub species include willow (*Salix* spp. L.), serviceberry (*Amelanchier alnifolia* Nutt.), and alder (*Alnus* spp. L.). Sedges (*Carex* spp. L.) are common in the riparian areas.

Sagebrush communities on the ranches are dominated by mountain big sagebrush (*Artemisia tridentata vaseyana* (Rydb.) Bovin) and Wyoming big sagebrush (*Artemisia tridentata wyomingensis* Nutt.)

Wyoming

Data were also collected from two cooperating beef cattle ranches in northwestern Wyoming. The MC Ranch (44.6101°N, -109.3877°W) is located 20-km west of Cody, Wyoming (Figure 3). This ranch is approximately 21,294 ha in area. The TE Ranch (44.2812°N, -109.4898°W) is located approximately 50-km southwest of Cody, Wyoming. This ranch is approximately 23,082 ha in area (Figure 3).

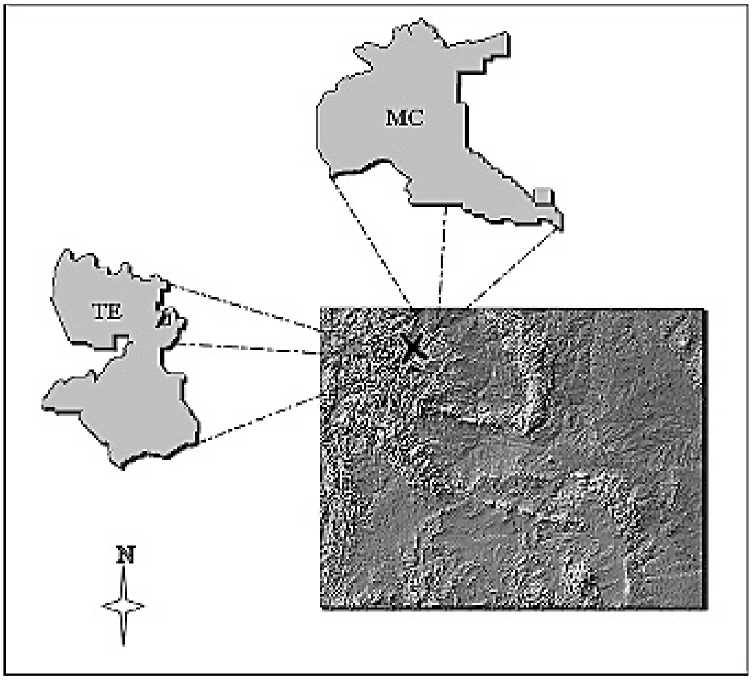

Figure 3. The TE and MC Ranches of northwestern Wyoming.

Mean annual precipitation in Cody, Wyoming (elev. 1521-m) is 25-cm based on precipitation data collected since 1925 (Western Regional Climate Center 2003). This area received higher precipitation levels during May, June, and July, with averages of 1.63, 1.65, and 1.07-cm, respectively. Elevations range from 1650 to 3500-m. Topography is highly variable on these ranches, and range from glacial outwashes and rolling hills to steep, rocky outcrops. Coarse Upland, Loamy, or Clayey range sites comprised the majority of landscapes in the sagebrush/mixed grass communities (SCS 1988).

Plant communities at my study sites were dominated by mountain big sagebrush and Wyoming big sagebrush. Prominent graminoids on the ranches included bluebunch wheatgrass, Columbia needlegrass, Idaho fescue, Indian ricegrass (*Oryzopsis hymenoides* Roem. And Schult.), needleandthread, plains reedgrass (*Calamagrostis montanensis* Scribn), prairie june grass (*Koeleria cristata* L.), Sandberg bluegrass (*Poa secunda* Presl), spikefescue (*Leucopoa kingii* S. Wats) and western wheatgrass.

Elk and Cattle Locations

Elk location data were collected by season. For this study, December, January, and February were classified as winter months. Spring months consisted of March, April, and May. The summer months were June, July, and August. Fall months were September, October, and November. Months were grouped into seasons based on seasonal changes in habitat use noted by Boyce (1991). Elk activities during seasonal habitat use are assumed to be: (1) winter survival; (2) spring movement and calving; (3) summer forage; and (4) fall breeding and post-breeding (Roloff 1998, Roloff et al. 2001). These seasonal designations corresponded well to seasonal changes in plant phenology.

Elk group locations were collected on three ranches for all four seasons. On the BCR Ranch in Montana, elk locations were collected from May 2001 to November 2002. In Wyoming, elk locations were collected on the TE and MC Ranches from November 2000 to November 2002.

Cattle group locations were collected during the grazing season for all ranches. I defined the grazing season as the period during spring through fall when beef cattle relied solely on rangelands with no supplemental hay offered. Even though cow groups were observed grazing during the winter feeding season, those locations were excluded because previously unobserved feeding bouts on haylines could subsequently influence feeding site selection in the pasture. Grazing seasons were determined by individual ranch records and observations during flights. To minimize the high variation of feeding site selection associated with age and physiology, only mature cows with calves were included in the data (Bell 1973, Bailey et al. 1996, Bailey 1999).

Biweekly aerial surveys (26 flights/yr) in fixed-wing aircraft were used to detect and record elk and cattle locations. Flights were scheduled the first and third week of every month. Occasionally, inclement weather forced flights to be rescheduled, but monthly aerial observation periods were minimally one week apart to ensure independent elk and cattle locations.

Observations were made by experienced pilots and observers. Flights were conducted approximately 0.5 hours post sunrise which coincided with prime foraging time for elk and cattle (Craighead et al. 1973, Arnold and Dudzinski 1978, Green and Bear 1990). At an altitude of 150-m above the ground, aerial observations were conducted along 0.8-km-wide transects or, depending on the topography, followed contour lines and paralleled drainages. A complete census of the ranches was not consistently feasible throughout my study because of meteorological events associated with the rough, mountainous terrain.

Cohesive animal group (e.g., at least 2 adults) locations were recorded using a global positioning system (GPS) receiver mounted inside the cockpit. Elk and cattle groups were marked in non-forested habitats because they were comparatively easier to observe than in forested habitats. The GPS receiver recorded animal locations (e.g., waypoints) in the center of the group. If animal groups were relatively large, more than one waypoint recorded the sub-groups that formed the large animal groups. Each recorded observation constituted one independent observation (Neu et al. 1974). Single animals were excluded from our surveys based upon their higher variability in habitat selection (Sheehy and Vavra 1996, Bailey 1999). Arha (1997) developed the elk HSI model for female elk and calves. To be consistent, I rejected 100% bull elk groups and single cows with calves. Hence, observations were collected on at least two adult cow elk in a group.

Model Inputs

Land Cover Layer

A vegetation coverage layer formed the basis for the execution of the elk HSI model. Arha (1997) described land cover based on Montana Gap Analysis Program (GAP) research conducted by the Wildlife Spatial Analysis Lab at the University of Montana (Fisher et al.1998). Arha (1997) identified 49 cover types applicable to the eastern foothills of the Rocky Mountains. He assigned an initial forage and cover value of 0.0 (unsuitable habitat); 1.0 (low habitat value); 2.0 (medium habitat value); or 3.0 (high habitat value) to each cover type.

Cover maps generated by GAP were comprised of 90-m pixels (e.g., grid cells). Hence, each pixel on the map represented 8,100-m^2 of a specific cover type. While this GIS tool is quite specific in land cover types, the resolution of GAP is considered coarse and could potentially have larger errors associated with the mapping of cover types. For example, a 90-m pixel may not accurately represent riparian zones or roads because of the relative size of the streams and roads compared to neighboring cover types (e.g., emergent herbaceous wetland, evergreen forest). Arha (1997) recommended using a grid cell size of 30-m although a 90-m cell may be acceptable.

I used the Montana and Wyoming National Land Cover Dataset (NLCD) for the cover layers in the elk and cattle HSI models (NLCD 2001). The NLCD was created from Landsat satellite TM imagery (circa 1992) and has a spatial resolution of 30-m (i.e., one pixel equals an area of 900 square meters). The NLCD has a 21-class land cover classification scheme (Table 3, USGS 2001). I used the NLCD because it was an up-to-date intermediate scale land cover data that would be continually updated to reflect ongoing changes in land cover use.

For all four ranches, I obtained "shapefiles" of the ranch boundaries. Shapefiles were GIS files that defined the geometry and attributes of a geographically-referenced feature. By overlaying the ranch boundary shapefile with the Montana and Wyoming NLCD, I was able to demarcate cover categories found on the ranches. To be consistent with Arha (1997), corresponding forage values used for the GAP layer were assigned to the NLCD cover types (Table 4).

Table 3. National Land Cover Data: Land cover class descriptions (USGS 2001).

Code	Cover Class	Description
11	Open Water	All areas of open water, generally with less than 25% cover of vegetation/land cover.
12	Perennial Ice/Snow	All areas characterized by year-long surface cover of ice and/or snow.
21	Low Intensity Res.	Includes areas with a mixture of constructed materials (30-80% cover) and vegetation (20-70% cover).
22	High Intensity Res.	Includes highly developed areas of constructed materials (80-100% cover) and vegetation (<20% cover).
23	Comm./Industrial/Trans.	Includes infrastructure (e.g., roads, railroads, etc.) and areas not classified as High Intensity Residential.
31	Bare Rock/Sand/Clay	Perennially barren areas of bedrock, scarps, talus, and other accumulations of earthen material.
32	Quarries/Strip Mines	Areas of extractive mining activities with significant surface expression.
33	Transitional	Areas of sparse veg. cover (< 25 %) that are dynamically changing from one land cover to another.
41	Deciduous Forest	Areas dominated by trees where 75% of the tree spp. shed foliage due to seasonal change.
42	Evergreen Forest	Areas dominated by trees where 75% of the tree species maintain their leaves all year.
43	Mixed Forest	Areas with trees that neither deciduous nor evergreen spp. represent more than 75 % of cover present.
51	Shrublands	Areas dominated by shrubs; shrub canopy accounts for 25-100 % of the cover.
61	Orchard/Vineyards/Other	Areas planted or maintained for the production of fruits, nuts, berries, or ornamentals.
71	Grasslands/Herbaceous	Areas dominated by upland grasses and forbs and usually not subjected to intensive management.
81	Pasture/Hay	Areas of grasses and/or legumes planted for livestock grazing or for the production of seed or hay crops.
82	Row Crops	Areas used for the production of crops, such as corn, soybeans, vegetables, tobacco, and cotton.
83	Small Grains	Areas used for the production of graminoid crops such as wheat, barley, oats, and rice.
84	Fallow	Areas used for alternation between cropping and tillage and usually does not exhibit visible vegetation.
85	Urban/Recreational Grasses	Vegetation (primarily grasses) planted in developed settings for recreation, erosion control, etc.
91	Woody Wetlands	Forest or shrubland vegetation accounts for 25-100 % of the cover where soil is periodically saturated.
92	Emergent Herb. Wetlands	Herbaceous cover accounts for 75-100 % of the cover where soil is periodically saturated.

Table 4. Corresponding forage values assigned to NLCD.

Code	NLCD Cover Class	Forage Values			
		Winter	Spring	Summer	Fall
51	Shrubland	2	2	1	2
71	Grasslands/Herbaceous	3	3	3	3
81	Pasture/Hay	3	3	3	3
82	Row Crops	3	3	3	3
83	Small Grains	3	3	3	3
92	Emergent Herbaceous Wetlands	3	3	3	3

Digital Elevation Models

Digital elevation models (DEM) from Montana and Wyoming were used to obtain georeferenced data on aspect, elevation, and slope. I acquired the Montana DEM from the Natural Resource Information System (NRIS) and the Wyoming DEM from the Wyoming Geographic Information Science Center (WyGISC) (Natural Resource Information Systems 2001, Wyoming Geographic Information Science Center 2001).

Aspect and elevation were topographic attributes addressed in the winter, spring and fall elk HSI models (Arha 1997). Elevation was not incorporated into the summer model because elevation was not considered a habitat hindrance (Arha 1997). Additionally, Arha (1997) excluded aspect for the summer model stating there was no significant evidence of selection for one exposure over another. Slope data were also obtained from the Montana and Wyoming DEM for the elk and cattle HSI models. All topographic model variables for the elk and cattle models were produced on individual GIS layers for each ranch.

Digital Raster Graphics

A digital raster graphic (DRG) is a scanned image of a U.S. Geological Survey (USGS) standard series topographic map georeferenced to the surface of the earth and fit to the Universal Transverse Mercator projection (USGS 2003). Montana DRG were obtained from the Montana State Library (Natural Resource Information System 2001). Wyoming DRG were obtained from the Wyoming Geographic Information Advisory Council (2001). The scale of all DRG was 1:24,000.

