PREDICTING FEEDING SITE SELECTION OF MULE DEER ON FOOTHILL AND MOUNTAIN RANGELANDS

by

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ABSTRACT

Determining areas on the landscape selected by mule deer (*Odocoileus hemionus*) for foraging and the characteristics of selected feeding sites is a crucial step in managing mule deer and its habitat. Mule deer populations in much of western North America have been declining since the early 1990's, making management of mule deer increasingly difficult. Limited research has examined the characteristics of mule deer habitat that influence feeding site selection in foothill and mountain rangeland habitats during the winter and spring. The purpose of the study was to develop and validate models that incorporate the effects of important habitat variables that influence feeding sites chosen by mule deer in the winter and spring, including aspect, distance to forested cover, distance to hiding cover, distance to agricultural fields, distance to improved roads, distance to ranch roads, elevation, previous cattle grazing, and slope. Data collected in northwestern Wyoming between the summer of 1999 and spring of 2001 were used for model development, and data collected between summer 2001 and spring 2003 were used for temporal validation. Additionally, data collected in west-central Montana between summer 2001 and spring 2003 were used for temporospatial validation. Logistic regression was used to develop models for the winter, spring, and winter-spring seasons. Akaike's Information Criterion was used to determine the best models for each season. Models were validated on both a temporal and temporospatial scale. Six habitat variables (distance to improved roads, distance to ranch roads, distance to security cover, aspect, slope, and previous summer's cattle grazing) were included in model development after collinearity tests. Four models had a model sensitivity $\geq$ 75% in both temporal and temporospatial validation. These models can be used to identify preferred mule deer feeding sites and assess potential impacts of land management practices on mule deer foraging habitat.

CHAPTER 1

INTRODUCTION

Rocky Mountain mule deer (*Odocoileus hemionus hemionus*) occupy vast amounts of habitat in the western United States (Cowan 1956). Rocky Mountain mule deer occur in numerous vegetation types, from tallgrass prairies on the eastern side of their range, westward across shortgrass plains and all shrublands, woodlands, and forest types of the Rocky Mountain region, to desert scrub of the Great Basin, and have the largest home range of any subspecies of mule deer (Wallmo 1981). Foothill and mountain rangelands may provide the most diverse and stable mule deer habitats (Mackie 1983; Peek and Krausman 1996). Foothill and mountain rangelands are not only diverse in topography, but can support many different vegetative communities.

Physical habitat characteristics play an important role in mule deer feeding site selection (Johnson et al. 2000). Various physical attributes of the landscape interact to make portions of the habitat more appealing than others to mule deer for feeding, and physical habitat characteristics have different seasonal effects on feeding site selection. Mule deer prefer southerly aspects in the winter and early spring (Mackie 1970). Use of steeper slopes and higher elevations by mule deer increases in late spring and summer (Julander and Jeffery 1964). Mule deer migrate in the spring and fall annually (Thomas and Irby 1990) and mule deer migration is typically driven by changes in the vegetation. Thomas and Irby (1990) stated that mule deer begin to migrate to higher elevations as the snow clears and vegetation begins to green up. Mule deer typically migrate to high elevation, north-facing slopes in the

summer (Nicholson et al. 1997) in search of forage. Mule deer dietary preference is also seasonally dependent. Mule deer winter diets are typically over 90% browse, while spring and summer diets are nearly 70% grass and forbs (Carpenter et al. 1979; Beck and Peek 2005; Torstenson et al. 2006). Optimal foraging areas for mule deer are no more than 125 m from security cover's edge (Leckenby et al. 1982) because at less than 125 from security cover, mule deer have adequate time to evade predators.

Human influences on the landscape play a major role in mule deer distribution and feeding site selection. Agricultural fields receive highest amounts of use by mule deer in the early spring and fall (Selting and Irby 1997). Agricultural fields, such as alfalfa (*Medicago sativa* L.) hay fields, are some of the first areas to green up in the spring and usually stay green for much longer than the surrounding native vegetation in the fall, which can provide a palatable and nutritious forage resource for mule deer in both the early spring and fall. Roads also influence mule deer distribution and feeding site selection. Mule deer are three times as likely to be found at distances 300 m from well-traveled roads, such as highways, as distances less than 100 m (Rost and Bailey 1979). In spring, mule deer are attracted to sites where cattle have grazed moderately during the previous fall (Willms et al. 1979).

One way to assimilate factors that influence mule deer feeding site selection is through habitat modeling. Habitat selection models can be a very powerful tool to explain habitat use by wildlife (Rotenberry et al. 2006). Feeding site selection models can explore how multiple habitat variables interact to influence a species like mule deer to select one area over another for foraging. Models can be used to make critical management decisions to conserve habitat for wildlife species. The objective of my research was to develop predictive

models that might identify preferred mule deer foraging sites and enable resource managers to assess potential impacts of land management practices on mule deer foraging habitat.

CHAPTER 2

LITERATURE REVIEW

Mule Deer History and Distribution

Mule deer (*Odocoileus hemionus*) have been found in 18 U.S. states, 5 Canadian provinces, and 6 Mexican states (Wallmo 1981). Nine subspecies of mule deer are known to exist, including Rocky Mountain mule deer (*Odocoileus hemoinus hemionus*) (Rafinesque), California mule deer (*Odocoileus hemoinus californicus*) (Caton), southern mule deer (*Odocoileus hemoinus fuliginatus*) (Cowan), peninsula mule deer (*Odocoileus hemoinus peninsulae*) (Lydekker), Tiburon Island mule deer (*Odocoileus hemoinus sheldoni*) (Goldman), desert mule deer (*Odocoileus hemoinus crooki*) (Mearns), Cedros Island deer (*Odocoileus hemoinus cerrosensis*) (Merriam), Columbian black-tailed deer or coast deer (*Odocoileus hemoinus columbianus*) (Richardson), and Sitka deer (*Odocoileus hemoinus sitkensis*) (Merriam).

Rocky Mountain mule deer have the widest distribution of any subspecies of large game animals in North America (Cowan 1956). Cowan (1956) noted that Rocky Mountain mule deer range from as far south as central Arizona and New Mexico and as far north as southern portions of the Northwest Territories. Mule deer include a wide variety of habitats in their natural range (Peek and Krausman 1996). Foothill and mountain habitats containing topographical variation, wide distribution along an elevation gradient, and a variety of plant communities ranging from riparian zones through shrub-grasslands to timbered slopes may

provide adaquate Rocky Mountain mule deer habitats (Mackie 1983; Peek and Krausman 1996).

Mule deer occupy variable environments, and their population numbers may fluctuate in response to a variety of different factors (Unsworth et al. 1999; Bishop et al. 2005). Unsworth et al. (1999) stated that factors ranging from weather, predation, or hunting pressure, to population density, habitat loss, or interspecfic competition can lead to mule deer population declines. The mule deer population in the western U.S. has fluctuated extensively over the past 45 years, declining in the 1960's and 1970's, increasing in the 1980's, and then decreasing again during the 1990's (Peek and Krausman 1996; Clements and Young 1997). Most recent studies have shown that the main driver in mule deer decline has been loss of critical habitat and critical plant species such as antelope bitterbrush (*Purshia tridentata* (Pursh) DC.) (Guethner et al. 1993; Clements and Young 1997).

Habitat Variables Influencing Mule Deer Habitat Selection

Aspect, Slope, and Elevation

Mule deer prefer southerly aspects in winter and early spring in Montana (Mackie 1970). In a study conducted in the Blue Mountains of Oregon, mule deer selected areas of easterly aspect during the spring (Johnson et al. 2000). Mule deer feeding sites showed seasonal preference for aspect in a similar study also done in Oregon (Ager et al. 2003). Ager et al. (2003) found that mule deer used habitats with southern aspects during the winter while they used habitat with eastern aspects during the spring and summer. Sun exposure and vegetation present can make south-facing slopes ideal winter habitat for mule deer

(Olson 1992). South-facing slopes are typically dominated by shrubs (Oedekoven and Lindzey 1987), and large shrubs such as sagebrush provide mule deer with adequate thermal cover and preferred forage in the winter months (Wambolt and McNeal 1987). Lack of snow on south-facing slopes influenced mule deer to select foraging sites on these slopes during the winter in Colorado (Gilbert et al. 1970). Mule deer were found to migrate to higher elevation, north-facing slopes during the summer months in northern California (Nicholson et al. 1997).

Mule deer use of steep or gentle slopes cycles seasonally (Nicholson et al. 1997). Mule deer forage in more open grasslands with gentler slopes in the early spring and migrate to steeper timbered habitats in the summer and fall (Sheehy and Varva 1996). Mule deer made more use of steep slopes than more gentle slopes in summer and fall in Utah (Julander and Jeffery 1964). Mule deer use of slopes 0-10% was greatest in spring, while use of slopes 26-35% was greatest in summer in eastern Montana (Mackie 1970).

Mule deer prefer low elevations during winter (Lovass 1958). Mule deer use of low elevation range was correlated with abundant, available browse and good hiding cover in northern California (Loft et al. 1987; Boroski et al. 1996). Mule deer tend to migrate from low elevation winter ranges to higher elevation summer ranges (Thomas and Irby 1990). The attractiveness of new grass growth on lower slopes and snow at higher elevations is sufficient enough to cause mule deer to migrate to lower elevation winter ranges (Willms et al. 1976). Mule deer migrate during the summer to avoid heat, while winter migration is to avoid deep snow (Willms et al. 1976). Prevalence of late fall-early winter storms is a major influence of

mule deer migration to lower elevation range (Loft et al. 1984). Seasonal forage use by mule deer corresponds with elevation changes in preferred habitat (Hill 1956).