Streams, lakes, ponds, springs and all naturally occurring perennial water sources found within the ranch boundaries on the DRG were digitized using ArcView 3.3 (ESRI 2002). Digitizing converted the positions of these features on the DRG to a series of x, y coordinates. These coordinates were later used for spatial analysis (e.g., determining distance from water). Additionally, all ranch managers were consulted to determine the locations of stock tanks and developed water sites generally not found on the DRG. These sites were also digitized and combined with the other water data in order to have a more accurate representation of available water sources. Consequently, a water layer was produced for each ranch that was used for spatial analysis in the cattle model.

Human disturbance represented by state highways, county roads, ranch roads and trails were digitized for the elk model. I obtained ranch road locations from all four ranch managers. All road types were digitized inside the ranch boundaries. Additionally, I digitized all road types outside the ranch boundaries up to the maximum distance for a given road class as described by Arha (1997). Hence, the value of a pixel located inside the ranch boundary and in close proximity to the ranch perimeter was determined by pixels representing road classes outside the ranch boundary. Trails were only used in the fall elk model because of increased use by humans during the hunting season.

Model Application

Elk Model

Arha (1997) described forage and cover components in the elk model in order to derive the final elk HSI value (Figure 4). In order to detect elk feeding site selection, I modified the existing elk model by excluding the cover component. Cover was not entirely dismissed, however, as Arha (1997) included a distance from cover variable in the forage component of the elk model.

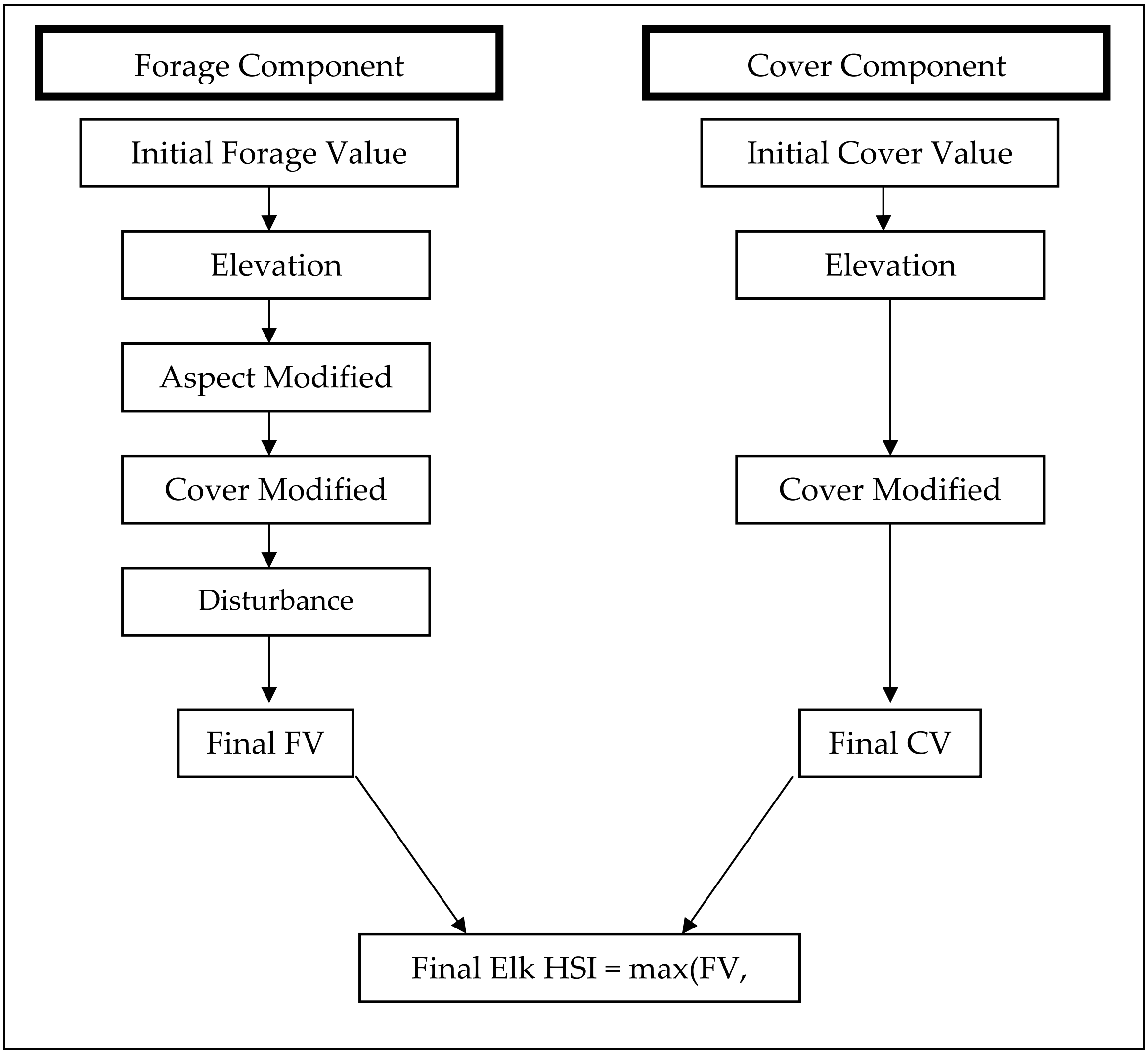

Figure 4. Conceptual elk HSI Model (Arha 1997).

To determine availability, the forage component was further modified so that only non-forested cover types were used in the model. Thus, I excluded evergreen and deciduous forests, water, bare rock, and quarries from the NLCD cover layer. This modified cover layer illustrated a more representative form of availability for elk feeding sites in non-forested cover types (Table 5).

Table 5. Available elk habitat modified by excluding forested habitats.

Ranch	Total Area (ha)	Adjusted Area (ha)
BCR	40,010	31,888
MC	21,294	11,450
TE	23,082	16,298

For each ranch, the layers comprised of the NLCD, elevation, aspect, distance to cover and roads were assigned values to reflect their potential suitability for elk selection (Arha 1997). Values of these variables potentially changed or were excluded in specific seasonal models as described by Arha (1997, Appendix A).

Final elk habitat suitability coverages were mapped in ARC/INFO GRID format using ARC/INFO Macro Language (AML) programs that incorporated the model inputs for each of the seasons (Arha 1997). After the models were run, each 30-m pixel had a final suitability score assigned to it: high habitat suitability (3.0); medium habitat suitability (2.0); low habitat suitability (1.0); and unsuitable habitat (0.0). Final habitat suitability maps were comprised of a matrix of grids (e.g., pixels) that became aggregated into relatively contiguous, homogeneous units (e.g., patches). Thus, each patch was composed of many grid cells. By using GIS analysis, suitability value classes were generated for all patches.

Cattle Model

Holechek (1988) developed a beef cattle stocking rate model that integrated total usable forage, forage demand, calculation of stocking rate and adjustment of the stocking rate for distance from water and percent slope. To predict cattle feeding site selection, I modified this stocking rate cattle model and integrated a non-forested NLCD cover layer with adjustments for percent slope and distance from water. All non-forested cover types were assigned an initial forage value of 3.0 (i.e., optimal suitability) because I assumed these cover types had high forage value for cattle. An ARC/INFO AML was created for this cattle selection model (Appendix B).

In order to integrate the NLCD cover layer with slope, the initial forage value (e.g., 3.0) was multiplied by a multiplier value associated with the slope value (Table 6). At this point, the cell had a value of either 3, 2.1, 1.2 or 0. To integrate distance from water with the combined layers of cover and slope, I multiplied the current cell value with the multiplier associated with distance from water (Table 7). At this point, the cell had a value of 3 , 2.1, 1.5, 1.2, 1.05, 0.6 or 0. These values were then rounded to the nearest integer value of 3, 2, 1 or 0 to produce the final habitat suitability scores.

Table 6. Percent slopes and associated multiplier values.

Slope (%)	Initial Forage Value (IFV)	Multiplier Value (MV)	Slope-Adjusted Value (IFV*MV)
0 - 10	3	1.0	3
11 - 30	3	0.7	2.1
31 - 60	3	0.4	1.2
> 60	3	0.0	0

Table 7. Integration of distance from water values with slope-adjusted values to determine final adjusted values.

Distance from Water (km)	Multiplier Value (MV)	Slope-Adjusted Value (SAV)[1]	Final Adjusted Value FAV = (MV*SAV)[2]
0 - 1.60	1.0	3.0, 2.1, 1.2, or 0.0	3.0, 2.1, 1.2, or 0.0
1.70 - 3.22	0.5	3.0, 2.1, 1.2, or 0.0	1.5, 1.05, 0.6, or 0.0
> 3.22	0.0	3.0, 2.1, 1.2, or 0.0	0

[1] For each distance category, the SAV is a unique number derived from the slope-adjusted value. Outcomes of potential cell values are presented.

[2] The FAV is a unique number. Outcomes of potential cell values are presented.

Elk are capable of traversing large tracts of land, and fences do not generally restrict elk movement. Therefore, I assumed that all resources were available to elk on all ranches. Conversely, cattle do not have access to all available areas on the ranches. Fenced pastures and management decisions directly influence where cattle graze. Hence, pastures were considered as unique units of availability. Grazing records that documented gate closures between pastures helped to determine total availability. If documentation did not exist, I assumed that the pasture with cattle present was the only resource unit available to them. I also assumed that the ability to detect selection would occur in largersized pastures and in pastures where cattle grazed for a relatively longer time. These two criteria were not considered mutually exclusive. Grazing records were examined to determine the length of time cattle were in pastures. In order to detect selection, I only used pastures that grazed cattle for more than two weeks and were greater than 200 ha.

Statistical Methods

Sampling protocol A was used to detect evidence of resource selection (Manly et al. 1993). Hence, animal locations, available units, and used units were randomly sampled across the ranches. Individual animals were not identified in our study because sampling was conducted at the population level (Manly et al. 1993).

Experimental units were the patches generated from the 30-m grids (e.g., habitat suitability values). Abiotic and biotic components of the elk and cattle models were not subject to change. Thus seasonal elk locations were pooled across the years and cattle locations were combined across the years if locations occurred in the same pasture. Chi-squared analyses were used to determine whether there was a significant difference between the expected use of suitability classes and the observed frequency of use (Neu et al. 1974). I used SAS 8.02

(1996) to test the null hypothesis that animals used habitat in proportion to availability. The level of significance was determined *a priori* at 0.05.

Manly et al. (1993) described two important assumptions for resource selection studies: 1) Animals have free and equal access to all available resource units; and 2) resource units are sampled randomly and independently. The first assumption was satisfied because elk have a high degree of mobility and were capable of traversing the study sites without impediment. Cattle also had access to all available resources because availability was defined by pastures. The second assumption was also met because the sampling design was based upon surveying study sites at least one week apart to detect independent animal locations.

Selection ratios were used to detect selection and avoidance by yielding values proportional to the probability of use of a resource unit (Manly et al. 1993). Selection functions were estimated using the following equation, where S_i represents the selection ratio, U_i refers to the observed use and P_i refers to expected use. If selection ratios equaled 1.0, use was said to be non-selective.

$$S_i = U_i/P_i$$

Selection occurred when S_i was greater than 1.0 . Avoidance occurred when the S_i value was less than 1.0. Preference for specific habitat classes was determined by using Bonferroni confidence intervals (Neu et al. 1974, Manly et al. 1993).

CHAPTER 4

RESULTS

NLCD Landcover Classes

According to the NLCD, grasslands/herbaceous was the dominant cover class on the STR and BCR Ranches in Montana and on the MC and TE Ranches in Wyoming (Tables 8 and 9, respectively). Because I was primarily interested in elk and cattle feeding sites, I removed non-herbaceous cover classes to establish available herbaceous cover classes for potential feeding sites in Montana and Wyoming.

Elk and Cattle Feeding Site Locations

A total of 1,076 independent elk group locations and 806 independent cattle group locations were collected during the course of my study. Elk group locations were collected on one ranch in Montana and two ranches in Wyoming. During the winter, spring, summer, and fall seasons, 268, 452, 209, and 147 elk group locations were recorded, respectively.

Cattle locations were collected in occupied pastures on two ranches in Montana and two ranches in Wyoming. In Montana, 627 cattle group locations were collected in 18 pastures. A combined total of 180 cattle group locations were collected in 10 pastures in Wyoming.

Table 8. Total NLCD cover classes for the BCR and STR Ranches, Montana.

NLCD Cover Class	BCR Ranch		STR Ranch	
	Area (ha)	Area (%)	Area (ha)	Area (%)
Open Water[a]	358	0.68	1	0.02
Commercial/Industrial/Transportation[a]	n/a	n/a	5	0.14
Bare Rock, Sand, and Clay[a]	13	0.03	0	0.01
Quarries/Strip Mines/Gravel Pits[a]	4	0.01	n/a	n/a
Deciduous Forest[a]	1,728	3.30	68	1.74
Coniferous Forest[a]	10,718	20.46	322	8.28
Shrubland	3,385	6.46	262	6.72
Grasslands/Herbaceous	34,846	66.52	2,539	65.27
Pasture/Hay	493	0.94	419	10.76
Row Crops	227	0.43	61	1.56
Small Grains	336	0.64	132	3.40
Fallow[a]	265	0.51	82	2.11
Woody Wetlands[a]	7	0.01	n/a	n/a
Total	52,381	100	3,890	100

[a] Cover classes removed from the NLCD in the elk and cattle HSI models.