Distance to Thermal Cover, Security Cover, and Agricultural Fields

The availability of thermal cover determines the adequacy of mule deer winter range (Wood 1988). Canopy cover of trees and shrubs assists deer in minimizing energy expenditure for thermoregulation by creating a buffer to extreme weather conditions (Peek et al. 1982; Loft et al. 1987). Many species of shrubs, such as bitterbrush (*Purshia tridentata*), can serve both as a winter forage source and thermal cover (Guethner et al. 1993). Deer exhibit high use of forested cover types during the summer for thermal cover (Ager et al. 2003).

Optimum security cover (i.e., hiding cover) for mule deer is at least 60 cm tall and is capable of hiding 90% of a bedded deer (Leckenby et al. 1982). Leckenby et al. (1982) also found that mule deer generally do not fully utilize forage areas that are more than 125 m from security cover which helps mule deer conserve energy (Terrel 1973; Leckenby et al. 1982). Optimum distribution of security cover for mule deer within a habitat consists of continuous, interconnecting zones and scattered patches of shrubs and trees (Leckenby et al. 1982). Closed canopy cover types are important for mule deer during hunting seasons for security cover (Nyberg 1980).

Use of agricultural fields by mule deer occurs predominately in early spring and mid-fall (Selting and Irby 1997). Selting and Irby (1997) also noted that mule deer use of agricultural fields, namely alfalfa, is proportional to the amount of security cover in the area, meaning that the more structural cover (trees, shrubs) there was present near alfalfa fields,

the more likely mule deer are to use them. Alfalfa comprised 21% of mule deer diets in the fall in Wyoming (Torstenson et al. 2006). Mule deer use of alfalfa increased in the fall as the surrounding vegetation matured in northern Montana (Martinka 1968). Mule deer consume alfalfa in spring, summer, and fall, but highest uses of alfalfa were seen in the fall and spring in northern Montana (Martinka 1968) and winter-spring in northwestern Wyoming (Torstenson et al. 2006).

Distance to Roads

Mule deer avoid roads, especially in shrublands (Rost and Bailey 1979). Rost and Bailey (1979) found that deer densities averaged 3.2 times greater 300-400 m from well-traveled roads than in areas within 100 m of roads. Pellet group concentrations for mule deer increased as distance from well traveled roads increased in Washington, and the effect was more pronounced for roads with more traffic (Perry and Overly 1977). Mule deer select areas closer to roads with medium to no traffic, but avoid roads with heavy traffic in Oregon (Johnson et al. 2000). Mule deer use areas close to open roads during the late evening and early morning hours, but select areas away from open roads after sunrise (Ager et al. 2003). Ager et al. (2003) found no seasonal effect of proximity to roads on mule deer habitat selection in Oregon. Rost and Bailey (1979) found a trend indicating greater avoidance by mule deer for paved roads than for gravel or dirt roads.

Previous Cattle Utilization

Mule deer select spring foraging areas moderately grazed (58% utilization) by cattle the previous fall (Willms et al. 1979). Willms et al. (1981) found that mule deer in British

Columbia select bluebunch wheatgrass (*Pseudoroegneria spicata* (Pursh) Scribn.) tillers in April following grazing by cattle the previous fall, but will not select forage among standing litter of bluebunch wheatgrass when alternative forage is available (Willms et al. 1981). Fall grazing by cattle (50% or greater utilization) may remove standing dead material, which allows mule deer easier access to live vegetation the following year (Taylor et al. 2004). Short and Knight (2003) found that intensive fall cattle grazing (50-90% utilization) can be a useful tool to enhance herbaceous forage production for big game in the spring and summer. No published studies have examined effects of summer cattle grazing on mule deer habitat use in winter and spring.

Habitat Selection Models

Geographic Information System (GIS) tools and applications are becoming more popular among resource managers for amassing information and modeling potential effects (Clevenger et al. 2002). Clevenger et al. (2002) showed how modeling habitat with GIS can be a means of determining the optimal placement of such things as wildlife crossing structures. Using GIS technology can be an adequate and simple way to map and characterize potential habitat for wildlife (Herr and Queen 1993). The ability to model wildlife habitat depends on the type of data, modeling techniques, and sensitivity analysis (Herr and Queen 1993). GIS is an effective way to monitor population distributions and trends, and to understand factors that influence these trends (Apps et al. 2004). Digital environmental layers such as slope, elevation, aspect, and land use may be incorporated into models using GIS (Rotenberry et al. 2006).

Akaike's Information Criterion (AIC) is an information theory-based algorithm used as a model selection criterion (Burnham and Anderson 2002). AIC can be a useful tool for model selection with wildlife habitat selection models (Driscoll et al. 2005), and many wildlife habitat selection studies have incorporated AIC techniques (Irby et al. 2002; Diefenbach et al. 2004; Glenn et al. 2004; Clark et al. 2005; Duff and Morrell 2007). AIC allows formal inference to be based on more than one model and these procedures can lead to more robust inferences (Burnham and Anderson 2002). Burnham and Anderson (2002) also state that AIC provides a simple, effective, and objective means for the selection of estimated "best approximate models".

Many wildlife studies have used AIC to successfully develop habitat models. For example, Irby et al. (2002) evaluated a forage allocation model for four species of herbivores in Theodore Roosevelt National Park in North Dakota. The model was sensitive to light precipitation, so they recommended rechecking optimal herbivore numbers on a regular basis. Clark et al. (2005) examined black bear population dynamics within Great Smoky Mountains National Park. Their model was able to accurately predict reproductive successes and failures, as well as the success of the yearling recruits the following year. They recommended that their technique be used to measure changes in long-term bear populations rather than for year-to-year estimations. Duff and Morrell (2007) developed a predictive occurrence model for bat species in California. Through their multiple models, they were able to find specific habitat characteristics that were important to each bat species they evaluated. They recommended that by using their occurrence models, managers could make more successful population samples for certain species of bats.

Ecological modelers are faced with several challenges when attempting to produce useful predictive models (Rotenberry et al. 2006). Habitat selection models are often produced with abundance, density, or presence-absence data (Rotenberry et al. 2006). Creation of models over large landscapes generally requires multiple sources of data collected with variable survey methods (Ciarniello et al. 2006). Predicting a species' occurrence outside of an original study area may be difficult (Rotenberry et al. 2006). The development of regional models that predict habitat suitability can serve as templates for wildlife management (Mackenzie 2006; Rottenberry et al. 2006). Model success and performance is heavily dependent on consistencies in data (White and Lubow 2002). White and Lubow (2002) cautioned that modeling techniques should be specific to the type of data obtained and when used incorrectly, modeling techniques will give unsatisfactory results.

Existing Mule Deer Habitat Selection Models

Three models that examine Rocky Mountain mule deer habitat selection exist for foothill and mountain rangelands (Johnson et al. 2000; Stewart et al. 2002; Ager et al. 2003). Johnson et al. (2000) examined resource selection by mule deer in late spring and early summer (April-June). They found that mule deer selected steep slopes, areas close to roads, and easterly slopes. Stewart et al. (2002) modeled mule deer habitat use from mid-June through October. They found that mule deer selected low elevations and gentle slopes in the summer-early fall. Mule deer also selected areas close to water (< 3 miles). Ager et al. (2003) examined daily and seasonal movements of mule deer from mid-April through November. They found that mule deer generally used habitats with high security cover, easterly aspects, and near open roads. All three studies were conducted on the U.S. Forest

Service Starkey Experimental Forest and Range in northeastern Oregon. None of these studies specifically examined feeding site selection of mule deer in the winter and early spring (December-May).

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CHAPTER 3

DEVELOPMENT AND VALIDATION OF FEEDING SITE SELECTION MODELS FOR MULE DEER IN FOOTHILL AND MOUNTAIN RANGELAND HABITATS

Introduction

Numerous habitat variables influence Rocky Mountain mule deer feeding site selection in winter and spring. Mule deer prefer southerly aspects during the winter (Mackie 1970) and southeasterly aspects during the spring (Johnson et al. 2000). Mule deer typically use low elevation ranges with gentle slopes in the winter and migrate to high elevation ranges in the summer (Julander and Jeffery 1964; Nicholson et al. 1997). Low elevation range has been associated with abundant browse and hiding cover for mule deer in the winter (Loft et al. 1987). Mule deer densities have been found to be 3.2 times greater 400 m from well-traveled roads than at 100 m from roads (Rost and Bailey 1979). Other factors, including slope (Julander and Jeffery 1964; Nicholson et al. 1997), thermal and security cover availability (Wallmo 1981; Loft et al. 1987), and previous cattle grazing (Willms et al. 1979; Willms 1981) have also been documented to influence mule deer feeding site selection.

Seasonal mule deer habitat selection has been assessed in various habitats (Boroski et al. 1996; Johnson et al. 2000; Stewart et al. 2002). Boroski et al. (1996) developed a habitat suitability model for mule deer that was specific to northern California. Johnson et al. (2000), Stewart et al. (2002), and Ager et al. (2003) developed resource selection models for mule deer in foothill and mountain rangeland. However, Johnson et al. (2000) examined mule deer resource selection in late spring, Stewart et al. (2002) investigated habitat use of

mule deer from late spring to mid fall, and Stewart et al. (2003) studied mule deer habitat use in the summer and fall.