Elk Habitat Selection

Four elk habitat suitability categories were tested using Chi-squared goodness-of-fit tests to determine if elk exhibited selection among habitat suitability categories. Selection ratios (S) determined selection, avoidance, or non-selection by elk within a given habitat suitability category.

Table 9. Total NLCD cover classes for the MC and TE Ranches, Wyoming.

NLCD Cover Class	MC Ranch		TE Ranch	
	Area (ha)	Area (%)	Area (ha)	Area (%)
Open Water[a]	< 1	0.00	4	0.02
Perennial Ice/Snow[a]	5	0.02	1	0.00
Low Intensity Residential[a]	< 1	0.00	1	0.00
Bare Rock, Sand, and Clay[a]	77	0.36	3	0.01
Deciduous Forest[a]	25	0.12	47	0.20
Evergreen Forest[a]	6,856	32.20	6,775	29.35
Mixed Forest[a]	2	0.01	4	0.02
Shrubland	5,155	24.21	6,160	26.69
Grasslands/Herbaceous	9,098	42.73	9,796	42.44
Pasture/Hay	27	0.13	213	0.92
Row Crops	30	0.14	19	0.08
Small Grains	10	0.04	23	0.10
Fallow[a]	7	0.03	17	0.07
Woody Wetlands[a]	< 1	0.00	10	0.04
Emergent Herbaceous Wetlands	1	0.01	11	0.05
Total	21,293	100	23,084	100

[a] Cover classes removed from the NLCD in the elk and cattle HSI models.

Winter

For illustrative purposes, Figure 5 depicts the distribution of winter elk group locations on the habitat suitability map for the upper unit of the BCR Ranch. According to the winter elk model, only the TE Ranch contained areas categorized as unsuitable (Table 10). Contrary to model expectations, elk significantly selected for the low suitability classes on the MC (S = 1.93) and TE ranches (S = 1.87) during the winter season. Furthermore, elk avoided the medium suitability class on the MC Ranch (S = 0.53) and the high suitability class on the TE Ranch (S = 0.36). On the BCR Ranch in Montana, elk use was in proportion to availability. Hence, the null hypothesis could not be rejected.

Table 10. Feeding site selection by elk in winter.

Habitat Suitability Class (Value)	n	Observed (U)	Expected (P)	S (U/P)	Lower Bound	Upper Bound
BCR Ranch, Montana: $X^2_{(df = 2)} = 1.53$ ($p = 0.47$)						
Low (1)	1	0.03	0.01	2.70	-3.68	9.08
Medium (2)	14	0.38	0.44	0.86	0.43	1.29
High (3)	22	0.59	0.55	1.08	0.73	1.43
MC Ranch, Wyoming: $X^2_{(df = 2)} = 14.35$ ($p < 0.01$)						
Low (1)	22	0.58	0.30	1.93*	1.29	2.57
Medium (2)	9	0.24	0.45	0.53*	0.16	0.89
High (3)	7	0.18	0.25	0.74	0.13	1.34
TE Ranch, Wyoming: $X^2_{(df = 3)} = 45.27$ ($p < 0.01$)						
Unsuitable (0)	2	0.01	0.01	1.04	-0.78	2.86
Low (1)	72	0.38	0.20	1.87*	1.43	2.30
Medium (2)	105	0.54	0.59	0.92	0.77	1.07
High (3)	14	0.07	0.20	0.36*	0.13	0.60

* = Significantly different from 1.0 ($p = 0.05$)

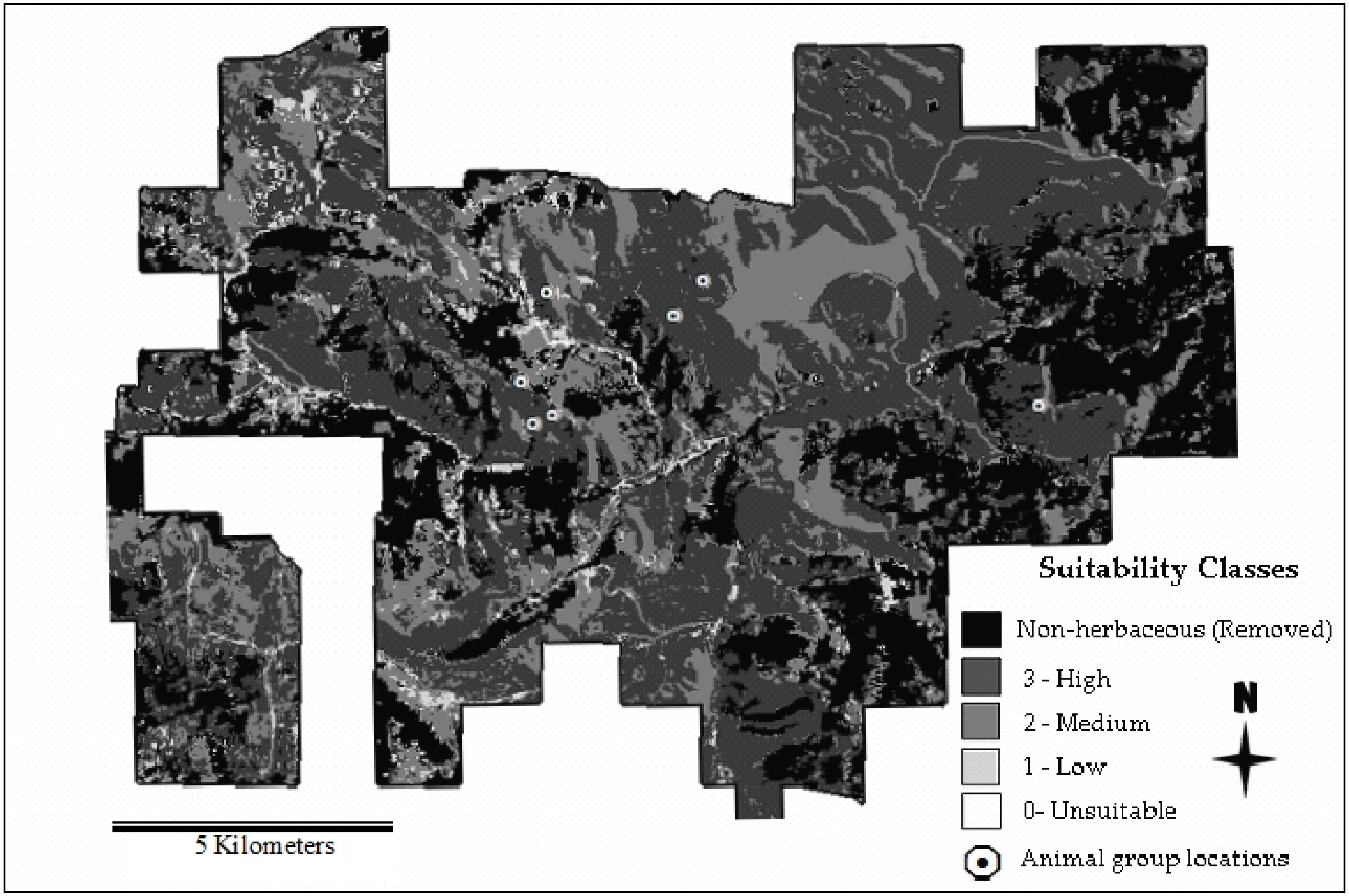

Figure 5. Elk 2001 and 2002 winter locations (n = 7) on the upper unit of the BCR Ranch, Montana.

Spring

According to the spring elk model, all four suitability classes were represented on MC and TE Ranches in Wyoming (Table 11). The BCR Ranch in Montana did not contain areas characterized as unsuitable spring habitat. Elk avoided the low suitability classes on the MC Ranch (S = 0.49) and the BCR Ranch (S = 0.45). Elk use on the TE Ranch in Wyoming was non-selective. The null hypothesis could not be rejected.

Table 11. Feeding site selection by elk in spring.

Habitat Suitability Class (Value)	n	Observed (U)	Expected (P)	S (U/P)	Lower Bound	Upper Bound
	BCR Ranch, Montana: $X^2_{(df = 2)} = 6.59$ (p = 0.04)					
Low (1)	5	0.04	0.10	0.45*	-0.02	0.91
Medium (2)	51	0.46	0.36	1.27	0.95	1.58
High (3)	56	0.50	0.54	0.93	0.72	1.14
	MC Ranch, Wyoming: $X^2_{(df = 3)} = 7.87$ (p = 0.05)					
Unsuitable (0)	2	0.03	0.01	2.82	-2.09	7.73
Low (1)	7	0.10	0.20	0.49*	0.05	0.93
Medium (2)	41	0.58	0.47	1.23	0.92	1.54
High (3)	21	0.30	0.32	0.92	0.50	1.35
	TE Ranch, Wyoming: $X^2_{(df = 3)} = 1.66$ (p = 0.65)					
Unsuitable (0)	3	0.01	0.01	1.12	-0.48	2.72
Low (1)	32	0.12	0.14	0.85	0.50	1.20
Medium (2)	140	0.52	0.53	0.98	0.84	1.13
High (3)	94	0.35	0.32	1.09	0.86	1.32

* = Significantly different from 1.0 (p = 0.05)

Summer

Elk selected (S = 1.29) high suitable habitat on the BCR Ranch but avoided the medium suitable habitat (S = 0.19) during the summer season (Table 12). Elk use was in proportion to availability on the MC and TE Ranches in Wyoming, and the null hypothesis could not be rejected.

Table 12. Feeding site selection by elk in summer.

Habitat Suitability Class (Value)	n	Observed (U)	Expected (P)	S (U/P)	Lower Bound	Upper Bound
BCR Ranch, Montana: $X^2_{(df = 2)} = 21.90$ ($p < 0.01$)						
Low (1)	19	0.15	0.20	0.77	0.38	1.15
Medium (2)	4	0.03	0.17	0.19*	-0.03	0.41
High (3)	101	0.82	0.63	1.29*	1.16	1.43
MC Ranch, Wyoming: $X^2_{(df = 1)} = 0.01$ ($p = 0.91$)						
Low (1)	20	0.41	0.40	1.02	0.63	1.41
High (3)	29	0.59	0.60	0.99	0.72	1.25
TE Ranch, Wyoming: $X^2_{(df = 3)} = 3.54$ ($p = 0.32$)						
Unsuitable (0)	2	0.06	0.11	0.51	-0.36	1.37
Low (1)	10	0.28	0.36	0.77	0.25	1.29
Medium (2)	2	0.06	0.07	0.79	-0.57	2.16
High (3)	22	0.61	0.46	1.33	0.89	1.77

* = Significantly different from 1.0 ($p = 0.05$)

Fall

Elk avoided the unsuitable class (S = 0.26) on the BCR Ranch and the low suitability class on the BCR Ranch (0.59) and the TE Ranch (S = 0.12) during the fall season (Table 13). On the MC Ranch, elk also avoided the high suitable class

(S = 0.14). Elk selected for the medium suitability classes on the BCR (S = 2.51) and MC Ranch (S = 1.68).

Table 13. Feeding site selection by elk in fall.

Habitat Suitability Class (Value)	n	Observed (U)	Expected (P)	S (U/P)	Lower Bound	Upper Bound
BCR Ranch, Montana: $X^2_{(df = 3)} = 60.92$ $(p < 0.01)$						
Unsuitable (0)	5	0.06	0.24	0.26*	-0.02	0.53
Low (1)	23	0.31	0.44	0.59*	0.32	0.85
Medium (2)	47	0.48	0.20	2.51*	1.89	3.14
High (3)	14	0.14	0.12	1.21	0.47	1.95
MC Ranch, Wyoming: $X^2_{(df = 2)} = 10.61$ $(p = 0.01)$						
Low (1)	9	0.31	0.37	0.84	0.28	1.39
Medium (2)	19	0.66	0.39	1.68*	1.14	2.22
High (3)	1	0.03	0.24	0.14*	-0.19	0.48
TE Ranch, Wyoming: $X^2_{(df = 3)} = 12.44$ $(p < 0.01)$						
Unsuitable (0)	1	0.03	0.29	0.12*	-0.17	0.41
Low (1)	9	0.31	0.33	0.94	0.29	1.59
Medium (2)	12	0.41	0.23	1.80	0.81	2.79
High (3)	7	0.24	0.15	1.61	0.29	2.93

* = Significantly different from 1.0 (p = 0.05)

Cattle Habitat Selection

BCR Ranch, Montana

A total of 270 cattle group locations were collected on five pastures located on the lower unit of the BCR Ranch (Table 14). Cattle group locations were obtained during the 2001 and 2002 grazing seasons on Pastures 1, 2, 4, and 5. During the 2001 grazing season, cattle group locations were collected on Pasture 3. For illustrative purposes, Figure 6 depicts a map of cattle habitat suitability, spatial arrangement of pastures, and associated cattle group locations.