A desirable feeding site selection model would have the ability to be used over multiple areas on the landscape and multiple locations. A good model is able to accurately classify 60% of feeding sites on a landscape and an excellent model can classify 75% or greater (Burnham and Anderson 2002). Many different factors affect mule deer within different types of habitat (i.e., topography, climate, vegetation), making it complicated to develop a model that incorporates multiple habitats (Ager et al. 2003). Identifying critical habitat variables that influence feeding site selection of mule deer in winter and spring and the development of a mule deer feeding site selection model within foothill and mountain rangeland habitat may be useful for wildlife and land managers because of the high occurrence of mule deer in these habitats. Therefore, the objectives of my study are to: 1) develop feeding site selection models for mule deer in the winter, spring, and winter-spring for foothill and mountain rangeland habitats, 2) validate the models spatially, and 3) validate the models temporospatially.

Materials and Methods

Study Area

The study area for this research consisted of three study sites on two cattle ranches in northwestern Wyoming and two study sites on one cattle ranch in west-central Montana. In Wyoming, the Diamond Bar study site was approximately 8,000 ha in size, the Rattlesnake study site was approximately 24,000 ha, and the Rock Creek study site was approximately 11,000 ha. These study sites are located 50 km southwest, 19 km northwest, and 60 km

southwest of Cody, Wyoming, respectively. In Montana, the Lingshire study site was approximately 13,500 ha and the Birch Creek study site was approximately 8,000 ha. These study sites are located approximately 72 km northwest and 12 km west of White Sulphur Springs, Montana, respectively. Each study site was considered an independent unit, each with a geographically distinct mule deer population.

Study area topography ranged from low elevation plains and rolling foothills to subtending rock outcrops and steep mountains at higher elevations. Elevations ranged from 1,650 to 3,700 m on the Wyoming sites and from 1,280 to 2,600 m on the Montana study sites. Mean annual precipitation in Wyoming averaged 28 cm, and averaged 37 cm on the Montana sites (Western Regional Climate Center 2003). This study focused exclusively on non-forested, foothill and mountain rangeland in the Absaroka Mountains of Wyoming and Big Belt Mountains of Montana. Forested plant communities are quite common throughout the study area, however, non-forested habitat provides most foraging opportunities for mule deer in the winter and spring (Constan 1972). Non-forested areas on the Wyoming and Montana study sites, which were dominated by sagebrush grassland and mountain grassland communities, were 30,180 and 28,860 ha, respectively.

Major plant species present within the sagebrush grassland communities were Sandberg bluegrass (*Poa secunda* Presl.), Idaho fescue (*Festuca idahoensis* Elmer), bluebunch wheatgrass (*Pseudoroegneria spicata* (Pursh) Scribn.), Wyoming big sagebrush (*Artemisia tridentata* ssp. *wyomingensis* Beetle), mountain big sagebrush (*Artemisia tridentata* ssp. *vaseyana* Beetle), Hood's phlox (*Phlox hoodii* Richardson), western yarrow (*Achillea millefolium* L.), and rose pussy-toes (*Antennaria rosea* Greene). Major species

present in the mountain grassland communities included Idaho fescue, Sandberg bluegrass, timber oatgrass (*Danthonia intermedia* Vasey), Columbia needlegrass (*Achnatherum nelsonii* Scribn.), needleandthread (*Hesperostipa comata* Vasey), milkvetch (*Astragalus* spp. L), and lupine (*Lupinus* spp. Kell.).

The summer cattle grazing season was approximately from June 1 to October 1 each year on all study sites and moderate stocking rates were implemented with approximately 2.8 ha/AUM (Animal Unit Month) across the Wyoming study sites and approximately 1.8 ha/AUM across the Montana study sites. Cattle were cow/calf pairs and a rotational grazing system was implemented throughout the grazing season. Mule deer, elk (*Cervus canadensis*), pronghorn antelope (*Antilocapra americana*), and white-tailed deer (*Odocoileus virginianus*) were present on all study sites throughout a majority of the year, however, large numbers of wild ungulates were present only during winter and spring.

Procedures

Habitat selection models based on biotic and abiotic habitat variables were developed to predict feeding site selection of mule deer during the winter (December-February), spring (March-May), and winter-spring (December-May) seasons on foothill and mountain rangeland. Models were developed from data obtained from the three Wyoming sites in Years 1 and 2 (1999-2000). These models were then temporally validated with data from the three Wyoming sites in Years 3 and 4 (2001-2002) and temporospatially validated with data from the two Montana sites in Years 3 and 4.