Table 14. Cattle study area on the lower unit pastures of the BCR Ranch, Montana.

Pasture Number	Area (ha)*	# Cattle Group Locations
1	2,493	126
2	1,901	49
3	1,454	43
4	663	44
5	265	10
Total	6,776	272

*Excluding forested and non-herbaceous cover types.

Table 15 summarizes the results of the cattle HSI model for the lower unit pastures of the BCR Ranch. Approximately 10 percent of Pasture 5 was comprised of the high suitable habitat, but this category did not contain any cattle group locations and was consequently omitted from the Chi-squared analysis. Contrary to model expectations, cattle avoided the high suitability classes in Pasture 1 (S = 0.88) and Pasture 4 (S = 0.33) on the lower unit of the BCR Ranch. There was no evidence of selection or avoidance in Pastures 2, 3, or 5.

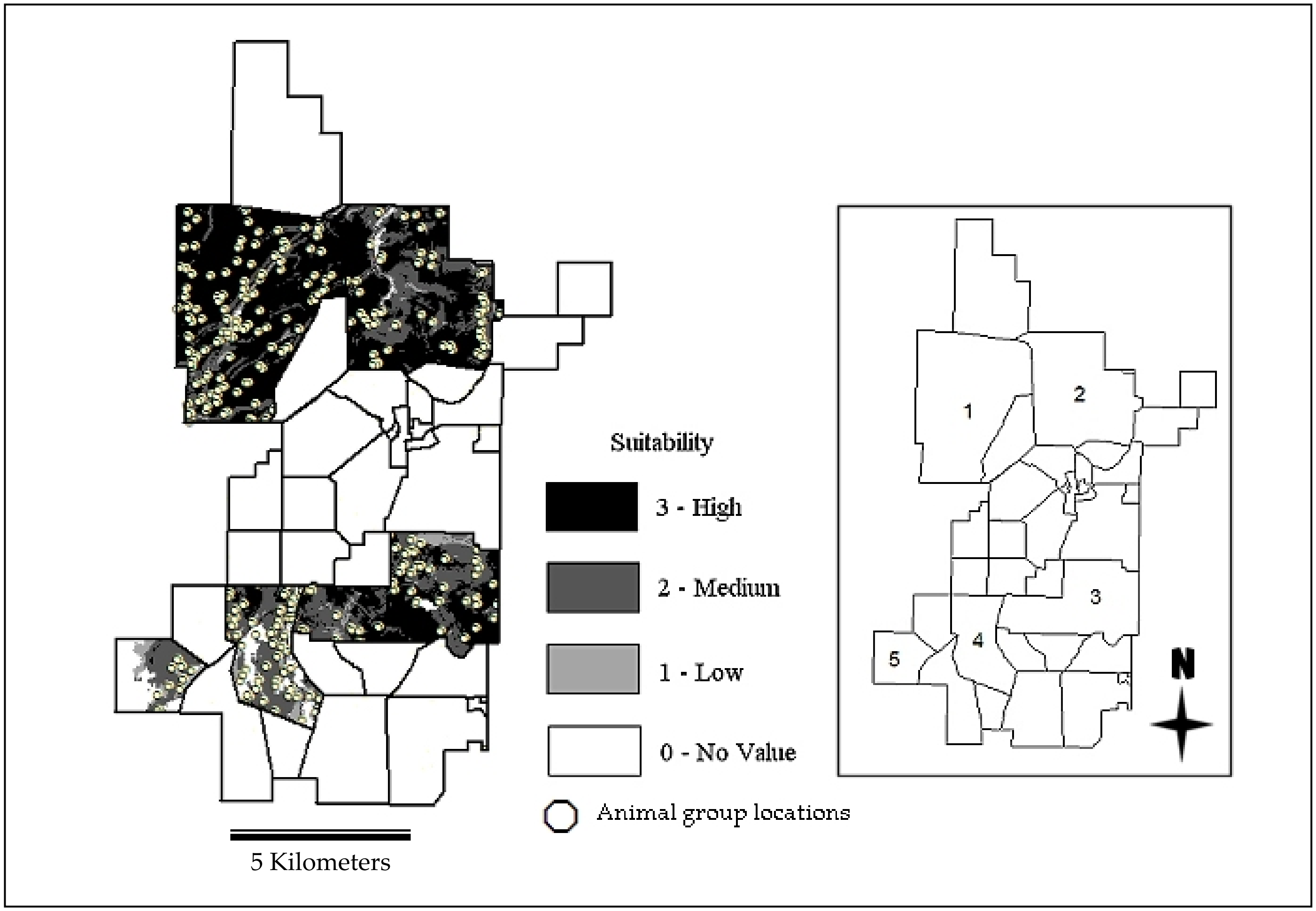

Figure 6. BCR Ranch, Montana: Cattle habitat suitability map of the lower unit pastures with cattle locations.

Table 15. Feeding site selection by cattle on the lower unit of the BCR Ranch, Montana.

Habitat Suitability Classes (Values)	n	Observed (U)	Expected (P)	S (U/P)	Lower Bound	Upper Bound
Pasture 1: $X^2_{(df = 2)} = 22.39$ $(p < 0.01)$						
Low (1)	6	0.05	0.01	4.76	0.22	9.30
Medium (2)	28	0.22	0.16	1.39	0.83	1.94
High (3)	92	0.73	0.83	0.88*	0.77	0.99
Pasture 2: $X^2_{(df = 2)} = 0.10$ $(p = 0.95)$						
Low (1)	1	0.02	0.02	1.06	-1.46	3.59
Medium (2)	16	0.34	0.32	1.06	0.55	1.58
High (3)	30	0.64	0.66	0.97	0.71	1.22
Pasture 3: $X^2_{(df = 2)} = 0.47$ $(p = 0.79)$						
Low (1)	3	0.07	0.05	1.40	-0.47	3.26
Medium (2)	17	0.40	0.43	0.92	0.50	1.33
High (3)	23	0.53	0.52	1.03	0.68	1.38
Pasture 4: $X^2_{(df = 2)} = 5.74$ $(p = 0.06)$						
Low (1)	11	0.25	0.15	1.67	0.62	2.71
Medium (2)	31	0.70	0.71	0.99	0.76	1.22
High (3)	2	0.05	0.14	0.33*	-0.21	0.86
Pasture 5: $X^2_{(df = 1)} = 1.69$ $(p = 0.19)$						
Low (1)	5	0.50	0.31	1.61	0.47	2.76
Medium (2)	5	0.50	0.69	0.72	0.21	1.24

* = Significantly different from 1.0 $(p = 0.05)$

Cattle group locations (n = 330) were collected on nine pastures located on the upper unit of the BCR Ranch in Montana (Table 16). For illustrative purposes, Figure 7 shows the upper unit pasture with corresponding numbered pastures used for cattle habitat selection analysis.

Table 16. Cattle study area on the upper unit of the BCR Ranch, Montana.

Pasture Number	Area* (ha)	# Cattle Group Locations
1	679	36
2	1,441	93
3	1,576	70
4	1,526	58
5	415	15
6	1,464	16
7	1,618	20
8	860	8
9	754	14
Total	10,333	330

*Excluding forested and non-herbaceous cover types.

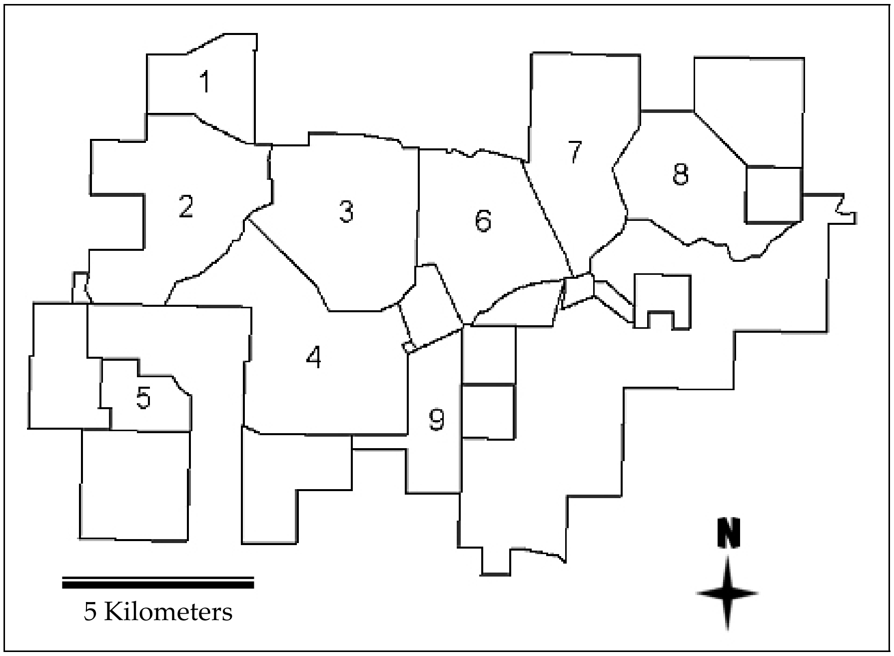

Figure 7. BCR Ranch, Montana: Map of the upper unit pastures.

During the 2001 and 2002 grazing seasons, I analyzed cattle group locations on Pastures 1, 2, 3, 4, 6, 8, and 9 (Table 17). Cattle group locations were collected in Pasture 5 during the 2002 grazing season.

Table 17. Feeding site selection by cattle on the upper unit of the BCR Ranch, Montana.

Habitat Suitability Classes (Values)	n	Observed (U)	Expected (P)	S (U/P)	Lower Bound	Upper Bound
		Pasture 1: $X^2_{(df=1)} = 2.96$ $(p = 0.09)$				
Low (1)	10	0.28	0.17	1.63	0.65	2.62
Medium (2)	26	0.72	0.83	0.87	0.67	1.07
		Pasture 2: $X^2_{(df=2)} = 1.05$ $(p = 0.59)$				
Low (1)	25	0.27	0.26	1.03	0.61	1.46
Medium (2)	57	0.61	0.65	0.94	0.76	1.13
High (3)	11	0.12	0.09	1.31	0.42	2.21
		Pasture 3: $X^2_{(df=2)} = 5.75$ $(p = 0.06)$				
Low (1)	35	0.50	0.53	0.94	0.67	1.21
Medium (2)	25	0.36	0.40	0.89	0.55	1.24
High (3)	10	0.14	0.07	2.04	0.61	3.47
		Pasture 4: $X^2_{(df=2)} = 2.05$ $(p = 0.35)$				
Low (1)	28	0.48	0.42	1.15	0.78	1.52
Medium (2)	28	0.48	0.50	0.97	0.65	1.28
High (3)	2	0.03	0.08	0.43	-0.29	1.15
		Pasture 5: $X^2_{(df=2)} = 0.64$ $(p = 0.72)$				
Unsuitable (0)	2	0.13	0.18	0.74	-0.43	1.91
Low (1)	6	0.40	0.45	0.89	0.22	1.56
Medium (2)	7	0.47	0.37	1.26	0.43	2.10
		Pasture 6: $X^2_{(df=2)} = 0.49$ $(p = 0.78)$				
Low (1)	5	0.31	0.28	1.12	0.12	2.11
Medium (2)	8	0.50	0.58	0.86	0.35	1.38
High (3)	3	0.19	0.14	1.34	-0.33	3.01
		Pasture 7: $X^2_{(df=2)} = 0.61$ $(p = 0.74)$				
Low (1)	1	0.05	0.10	0.50	-0.67	1.67
Medium (2)	10	0.50	0.45	1.11	0.52	1.71
High (3)	9	0.45	0.45	1.00	0.41	1.59

Table 17. (cont'd). Feeding site selection by cattle on the upper unit of the BCR Ranch, Montana.

Habitat Suitability Classes (Values)	n	Observed (U)	Expected (P)	S (U/P)	Lower Bound	Upper Bound
Pasture 8: $X^2_{(df = 1)} = 0.77$ (p = 0.38)						
Medium (2)	3	0.38	0.53	0.71	-0.02	1.43
High (3)	5	0.63	0.47	1.33	0.51	2.15
Pasture 9: $X^2_{(df = 1)} = 0.00$ (p = 1.00)						
Medium (2)	7	0.50	0.50	1.00	0.40	1.60
High (3)	7	0.50	0.50	1.00	0.40	1.60

Pasture 7 contained cattle group locations that were collected during the 2001 grazing season. According to the model, 10 percent of Pasture 1 was classified as high suitable habitat, but no cattle group locations were observed in this area. The model also classified low suitable habitat in Pastures 8 and 9 (10 and 2 percent, respectively) but no cattle groups were observed in this category. Consequently, these categories were omitted from Chi-squared analyses. I did not detect evidence of selection or avoidance for any suitability class in the upper unit pastures of the BCR ranch.