Nine habitat variables were identified from the research literature that influence mule deer feeding site selection and all were included in the initial analysis. Variables chosen for

inclusion in the analysis included aspect (Mackie 1970; Ager et al. 2003), distance to forested cover (25-39% forested cover) (Loft et al. 1987), distance to security cover (≥ 40% forested cover) (Leckenby et al. 1982; Peek 1982), distance to agricultural fields (Selting and Irby 1997), distance to ranch roads (Perry and Overly 1977), distance to improved roads (Rost and Bailey 1979), elevation (Hill 1956; Lovaas 1958), percent slope (Julander and Jeffery 1964; Nicholson et al. 1997), and level of previous summer's cattle utilization (Willms et al. 1979; Willms et al. 1981).

For model development, 100 random points were generated for each of the three Wyoming study sites in Years 1 and 2 (n=600) following the protocol described by Edge et al. (1988). Random points were restricted to non-forested areas of the study site and to ensure independence, random points were restricted from being located < 60 m from each other. Aspect, elevation, distance to forested cover, distance to hiding cover, distance to agricultural fields, distance to ranch roads, distance to improved roads, previous cattle utilization, and slope were then characterized for each random point with a Geographic Information System (GIS).

Mule deer feeding sites were identified with aerial flights administered once monthly from December through May in Years 1 and 2 in Wyoming and bi-monthly from December to May in Years 3 and 4 in Wyoming and Montana. Flight transects were 0.8 km-wide and flown approximately 150 m above the ground. Flight crews included an experienced pilot and observer, both of whom assisted in observing mule deer and documenting locations. An occurrence of mule deer was considered an observation when a group of ≥ 2 mule deer were seen feeding. Mule deer observations were then marked using a Global Positioning System

(GPS). Aerial surveys encompassed all non-forested habitats. Study sites within each state were surveyed consecutively on the same day to avoid double counting groups of animals (Unsworth et al. 1990). Aerial surveys were initiated at sunrise and averaged 3 hours in length because a majority of mule deer feeding occurs during the dawn hours (Kie 1996). Mule deer feeding site locations were characterized with the same habitat variables as the random points using GIS.

A systematic inventory was conducted to describe the level of cattle grazing utilization after the summer cattle grazing season ended each year (Anderson and Currie 1973). Cattle grazing utilization was inventoried in October via horseback and all-terrain vehicle, and utilization was characterized as heavy (> 60% utilization), moderate (31-60% utilization), light (11-30% utilization) and none (≤ 10% utilization) using landscape appearance guidelines presented in USDA-USDI (1996).

Experimental Design and Data Analyses

Mule deer feeding site observations and random point locations were replicated on 3 sites (Rattlesnake, Rock Creek, and Diamond Bar) in a completely randomized design for model development. Data from the three Wyoming study sites in Years 1 and 2 were used for model development. Mule deer feeding site observations were replicated on 2 sites (Birch Creek and Lingshire) in Montana and the 3 sites in Wyoming for model validation. Data from the three sites in Wyoming in Years 3 and 4 and data from the two Montana sites in Years 3 and 4 were used for temporal and temporospatial model validation, respectively.

Model Development Random points and mule deer feeding site data were first tested for outliers using a univariate procedure in SAS (PROC UNIVARIATE) (SAS 2003) in the winter, spring, and winter-spring seasons. If a particular observation was suspected of being an outlier, it was then analyzed with Grubb's test (Jones et al. 2001). Any observation found to be significant with a critical Z value of the Grubb's test ($P \leq 0.05$) was removed from the data set.

To evaluate potential dependence among variables, all habitat variables were tested for collinearity using Spearman's Rank Correlation with the correlation procedure of SAS (PROC CORR) (SAS 2003). Data from each season was tested independently. If significant ($P \geq 0.05$) correlation was detected between a pair of variables with $|r| > 0.7$ (Green 1979; Fielding and Haworth 1995), the variable deemed to biologically contribute the most to predicting mule deer feeding site selection or the one correlated with fewer variables was retained. The other variable in the pair was eliminated from the analyses.

Once the final data sets were obtained, all possible model combinations were analyzed with logistic regression using the logistic procedure of SAS (PROC LOGISTIC) (SAS 2003) to obtain a set of candidate models (Hosmer and Lemeshow 2000). Candidate model sets were developed using the random and observed points of the development data set obtained from the Wyoming sites in Years 1 and 2. Three sets of candidate models (winter, spring, winter-spring) were obtained from logistic regression. For the categorical variable of cattle utilization, ungrazed sites comprised the reference category.

Akaike's Information Criterion (AIC) was used to assess the relative fit of each model and to choose the "competing models" from each set of candidate models (Burnham

and Anderson 2002). The model with smallest AIC value was considered the "best" model for a particular set and a Δ AIC (Δ_i) was calculated for each of the other candidate models in relation to the AIC value of the "best" model (Burnham and Anderson 2002). All candidate models with a $\Delta_i \leq 2$ were included in the set of competing models (Burnham and Anderson 2002). Akaike weights (w_i) were calculated for all models within each set of competing models to determine the normalized relative likelihoods for the set of models. Akaike weights give the probability estimate for each model that it is the best model for the set (Burnham and Anderson 2002). The resultant set of models for each season included all competing models. The exponential format ($e^{(n1x + n2y + n3z)}$) was used because the logistic regression models contrasted mule deer feeding sites versus random sites, rather than feeding sites versus non-feeding sites (Manly et al. 2002).

In order to validate the competing models and the composite model, a Youden Index (*J*) was calculated to determine an optimal cutpoint for each model obtained in the model development stage. *J* is a measure of a model's sensitivity (number of feeding sites correctly classified as feeding sites ÷ total number of feeding sites) versus specificity (number of random sites correctly classified as random sites ÷ total number of random sites), and is calculated as (sensitivity – specificity) + 1. The optimal cut point for a model is defined as the point at which *J* has the greatest value. Both random points and observed points from Years 1 and 2 were used to determine the optimal cut point for each model.

<u>Model Validation</u> Each competing model was validated using the optimal cut point identified for that model in the model development stage. Models were temporally validated using mule deer feeding site locations from the three Wyoming sites in Years 3 and 4.

Temporospatial validation was completed using mule deer feeding site locations from the two Montana study sites in Years 3 and 4. Models with ≥ 75% sensitivity in both temporal and temporospatial validation were considered the best models.

Results

Mule Deer Feeding Site Observations

In Years 1 and 2, 424 mule deer feeding site locations were recorded across all three Wyoming study sites, with 156 mule deer observations recorded in winter (December-February) and 268 recorded in spring (March-May). In Years 3 and 4, 640 mule deer feeding site locations were recorded from the three Wyoming sites and 207 mule deer feeding site observations were recorded from the two Montana study sites. In Years 3 and 4, in Wyoming 299 mule deer feeding site observations were recorded during the winter and 356 mule deer feeding site observations were recorded in the spring, while in Montana, 41 observations were recorded during the winter and 166 observations were recorded during the spring. Means and ranges for the feeding site variables from the development data (Wyoming Years 1 and 2) are shown in Table 1. Proportions of the study area and mule deer feeding sites associated with each level of cattle grazing utilization are presented in Table 2.

Table 1. Mean values and ranges for variables associated with mule deer feeding sites used in model development (Wyoming Years 1 & 2).

Variable	Mean	Range
Distance to Security Cover (m)	1160	3 – 3,621
Distance to Forested Cover (m)	774	2 – 2,597
Distance to Improved Roads (m)	2510	19 – 11,109
Distance to Ranch Roads (m)	1149	2 – 6,825
Distance to Agricultural Fields (m)	3166	0.0 – 11,100
Elevation (m)	2068	1739 – 2865
Slope (%)	24	0 – 77
Aspect (°)	154	0 – 359

Variable Selection

Three habitat variables were found to be highly correlated through Spearman's Rank Correlation. Elevation, distance to agricultural fields, and distance to forested cover were correlated with multiple variables in all three seasons and subsequently removed from analyses. Models were developed with the remaining eight habitat variables: aspect, distance to improved roads, distance to ranch roads, distance to security cover, previous summer's cattle utilization (light, moderate, heavy), and slope.

Model Development

Three sets of competing models (winter, spring, winter-spring) were obtained from logistic regression. Eight models had a $\Delta AIC \leq 2$ in winter and were included in the winter competing model set (Table 3). Distance to improved roads and aspect were found in all of the competing models in the winter season. Distance to security cover, distance to ranch roads, and slope were found in four of the eight competing models, while cattle utilization

Table 2. Proportion of the study area and mule deer feeding sites associated with each level of cattle grazing utilization.

Previous Summer Cattle Grazing Intensity	Season	Site					
		WY Years 1 and 2		WY Years 3 and 4		MT Years 3 and 4	
		Area	Feeding Sites	Area	Feeding Sites	Area	Feeding Sites
		(%)					
Ungrazed	Winter	67	67	66	70	78	98
	Spring	65	66	70	69	86	87
	Winter-Spring	65	66	68	70	82	89
Light	Winter	12	15	15	12	8	2
	Spring	18	9	14	14	4	4
	Winter-Spring	15	11	14	13	6	4
Moderate	Winter	19	17	18	17	12	0
	Spring	16	23	16	15	9	7
	Winter-Spring	18	21	17	16	10	6
Heavy	Winter	2	1	1	1	2	0
	Spring	1	2	0	2	1	2
	Winter-Spring	2	2	1	1	2	1

Table 3. Competing models for winter, spring, and winter-spring.