STR Ranch, Montana

A total of 27 cattle group locations were collected on four pastures located on the STR Ranch (Table 18). Cattle group locations were collected in Pasture 1 during the 2002 grazing season and in Pasture 2 for 2001. For Pastures 3 and 4, cattle group locations were collected during the 2001 and 2002 grazing seasons.

Figure 8 illustrates spatial distribution of pastures used for habitat selection analyses.

Table 18. Cattle study area on the STR Ranch, Montana.

Pasture Number	Area* (ha)	# Cattle Group Locations
1	224	9
2	175	4
3	198	6
4	239	8
Total	836	27

*Excluding forested and non-herbaceous cover types.

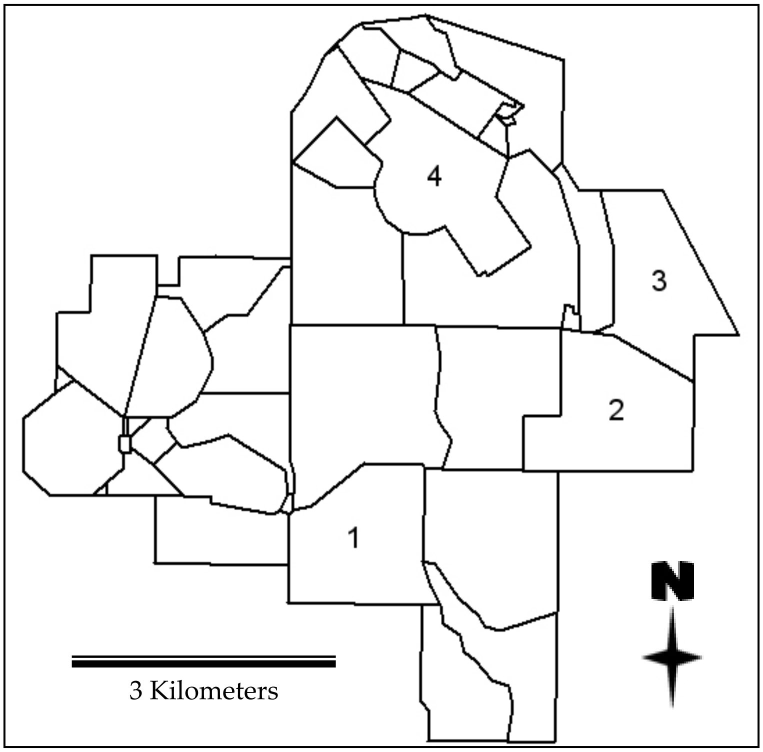

Figure 8. Pasture locations: STR Ranch, Montana.

Cattle use was in proportion to availability in all four pastures (Table 19). Hence, cattle use was non-selective in these pastures and the null hypothesis could not be rejected.

Table 19. Feeding site selection by cattle on the STR Ranch, Montana.

Habitat Suitability Classes (Values)	n	Observed (U)	Expected (P)	S (U/P)	Lower Bound	Upper Bound
		Pasture 1: $X^2_{(df = 1)} = 0.58$ $(p > 0.46)$				
Medium (2)	6	0.67	0.54	1.24	0.59	1.89
High (3)	3	0.33	0.46	0.72	-0.05	1.48
		Pasture 2: $X^2_{(df = 1)} = 0.71$ $(p = 0.40)$				
Low (1)	1	0.25	0.46	0.54	-0.51	1.60
High (3)	3	0.75	0.54	1.39	0.49	2.29
		Pasture 3: $X^2_{(df = 1)} = 0.30$ $(p = 0.59)$				
Low (1)	1	0.17	0.10	1.67	-1.74	5.08
Medium (2)	5	0.83	0.90	0.93	0.55	1.30
		Pasture 4: $X^2_{(df = 1)} = 0.95$ $(p = 0.33)$				
Medium (2)	1	0.12	0.05	2.50	-2.74	7.74
High (3)	7	0.88	0.95	0.92	0.65	1.20

MC Ranch, Wyoming

During the 2001 and 2002 grazing seasons, 56 cattle group locations were collected on 5 pastures on the MC Ranch (Table 20). Figure 9 illustrates spatial arrangements of pastures used for selection analyses.

Table 20. Cattle study area on the MC Ranch, Wyoming.

Pasture Number	Area (ha)	# Cattle Group Locations
1	1,578	18
2	1,263	11
3	827	9
4	667	9
5	616	9
Total	4,951	56

*Excluding forested and non-herbaceous cover types.

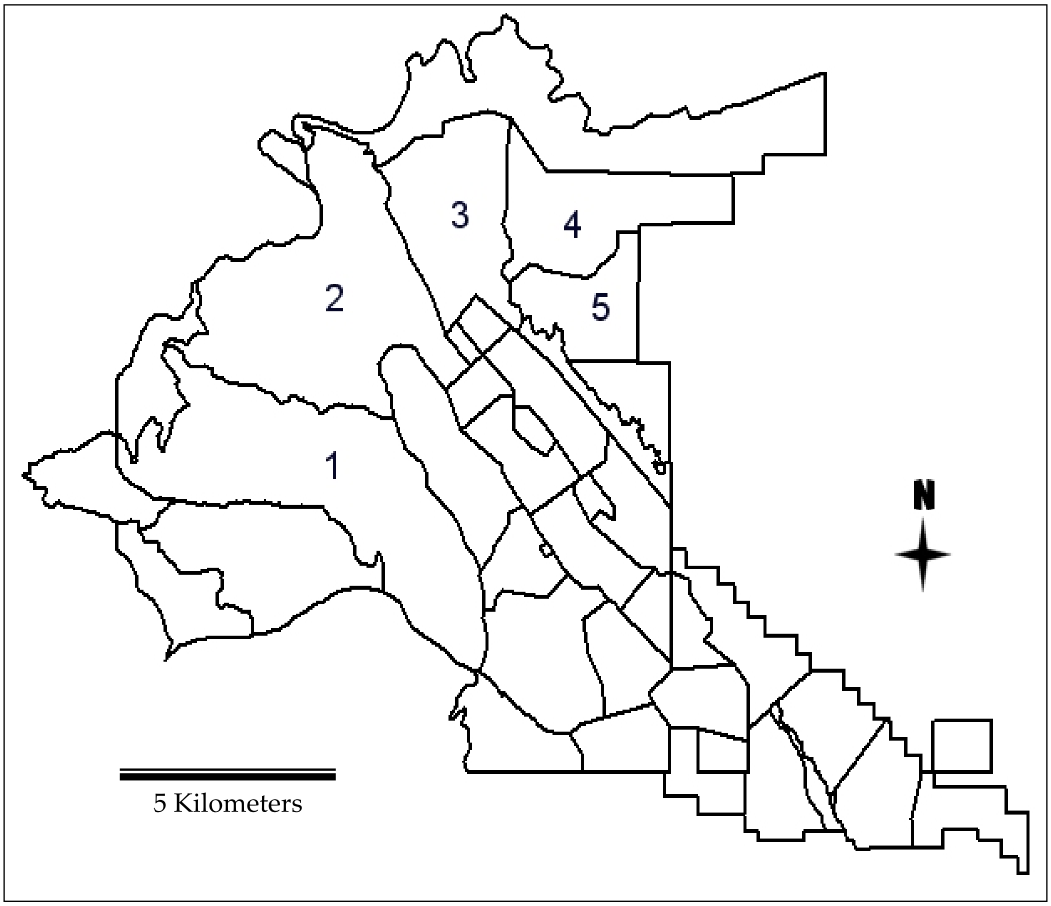

Figure 9. Pasture locations: MC Ranch, Wyoming.

Only Pasture 1 contained the entire array of suitability categories (Table 21). Cattle use was proportionate to availability in Pastures 2, 3, 4 and 5. In Pasture 1, cattle avoided the low suitability class (S = 0.42).

Table 21. Feeding site selection by cattle on the MC Ranch, Wyoming.

Habitat Suitability Classes (Values)	n	Observed (U)	Expected (P)	S (U/P)	Lower Bound	Upper Bound
Pasture 1: $X^2_{(df = 3)} = 4.59$ (p = 0.20)						
Unsuitable (0)	1	0.06	0.07	0.79	-1.13	2.72
Low (1)	3	0.17	0.40	0.42*	-0.13	0.97
Medium (2)	13	0.72	0.49	1.47	0.94	2.01
High (3)	1	0.06	0.04	1.39	-1.98	4.76
Pasture 2: $X^2_{(df = 1)} = 0.03$ (p = 0.87)						
Low (1)	6	0.55	0.57	0.96	0.37	1.55
Medium (2)	5	0.45	0.43	1.06	0.27	1.84
Pasture 3: $X^2_{(df = 1)} = 0.06$ (p = 0.13)						
Medium (2)	7	0.78	0.81	0.96	0.58	1.34
High (3)	2	0.22	0.19	1.17	-0.46	2.80
Pasture 4: $X^2_{(df = 1)} = 0.01$ (p = 0.93)						
Medium (2)	5	0.56	0.54	1.03	0.34	1.72
High (3)	4	0.44	0.46	0.97	0.16	1.77
Pasture 5: $X^2_{(df = 1)} = 0.0088$ (p = 0.93)						
Medium (2)	5	0.50	0.68	0.74	0.02	1.45
High (3)	4	0.33	0.07	4.76	-1.82	11.35

* = Significantly different from 1.0 (p = 0.05)

TE Ranch, Wyoming

Cattle group locations on 5 (n = 124) were collected on 5 pastures on the TE Ranch (Table 22). Figure 10 illustrates spatial arrangements of pastures used for selection analyses. Cattle group locations were collected during the 2001 and 2002 grazing seasons on Pastures 1, 4, and 5. During the 2001 grazing season, cattle group locations were collected on Pasture 3. Cattle locations were obtained during the 2002 grazing season on Pasture 2.

Table 22. Cattle study area on the TE Ranch, Wyoming.

Pasture Number	Area* (ha)	# Cattle Group Locations
1	2,455	64
2	737	5
3	609	7
4	722	11
5	2,557	37
Total	7,080	124

*Excluding forested and non-herbaceous cover types.

Cattle used habitat suitability classes in Pasture 5 disproportionately to availability (Table 23). Cattle selected the medium suitability class (S = 1.45) and avoided the low suitability class (0.21). Cattle used habitat suitability classes in Pastures 1, 2, 3, and 4 in proportion to availability.

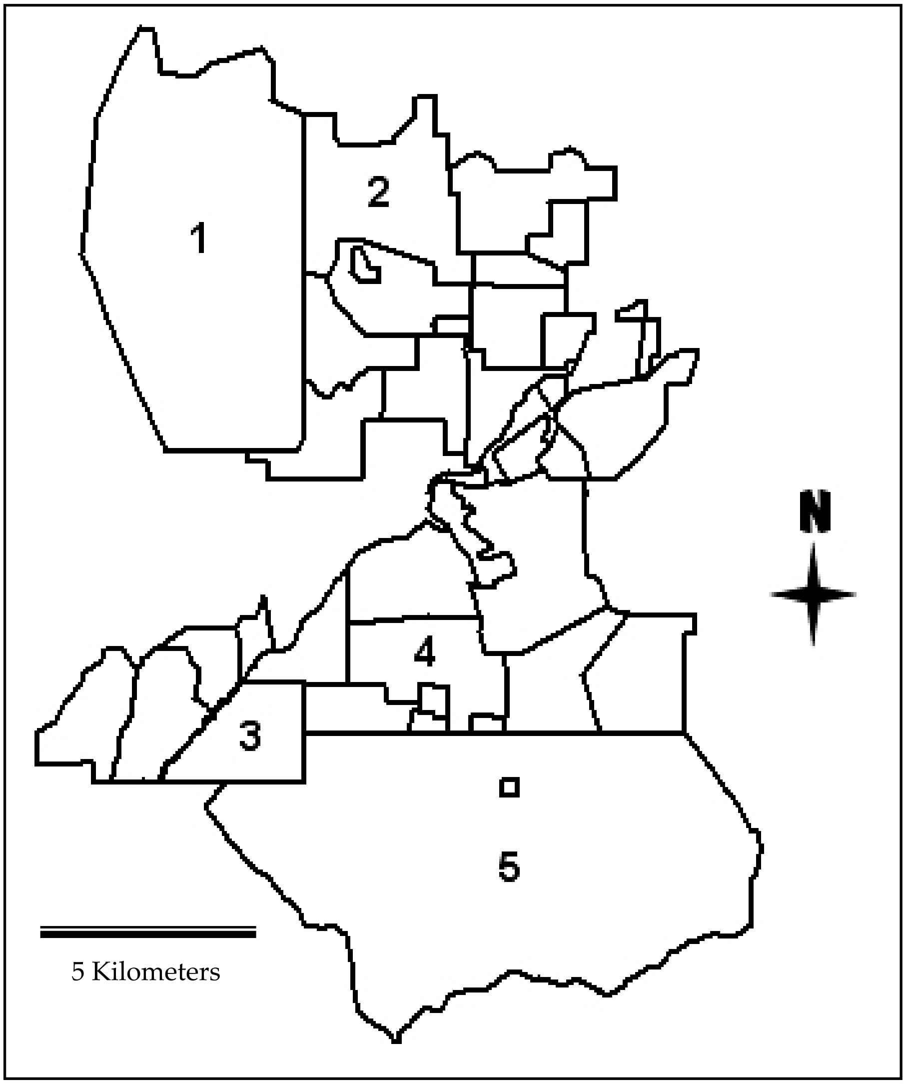

Figure 10. Pasture locations: TE Ranch, Wyoming.

Table 23. Feeding site selection by cattle on the TE Ranch, Wyoming.

Habitat Suitability Classes (Values)	n	Observed (U)	Expected (P)	S (U/P)	Lower Bound	Upper Bound
Pasture 1: $X^2_{(df = 2)} = 0.21$ (p = 0.50)						
Low (1)	26	0.41	0.43	0.94	0.60	1.29
Medium (2)	35	0.55	0.49	1.12	0.81	1.42
High (3)	3	0.05	0.08	0.59	-0.21	1.38
Pasture 2: $X^2_{(df = 1)} = 0.99$ (p = 0.32)						
Low (1)	1	0.20	0.42	0.48	-0.48	1.43
Medium (2)	4	0.80	0.58	1.38	0.69	2.07
Pasture 3: $X^2_{(df = 1)} = 2.24$ (p = 0.13)						
Medium (2)	3	0.43	0.69	0.62	0.01	1.23
High (3)	4	0.57	0.31	1.84	0.49	3.19
Pasture 4: $X^2_{(df = 1)} = 0.21$ (p = 0.65)						
Medium (2)	7	0.64	0.70	0.91	0.45	1.37
High (3)	4	0.36	0.30	1.21	0.13	2.29
Pasture 5: $X^2_{(df = 2)} = 14.18$ (p < 0.01)						
Low (1)	3	0.08	0.38	0.21*	-0.07	0.50
Medium (2)	29	0.78	0.54	1.45*	1.15	1.75
High (3)	5	0.14	0.08	1.69	0.01	3.37

* = Significantly different from 1.0 (p = 0.05)

CHAPTER 5

DISCUSSION

I evaluated the GIS-based modified elk and cattle HSI models developed by Arha (1997) and Holechek (1988), respectively, on four beef cattle ranches in Montana and Wyoming. The objective of my research was to test the hypothesis that elk and cattle feeding site selection were positively related to HSI categories. I predicted that elk and cattle would avoid the unsuitable class (e.g., HSI = 0) but incrementally increase selection of the higher suitability classes (HSI = 1.0, 2.0, and 3.0). If the models accurately predicted elk and cattle use, I could endorse the use of these models as reliable resource management tools.

Relatively few studies are directly comparable to this study. I know of no other study that tested a seasonal elk HSI model or a cattle HSI model at a similar landscape scale using independent data. Based on the available literature, multiple regression appears to be widely used to develop habitat suitability models (Thomas et al. 1979, Lonner 1984, Grover and Thompson 1986). However, many of these models are constructed and tested with the same data (Brooks 1997). These HSI models may perform well at the locations where the data used to construct them were collected, but the accuracy may be low on other geographical locations.

The models used in this study were constructed from knowledge synthesized from previous research on elk and cattle habitat selection. Holechek (1988) and Arha (1997) assigned values to habitat variables that were integrated as the models derived HSI categories. The associations of animal observations and HSI values were evaluated using Chi-squared tests. Thus, I could not determine which specific habitat variables (e.g., elevation, slope, aspect, vegetative cover, distance from water, distance from roads) significantly contributed to elk and cattle habitat selection.

Seasonal Habitat Selection and Use by Elk

Winter

The winter model performed contrary to what I expected. Elk selected the low suitability class on the MC and TE Ranches in Wyoming but avoided the high suitability areas on the TE Ranch. Elk may have avoided high suitability areas and selected for low suitability areas because the HSI model did not account for foraging areas found in forested areas or because of complex social and biological interactions.

I was unable to detect selective use or avoidance of any suitability classes on the Montana ranch during winter. Similarly, a winter elk HSI model used in west-central Alberta, Canada, did not detect elk selection or avoidance for any suitability class (Jones 1997).

Arha (1997) did not include slope in the winter model, and this exclusion may contribute to some of the inconsistencies of the model during this season. According to Mackie (1970), approximately 65 percent of the elk studied used slopes of 0 to 18 percent during winter, an increase from 50 percent use during spring and autumn. Conversely, McCorquodale (2003) determined that at a home range scale, female elk selectively used more areas of steep slopes (>50%) and moderately steep slopes (40-49%) during winter. At patch scales, cow elk preferred 30 – 39 percent slopes (McCorquodale 2003).

Spring

The predictive ability of the spring elk model was poor. Elk did not select for any suitability class on any of the ranches in Montana and Wyoming. However, elk avoided the low suitability class, but only on the MC Ranch in Wyoming. Elk use was non-selective over the remaining ranches and suitability classes.

Other variables not addressed in the elk model may have helped to predict elk feeding site selection. A study conducted by Grover and Thompson (1986) investigated factors that influenced elk spring feeding selection in southwestern Montana. Based on regression models, they concluded that previous cattle use influenced elk spring feeding site selection. Research by Crane (2002) concluded that residual forage was the primary habitat attribute that influenced spring elk feeding site selection. The elk model I tested did not incorporate a residual forage variable, however, this variable may be an essential model component.

In addition, distance from the nearest visible road, density of bunchgrass plants, and distance from cover accounted for 65 percent of the variation in elk feeding distribution (Grover and Thompson 1986). Crane (2002) also determined that distance from forested cover was a significant variable in elk resource selection functions. Arha (1997) accounted for presence of roads but did not account for sightability of roads. For example, elk may feel a sense of security in areas less than 20-m from a ranch road if the topography shields the road from the elk's view. Hence, the suitability index value for distance from cover may be artificially low in some areas of the ranches.

Summer

The summer suitability model did not consistently predict elk use across the three ranches. On the BCR Ranch in Montana, elk selected for the high suitability level but avoided the medium suitability level. The model also performed poorly on the Wyoming ranches. My findings concur with the outcome of a summer elk model tested by Roloff et al. (2001). Their elk model also did not consistently predict summer elk use. The authors reported that elk used topographic barriers for cover during the summer months, but this feature was not incorporated into the model.

Arha (1997) did not incorporate aspect into the summer elk model because he assumed there was no significant evidence of selection by elk for one exposure over another. In western Montana, Skovlin (1982) documented elk use on north-facing slopes because of cooler temperatures in the summer. Marcum (1975) noted that cow elk selected southwesterly through northwesterly and northeasterly exposures during the summer in Montana. Based on these previous studies, aspect may be an important variable that could help predict summer elk habitat selection.

According to the summer HSI model output, the MC Ranch contained all four levels of suitability. However, elk were only located on the low and high suitability classes. Because of the limitations of Chi-squared analysis, I could not consider the unsuitable and medium suitability classes available to elk in my analyses, even though these classes were actually available to the elk on the ranch.

Fall

Relative to the other seasonal models, the fall model was slightly better in predicting elk use on the BCR Ranch in Montana. Elk selected for medium suitable habitat on the BCR Ranch and the MC Ranch in Wyoming. Elk avoided the unsuitable class and the low suitable class on the BCR Ranch. Elk avoided the unsuitable habitat class on the TE Ranch in Wyoming. Contrary to model prediction, elk avoided the high suitability class on the MC Ranch.

The elk model tested by Roloff et al. (2001) also performed more consistently in the fall. They reported that cover, which was incorporated into their model, may have been the over-riding factor influencing elk use in the fall.

The improved performance of the fall HSI model could have several explanations. The roads variable, distance from cover variable, and elevation component may become increasingly important to elk because of hunting pressures and the start of the fall migration. Crane (2002) reported that during the fall season, elk selected feeding sites further from roads and at higher elevations than random sites.

Habitat Selection and Use by Cattle

The cattle HSI models did not perform consistently in Montana. Contrary to what the model predicted, cattle avoided the high suitability class on two pastures on the BCR Ranch. Based on the model output, cattle use was non-selective on the remaining 16 pastures of the BCR Ranch and the STR Ranch.

Model performance slightly improved on the Wyoming ranches. In Pasture 1 on the MC Ranch and Pasture 1 on the TE Ranch, cattle avoided the low suitable class. On Pasture 5 of the TE Ranch, cattle avoided the low suitability but selected the medium suitability. Although this trend in cattle selection and avoidance came close to supporting my hypothesis (i.e., cattle feeding site selection was positively related to HSI suitability levels), results were not consistent on all ranches.

Because the individual habitat variables included in the cattle model were integrated into distinct HSI categories, I was unable to identify those individual variables that could or could not predict cattle selection. I was able to use my results to speculate on reasons for the poor performance of the cattle HSI model that I evaluated.

Senft et al. (1985) used *ad hoc* regression models to determine those variables that influenced cattle selection. Based on a study on the shortgrass steppe of Colorado, Senft et al. (1985) reported that the distribution of cattle was influenced by proximity to water and nutritional properties of vegetation. Nutritional quality was not considered in the original Holechek (1988) model. I modified the model and used the NLCD to delineate non-forested cover types found on the ranches. I assumed that all non-forested cover types represented forage with a high degree of value (HSI = 3.0). This broad classification did not attempt to account for differences in forage quality.

A GIS-based model was tested by comparing the proportion of grazing potential classes to the density of beef cattle in Oregon by Wade et al. (1998). Using Spearman rank correlations, they determined that Class 0 (e.g., unsuitable habitat) was negatively correlated with cattle density. Conversely, the higher suitabilities (e.g., Classes 1, 2, and 3) were positively correlated with cattle density ($r = 0.47\text{-}0.53$, $P < 0.005$). Unlike Wade et al. (1998), the model I used did not consistently predict cattle selection or avoidance to the corresponding habitat suitabilities. However, the model used by Wade et al. (1998) was at a coarser resolution and more applicable for a larger land management area (i.e., state of Oregon).

Harris et al. (2002) emphasized the importance of forage characteristics, distance from water, and slope as determinants of cattle distribution. They pointed out that forage quantity was dependent on weather factors but forage quality was dependent on season. As plants mature, forage quality diminishes and cattle may travel to less desirable areas to graze (Senft et al. 1985, Pinchak et al. 1991). Marlow and Pogacnik (1986) investigated seasonal trends of cattle use in a foothills riparian area. They concluded that cattle concentrated use in foothill upland areas until early July then gradually shifted to riparian areas in late August and September. Marlow and Pogacnik (1986) suggested that as upland forages mature and become unpalatable, cattle will concentrate in riparian zones. Parsons et al. (2003) also determined that cattle use of upland vegetation was greater during early summer than late summer. Furthermore, cattle utilized riparian areas to a greater degree during the late summer season. The NLCD does not account for seasonal changes in forage quality and may not adequately address the apparent shift in cattle habitat use.

The failure of the cattle model to accurately predict cattle selection may also be a function of good livestock management. The goal of successful grazing management is to promote uniform livestock distribution and use of the rangeland. Management strategies, such as placement of salt blocks and herding, may have encouraged cattle use of steeper slopes and areas further from water, but these variables were not accounted for in the cattle HSI model.

The current values assigned to slope and distance from water may be too conservative to accurately predict western cattle habitat selection. It is possible that the cows in my study have adapted to the mountainous terrain (Bailey 1999). Furthermore, Bailey et al. (1996) have also shown that cows with older calves will utilize steeper slopes and areas further from water.

At present, the cattle HSI model did not accurately predict cattle distribution on 4 ranches in Montana and Wyoming and cannot be considered for use in land resource planning in this area. The current model is relatively parsimonious, incorporating only a vegetative coverage map, distance from water, and slope. Although no single factor influences cattle distribution, previous studies have shown that distance from water, shade, slope, and vegetative characteristics can help determine cattle distribution patterns (DelCurto et al. 1999). I recommend incorporating those variables not addressed in the current cattle HSI (i.e., distance from shade and location of salt blocks) and conduct further validation tests of the model.

Accuracy of the National Land Cover Data

For the purposes of my study, I used the Region 8 NLCD as a vegetative cover layer instead of conducting vegetative sampling. An accuracy assessment has been completed for the NLCD coverage maps for Montana, Wyoming, North Dakota, South Dakota, Colorado, and Utah (Howard, pers. comm). The user's accuracy referred to the probability that what the map showed was in-fact what was on the ground (Table 24). The NLCD was assessed on three scales: patch, pixel, or mode. These assessments were related to the idea of mis-registration of the Landsat data relative to the aerial photo that was used to assess the accuracy. A pixel in the Landsat data may or may not fall exactly where it was suppose to relative to the photo (Howard 2003, personal communication). The "mode" assessment tells us the degree of accuracy in which the classified pixel matches the most frequently occurring land cover in the 3x3 pixel window on the photo.

The overall accuracy of the NLCD was 0.61, however my study focused on non-forested cover types. Grasslands and shrublands scored relatively higher (0.65 and 0.79, respectively). Because the NLCD forms the basis of the HSI models I tested, potential inaccuracies for a given cover type could lead to an initial over- or under-estimation of relative forage value and would subsequently produce erroneous outputs in the HSI models.

Table 24. Accuracy (mode*) of NLCD Federal Region 8.

Land Cover Code	Land Cover Type		User's Accuracy
11	Water		0.76
12	Perennial Ice/Snow		0.09
21	Low Density/Residential		0.71
22	High Density Residential		0.45
23	Commercial/Industrial/Transportation		0.31
31	Bare Rock/Sand/Clay		0.49
32	Mining		0.26
33	Transitional		0.01
41	Deciduous Forest		0.16
42	Evergreen Forest		0.62
43	Mixed Forest		0.15
51	Shrublands		0.79
71	Grasslands		0.65
81	Hay and Pasture		0.34
82	Cropland		0.79
83	Small Grains		0.39
84	Bare Soil/Fallow Land		0
85	Urban Grass		0.14
91	Woody Wetland		0.04
92	Emergent (Herbaceous) Wetland		0.13
		Overall accuracy	0.61

*Agreement is defined as a match between the primary or alternative cover class of the corresponding 3x3 pixel window.

Model Testing

Roloff and Kernohan (1999) identified seven criteria that may account for sources of HSI model validation errors. Additionally, they developed a framework to score HSI validation studies and applied their criteria to 58 HSI model validation studies. The maximum possible score was 7.0, but 4.05 was the maximum score assigned to a HSI validation test (Roloff and Kernohan 1999). I compared my validation process to their recommended criteria in order to recognize strengths and weaknesses in my study. For each of the seven criteria, I have similarly ranked my model validation study using the numerical scoring process described by Roloff and Kernohan (1997).

Roloff and Kernohan (1999) pointed out that HSI models are comprised of assumptions, input variables, variable relationships, and model outputs. They recommended that all components of the model should be verified in a step-wise manner, beginning with the assumptions. According to Arha (1997), several habitat relationships in the elk model were based upon untested assumptions. Verification of the input variables and the variable relationships prior to testing the elk and cattle HSI models would have been a more rigorous approach. According to the scoring criteria of Roloff and Kernohan (1999), the elk and cattle HSI validation tests would each receive 0.0 points.

A common deficiency in model validation has been the description of model inputs (Roloff and Kernohan 1999). They described two sources of error associated with input data. Sampling error can occur when assigning values to the vegetative cover in mapped polygons. The second error can occur if the spatial depiction of mapped polygons was initially erroneous. These errors can profoundly affect model output interpretation. Roloff and Kernohan (1999) recommended the application of confidence intervals to HSI scores or similar statistical methods to quantify the differences in HSI scores that may reflect errors in vegetative sampling. My study was unique because I did not sample vegetation. Rather, I used the NLCD in place of vegetative samples. I reported the accuracy level of the NLCD land coverage, however, it is difficult to determine the errors associated for each pixel. My study would have received a score of 0.0 for both the elk and cattle HSI models.

The importance of replicates, statistical power and sample size was stressed by Roloff and Kernohan (1999). I tested the elk models on three replicated study sites and the cattle model on four replicated study sites. Additionally, objective analyses were conducted using Chi-squared tests. My study would have received a score of 0.25 points for identifying and defining replicates used to test the elk and cattle HSI models. Use of Chi-squared tests scored an additional 1.0 point for both the elk and cattle HSI models.

Previous research by Johnson (1981) determined that the general sample-size criteria was determined by [(3*(number of variables)) + 20). The winter elk HSI model had five variables. Thus, a sample size of 35 would satisfy the sample size criteria. I obtained sample sizes of 37, 38, and 194 for the three participating ranches. The spring elk HSI model was comprised of six variables, indicating that a sample size of 38 would have reasonable statistical power. The sample size was statistically sound for the spring seasonal model. The summer elk model had three variables, thus a sample size of 29 would be considered powerful. Johnson's (1981) criteria was satisfied for the summer elk model. The fall elk model contained five variables, thus an adequate sample size would be 35. My sample size on the BCR Ranch was n = 138, however, I was deficient in meeting Johnson's (1981) criteria on the MC Ranch (n = 29) and the TE Ranch (n = 32). Most of the sample sizes in my elk HSI study satisfied Johnson's (1981) criteria, with the exception of two ranches in fall. For this criterion, I would receive a score of 0.75.

There were three variables in the cattle model. Hence, if the animal sample per pasture was greater than n = 29, the sample sizes would be considered to be sufficient. On the BCR Ranch, one pasture on the lower unit had a sample size of n = 10 and did not meet the criteria determined by Johnson (1981). Likewise, five of the pastures on the upper unit of the BCR Ranch had sample sizes less than n = 29. All of the pastures on the STR Ranch had sample sizes less than n = 29. I also did not meet the sampling criteria for the MC Ranch for any of the pastures. Only two of the five pastures on the TE Ranch had sample sizes greater than n = 29. According to Johnson (1981), sample sizes used in the cattle HSI analyses were not considered robust, thus I would score 0.0.

Appropriateness of spatial scale is an important element of HSI validation tests (Roloff and Kernohan 1999). My study sites were relatively large (ranging from 3,481 to 40,010 ha) compared to most HSI validation studies (Roloff and Kernohan 1999). The scores for the elk and cattle models would be 1.0.

In order to evaluate the model's predictive power, the entire range of habitat suitability should be included in HSI model verification tests (Roloff and Kernohan 1999). Additionally, the range of habitat SI scores should be wide enough to reflect real differences in habitat quality. For the HSI models I tested, the full range of suitabilities (e.g., 0.0 to 1.0) were consistently captured by the elk and cattle models, as described by Arha (1997) and Holechek (1988). The HSI distribution was typically divided into four parts (e.g., 0.0, 0.33, 0.67, and 1.0). Thus, scores for the elk and cattle HSI would be 0.6.

Roloff and Kernohan (1999) noted that incorporating population indices increased the robustness of the HSI models. They recommended measuring surrogates of fitness (e.g., reproductive rate, fecundity, survival, and mortality). For my study, habitat suitability models were constructed with attributes thought to be important to an animal's welfare. The mechanistic qualities of the model conveyed habitat quality yet suggested nothing about habitat importance or suitability in terms of fitness (Garshellis 2000). The utility of these models would be further enhanced with corresponding demographic measurements for elk (e.g., birth rates, death rates) and cattle (e.g., calf crops, birth weights, weaning weights). My study was based on presence-absence data, and I did not measure any surrogates of fitness. Hence, my score for the elk and cattle HSI models would be 0.0 for this category.

Variability in population density and animal distribution affect the ability to demonstrate habitat quality and population index relationships (Van Horne 1983). Shifts in numerous environmental variables influence changes in demographics. To minimize variation, Roloff and Kernohan (1999) recommended that population data collection should correspond with the breeding cycle of the targeted animal. Additionally, data should be collected for a minimum of three years. I collected data for 2 years without consideration to breeding cycle of elk or cattle, thus my score would be 0.0.

The final scores for the HSI validation test was 3.60 for the elk and 2.85 for the cattle model. My scores were higher than the mean (i.e., 2.10) based on their evaluations.

Other Considerations

Habitat modeling is an evolving process. I cannot recommend the seasonal elk HSI model developed by Arha (1997) for use in land resource management. I recommend that the model be revised with consideration given to the seven criteria outlined by Roloff and Kernohan (1999). I also recommend the variables outlined in the following section be incorporated into the elk model. Once refined, the elk model should be retested with independent data to determine whether the model can be used as an practical resource management tool.

The elk HSI model assumed that water was not a limiting factor and was excluded as a variable of interest (Arha 1997). However, several studies indicated that water was an important habitat component for lactating elk (Marcum 1975, Thomas et al. 1976) and elk on summer range (Marcum 1975). Integrating a GIS-based water component into the spring and summer elk models may portray elk suitabilities more accurately.

Research by Crane (2002) has shown that elk preferentially select feeding sites previously grazed by cattle at varying degrees of utilization. Elk resource selection functions established that abundance of residual forage was a significant predictor of elk feeding sites (Crane 2002). Incorporating a cattle utilization layer into the elk HSI may improve model performance.

Under controlled, clinical conditions, preference may be determined by offering equal portions of different resources and observing the choices that are made (Elston et al. 1996). However, equal proportions of suitability classes was not likely. Thus, I may not have been able to detect significant evidence of selection because each suitability class was not found in relatively equal proportions on the ranches.

Chi-squared tests require a sufficient sample size in order for the Chi-squared approximation to be valid. Generally, sample sizes are considered large enough when every expected count is at least five (Devore and Peck 2001). Snedecor and Cochran (1967) pointed out that this restriction might be too strict. They suggested that the Chi-squared test is accurate enough if the smallest expected value is at least one.

I examined the expected cell values for the elk and cattle Chi-squared analyses. A total of 12 Chi-squared analyses were conducted on the seasonal elk models (e.g., four seasons per three ranches). Only one Chi-squared test for winter, spring, and fall, and two Chi-squared tests for summer had sample sizes greater than or equal to five (i.e., 5 of 12). Only two Chi-squared tests conducted on the elk models had expected values less than 1. A total of 23 Chi-squared tests were conducted on four ranches for the cattle HSI model. For expected values equal to or greater than five, only four pastures had adequate sample sizes. When the expected value was at least one, 18 of the 23 pastures had samples of sufficient size. Using the minimum criteria, sample sizes were adequate to make proper inferences about both models. Using the more strict criteria, suggests that inferences from the Chi-squared tests should be made with caution.

CHAPTER 6

SUMMARY

Managing elk and cattle habitats in the western United States challenges many resource managers. One contributing factor is that elk and cattle exhibit dietary and habitat overlap that varies spatially and temporally (Wisdom and Thomas 1996). Land resource managers must focus management plans to address the impacts from the combined and repeated resource use by cattle and elk that can potentially contribute to habitat degradation. Furthermore, contrasting public and private land management practices contribute to the complexity of wildlife/livestock management.

Land-use decisions are preferably made using information gathered from research studies. At times, managers must make land-use decisions swiftly without the benefit of research. Quantitative models are tools used to help make decisions regarding the use and conservation of resources. Unfortunately, many of these models are used without field validation (Brooks 1997).

The purpose of my research was to evaluate elk and cattle HSI models to determine their efficacy as tools for land resource managers. Many species-habitat models exist, but can be cumbersome to use because they contain complex variable inputs. I field-tested a modified elk HSI model and a cattle HSI to evaluate their utility in natural resource planning. The objective of my study was to test the hypothesis that elk or cattle feeding site selection increased as values for the suitability classes increased. Because my focus was on feeding site selections, I sampled animal group locations within 3.0 hours post sunrise. Additionally, I used forage-based modifications of both models.

A total of 1,076 independent elk group locations and 806 independent cattle group locations were collected on four ranches located in Montana and Wyoming. I used Chi-squared analyses to test the hypothesis that elk and cattle selection increases as habitat suitability classes increase.

I found little evidence that these models consistently predicted seasonal elk and cattle use on the ranches in my study. Contrary to my hypothesis, the winter elk model determined that elk selected low suitable habitat on the MC Ranch ($S = 1.93$) and the TE Ranch ($S = 1.88$) but avoided the medium suitable habitat ($S = 0.53$) on the MC Ranch and the high suitable habitat ($S = 0.36$) on the TE Ranch.

Using the spring elk model, I only detected significant avoidance of the low suitability class ($S = 0.49$) on the MC Ranch. Elk spring use was non-selective for the remaining suitability classes on all three ranches.

Elk summer use was selective for the high suitability class (S = 1.23) but elk avoided the medium suitability class (S = 0.18) on the BCR Ranch. Elk did not select or avoid any suitability class on the Wyoming ranches during summer.

On the BCR Ranch, the fall elk model demonstrated that elk avoided the unsuitable (S = 0.26) and low suitability (S = 0.70) classes but selected the medium suitability class (S = 2.42). Elk use was non-selective on the high suitable class. This use-avoidance trend was the only outcome from all seasonal elk models that came close to my hypothesis. Based on the model output, fall elk use was unpredictable on the Wyoming ranches. Elk significantly selected for the medium suitability class (S = 1.68) on the MC Ranch but avoided the high suitability class (S = 0.14). I could only detect avoidance of the unsuitable class (S = 0.10) on the TE Ranch. The rest of elk use on this ranch was non-selective.

The cattle model was a poor predictor of animal use on all four ranches. On the BCR Ranch in Montana, cattle avoided the high suitability classes on two pastures (S = 0.88, S = 0.33) but were non-selective on the remaining pastures. I was also unable to detect selection or avoidance on the STR Ranch. In Wyoming, cattle significantly avoided the low suitability class (S = 042) on the MC Ranch. Only one pasture on the TE Ranch satisfied my hypothesis that cattle selection increases as suitabilities increase. Cattle avoided (S = 0.21) the low suitability class but selected for the medium suitability class (S = 1.45). For the rest of the pastures, cattle use was non-selective.

As they currently stand, I cannot endorse use of these models as tools for land resource planning. I recommend that the elk model should be further refined by incorporating those variables known to influence selection. Previous research indicated that residual forage was the primary habitat attribute that influenced elk feeding site selection (Crane 2002). Proximity to water may also be an important predictor of elk selection (Marcum 1975, Thomas et al. 1976). Likewise, variables such as locations of salt blocks and distance from cover (e.g., shade) may improve performance of the current cattle HSI model to predict cattle selection. Furthermore, the variables used in the models were not previously validated, and may have not accurately portrayed relationships among habitat variables and habitat use by cattle and elk.

Refinement of these models may increase their predictability and enhance their use in resource management. For future consideration, I encourage any further revisions to the models be tested with independent data and on replicated sites to determine their utility as decision-making tools in natural resource management.

Habitat selection models are commonly used in resource planning before they are validated with independent field data (Brooks 1997). Schamberger and O'Neil (1986) commented on the utility of HSI models in resource management: "The reliability of these planning models is not as high as we would like, yet alternatives have not been developed that are widely accepted." Nevertheless, the poor performance of the elk and cattle models underscores the need to test habitat models before they are used in resource planning.

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APPENDICES

APPENDIX A:

ELK HSI MODEL

Modification of Initial Forage Values Based on Winter Habitat Suitability.

Table 25. Modification of forage values (FV) based on elevation in winter.

Modification in FV	Elevation (m)
FV * 1.00	0 - 2,438
FV * 0.50	2,439 - 2,743
FV * 0.25	2,744 +

Table 26. Modification of forage values (FV) based on aspect in winter.

Modification in FV	Aspect (degrees)
FV * 1.00	South & West (141 - 319)
FV * 0.75	North & East (320 - 140)

Table 27. Modification of forage values (FV) based on distance from cover in winter.

Modification in FV	Distance from cover (depending on cover value (CV))		
	CV = 3 (High)	CV = 2 (Medium)	CV= 1 (Low)
FV * 1.00	0 - 1 km	0 - 1 km	0 - 0.5 km
FV * 0.75	1 - 2 km	1 - 2 km	0.5 - 1.0 km
FV * 0.50	2 - 3 km	2 - 3 km	1.0 - 1.5 km
FV * 0.25	3 - 3.5 km	3 - 3.5 km	1.5 - 2.0 km
FV * 0.00	3.5 + km	3.5 + km	2.0 + km

Table 28. Modification of forage values (FV) based on human disturbance (roads) in winter.

Modification in FV	Distance from roads		
	State HW	Co. Rd.	Ranch Roads
FV * 1.00	201 + m	61 + m	31 + m
FV * 0.50	1 - 200 m	1- 60 m	1 - 30 m

Modification of Initial Forage Values Based on Spring Habitat Suitability.

Table 29. Modification of forage values (FV) based on elevation in spring.

Modification in FV	Elevation (m)
FV * 1.00	0 - 2,743
FV * 0.50	2,744

Table 30. Modification of forage values (FV) based on aspect in spring.

Modification in FV	Aspect (degrees)
FV * 1.00	South & West (141 - 319)
FV * 0.75	North & East (320 - 140)

Table 31. Modification of forage values (FV) based on ruggedness of terrain.

Modification in FV	S.D. in surrounding 9 cells (m)	Ruggedness
FV * 1.00	0 - 8	Gentle
FV * 0.75	8 - 15	Rolling
FV * 0.50	15 - 25	Rugged
FV * 0.25	25 +	Steep

Table 32. Modification of forage values (FV) based on distance from cover in spring.

Modification in FV	Distance from cover (depending on cover value (CV))		
	CV = 3 (High)	CV = 2 (Medium)	CV= 1 (Low)
FV * 1.00	0.0 - 0.8 km	0.0 - 0.8 km	0.0 - 0.4 km
FV * 0.75	0.8 - 1.2 km	0.8 - 1.2 km	0.4 - 0.6 km
FV * 0.50	1.2 - 1.6 km	1.2 - 1.6 km	0.6 - 0.7 km
FV * 0.25	1.6 - 2.0 km	1.6 - 2.0 km	0.7 - 0.8 km
FV * 0.00	2.0 + km	2.0 + km	0.8 + km

Table 33. Modification of forage values (FV) based on human disturbance (roads) in spring.

Modification in FV	Distance from roads		
	State HW	Co. Rd.	Ranch Roads
FV * 1.00	401 m +	250 m +	150 m +
FV * 0.50	200 - 400 m	150 - 250 m	100 - 150 m
FV * 0.25	0 - 200 m	0 - 150 m	0 - 100 m

Modification of Initial Forage Values Based on Summer Habitat Suitability.

Table 34. Modification of forage values (FV) based on distance from cover in summer.

Modification in FV	Distance from cover (depending on cover value (CV))		
	CV = 3 (High)	CV = 2 (Medium)	CV= 1 (Low)
FV * 1.00	0.0 - 0.8 km	0.0 - 0.8 km	0.0 - 0.4 km
FV * 0.75	0.8 - 1.2 km	0.8 - 1.2 km	0.4 - 0.6 km
FV * 0.50	1.2 - 1.6 km	1.2 - 1.6 km	0.6 - 0.7 km
FV * 0.25	1.6 - 2.0 km	1.6 - 2.0 km	0.7 - 0.8 km
FV * 0.00	2.0 + km	2.0 + km	0.8 + km

Table 35. Modification of forage values (FV) based on human disturbance (roads) in summer.

Modification in FV	Distance from roads		
	State HW	Co. Rd.	Ranch Roads
FV * 1.00	800 km +	500 km +	200 km
FV * 0.50	500 - 800 km	250 - 500 km	150 - 200 km
FV * 0.25	0 - 500 km	0 - 250 km	0 - 150 km

Modification of Initial Forage Values Based on Fall Habitat Suitability.

Table 36. Modification of forage values (FV) based on elevation in fall.

Modification in FV	Elevation (m)
FV * 1.00	0 - 3,048
FV * 0.50	3,049 - 3,353
FV * 0.25	3,354 +

Table 37. Modification of forage values (FV) based on aspect in fall.

Modification in FV	Aspect (degrees)
FV * 1.00	North & East (320 - 140)
FV * 0.75	South & West (141 - 319)

Table 38. Modification of forage values (FV) based on distance from cover in fall.

Modification in FV	Distance from cover (depending on cover value (CV))		
	CV = 3 (High)	CV = 2 (Medium)	CV= 1 (Low)
FV * 1.00	0.0 - 0.25 km	0.0 - 0.10 km	0.0 - 0.05 km
FV * 0.75	0.25 - 0.40 km	0.10 - 0.20 km	0.05 - 0.10 km
FV * 0.50	0.40 - 0.50 km	0.20 - 0.30 km	0.10 - 0.20 km
FV * 0.25	0.50 - 0.60 km	0.30 - 0.40 km	0.20 - 0.30 km
FV * 0.00	0.60 km +	0.40 km +	0.30 km +

Table 39. Modification of forage values (FV) based on human disturbance (roads) in fall.

	Distance from roads			
Modification in FV	State HW	Co. Rd.	Ranch Roads	Trails
FV * 1.00	1 km +	0.8 km +	0.5 km +	0.3 km +
FV * 0.50	0.8 - 1.0 km	0. - 0.8 km	0.4 - 0.5 km	0.2 - o.3 km
FV * 0.25	0.0 - 0.8 km	0.0 - 0.6 km	0.0 - 0.4 km	0.0 - 0.2 km

APPENDIX B:

CATTLE HSI MODEL AML

```
/* This aml cattlewatdist.aml was written 6/20/03.
/* It calculates cattle habitat suitability indices which can have
/* values of 0 (non-habitat), 1 (poor habitat), 2 (moderate habitat) , and
/* 3 (good habitat).
/* It uses percent slope classes, distance from nearest water classes, and NLCD
/* (National Land Cover Dataset) land cover types to calculate index values
/* at regularly spaced locations on a ranch.
/*
/* It reads Arc/Info format grids for percent slope and distances from the nearest
/* water source which can be a spring or pond, a stream, or a developed water
source.
/* The index values are calculated at each cell location for the grids.
/*
/* Each cell is initially assigned a value of 3. This initial value is multiplied by a
/* multiplier value depending on the slope of the cell. These multiplier values are
/* determined as follows:
/*                  Percent Slope Range    Multiplier Value
/*                        0 - 10            1.0
/*                     > 10 and <= 30          0.7
/*                     > 30 and <= 60          0.4
/*                         > 60            0.0
/* A cell will now have a value of 3, 2.1, 1.2, or 0 at this point. This value is then
/* multiplied by a multiplier value based on distance from the nearest water
source. These
/* multiplier values are determined as follows:
/*        Distance from Water in Kilometers    Multiplier Value
/*                    0 - 1.60                1.0
/*                 > 1.6 and <= 3.22               0.5
/*                    > 3.22                 0.0
/* A cell will now have a value of 3, 2.1, 1.5, 1.2, 1.05, 0.6 or 0 at this point. These
/* values are then rounded to the nearest integer value of 0, 1, 2, or 3.
/*
/* The aml prompts for NLCD land cover code numbers that represent land cover
types
/* considered non-habitat for cattle. If a cell is in one of these land cover types, it
is
/* assigned a final habitat suitability index value of 0. Otherwise the value index
value
```

```
/* that was calculated for the cell is retained.

/* ----------------------------------------------------------------

&args nlcdgrid slopegrid springdistgrid streamdistgrid devwaterdistgrid


/*  Bound (Boundary grid name): the grid containing only the
/*   boundary of the ranch. All cells inside the ranch
/*   have a value of 1. All cells outside the ranch must
/*   have a value < 0.


/*   AcreCalc:  The number needed to convert square units
/*             (feet or meters) to acres.


/* Start Grid

grid

&DESCRIBE %nlcdgrid%
SETWINDOW %nlcdgrid%
SETCELL %GRD$DX%

&type  Calculating Initial Value

zinitial = 3

&type Modifying initial value by percent slope

if ((%slopegrid% > 10.0) and (%slopegrid% <= 30.0))
  zslope = zinitial * 0.7
else if ((%slopegrid% > 30.0) and (%slopegrid% <= 60.0))
  zslope = zinitial * 0.4
else if (%slopegrid% > 60.0)
  zslope = 0.0
else
  zslope = zinitial
```

```
endif
&s dist1 1600.0
&s dist2 3200.0

&type Calculating effect of distance from water

if ((%streamdistgrid% > %dist2%) and (%springdistgrid% > %dist2%) and
(%devwaterdistgrid% > %dist2%))
    zwat = 0.0
else if ((%streamdistgrid% > %dist1%) and (%springdistgrid% > %dist1%) and
(%devwaterdistgrid% > %dist1%))
    zwat = zslope * 0.5
else
    zwat = zslope
endif

zwater = int(zwat + 0.5)

/* Get list of NLCD vegetation types that are not to be considered in the cattle
model

&type You will be prompted to enter NLCD cover type codes, one at a time, for
land cover types that
&type are to be excluded from the cattle model. Enter a value of 0 when done.
&s count = 0
&s code = -1
zcattlesuit = zwater
&do &until %code% eq 0
  &s code [response 'Enter a code value']
  zcattle = setnull(%nlcdgrid% == %code%,zcattlesuit)
  kill zcattlesuit
  zcattlesuit = zcattle
  kill zcattle
&end

cattlesuit = setnull(bound == 0,int(zcattlesuit + .5))


/* kill intermediate grids
```

```
kill zinitial
kill zslope
kill zwat
kill zwater
kill zcattlesuit

/* quit grid
quit

&type Calculating acreages


additem cattlesuit.vat cattlesuit.vat acres 10 10 i
&DESCRIBE cattlesuit
&data arc info
arc
OUTPUT ../CATTLESUITACRES.TXT INIT
SELECT CATTLESUIT.VAT
PRINT 'FINAL SUITABILITY ACRES BY SUITABILITY VALUE'
CALC ACRES = ( COUNT * %GRD$DX% * %GRD$DX% ) / 4047
PRINT VALUE,  5X,  ACRES
Q STOP

&END


&type -------------- All done! ----------------

&return
```