Season	Model	Δ AIC	w_i	Model Sensitivity
Winter	IR[1], A[2]	0	0.158	70%
	IR, A, SC[3]	0.113	0.149	59%
	IR, A, S[4]	0.277	0.137	62%
	IR, A, SC, S	0.394	0.129	53%
	IR, A, RR[5]	0.404	0.129	64%
	IR, A, SC, RR	0.559	0.119	57%
	IR, A, S, RR	1.092	0.091	66%
	IR, SC, S, RR	1.245	0.084	56%
Spring	IR, A, SC, S, GC[6]	0	0.148	61%
	IR, A, SC,RR, CG	0.04	0.1458	59%
	IR, A, S, CG	0.146	0.138	61%
	IR, A, SC, CG	0.399	0.121	58%
	IR, A, S, RR, CG	0.655	0.107	60%
	IR, A, RR, CG	0.992	0.090	64%
	IR, A, CG	1.448	0.072	51%
	IR, S, CG	1.938	0.056	48%
Winter-Spring	IR, A, S, RR	0	0.235	66%
	IR, A, S, RR, CG	0.013	0.234	56%
	IR, A, S, CG	1.068	0.138	60%
	IR, A, S	1.616	0.105	61%
	IR, A, RR, CG	1.642	0.103	68%
	IR, A, RR	1.818	0.095	65%
	IR, A, SC, S, RR	1.978	0.087	66%

[1]IR = Distance to improved roads
[2]A = Aspect
[3]SC = Distance to security cover
[4]S = Slope
[5]RR = Distance to ranch roads
[6]CG = Cattle grazing utilization in previous summer

was not found in any of the eight competing models in winter. Five of the eight competing models in winter were considered "good" with a model sensitivity ≥ 60%.

Eight models had a ΔAIC ≤ 2 in spring and were included in the spring competing model set (Table 3). Distance to improved roads and cattle utilization were found in all eight competing models for the spring season, while aspect was found in seven of the eight competing models. Slope appeared in four of the competing models in the spring season. Distance to security cover and distance to ranch roads were found in three of the eight models in the spring season. Five of the eight competing models in spring were considered "good" with model sensitivities ≥ 60%.

Seven models had a ΔAIC ≤ 2 in the winter-spring season and were included in the winter-spring competing model set (Table 3). Distance to improved roads and aspect were found in all seven competing models for the winter-spring season. Distance to ranch roads and slope were found in five of the seven competing models. Cattle utilization was found in three competing models while distance to security cover was found in only one competing model for the winter-spring season. All seven of the competing models in winter-spring had ≥ 60% sensitivity.

Model Validation

Only one winter model had ≥ 75% sensitivity in both the temporal and temporospatial validation stages. The best winter model, comprised of distance to improved roads and aspect, had a temporal model sensitivity of 76% and a temporospatial model sensitivity of 83% (Table 4). The best spring model, comprised of distance to improved roads, aspect, slope and previous summer's cattle utilization, had a temporal model sensitivity of 83% and

Table 4. Temporal and temporospatial validation model sensitivities for competing models for winter, spring, and winter-spring.

Season	Model	Temporal Validation	Temporospatial Validation
		----------%----------	
Winter	IR[1], A[2]	76	83
	IR, A, SC[3]	65	44
	IR, A, S[4]	43	46
	IR, A, SC, S	63	46
	IR, A, RR[5]	68	70
	IR, A, SC, RR	64	46
	IR, A, S, RR	71	83
	IR, SC, S, RR	63	54
Spring	IR, A, SC, S, CG[6]	73	73
	IR, A, SC, RR, CG	70	66
	IR, A, S, CG	83	82
	IR, A, SC, CG	69	70
	IR, A, S, RR, CG	72	81
	IR, A, RR, CG	76	74
	IR, A, CG	63	52
	IR, S, CG	61	52
Winter-Spring	IR, A, S, RR	77	77
	IR, A, S, RR, CG	68	67
	IR, A, S, CG	70	73
	IR, A, S	72	74
	IR, A, RR, CG	78	76
	IR, A, RR	78	74
	IR, A, SC, S, RR	57	77

[1]IR = Distance to improved roads
[2]A = Aspect
[3]SC = Distance to security cover
[4]S = Slope
[5]RR = Distance to ranch roads
[6]CG = Cattle grazing utilization in previous summer

a temporospatial model sensitivity of 82% (Table 4). One winter-spring model, which contained distance to improved roads, distance to ranch roads, slope and aspect, had both temporal and temporospatial model sensitivities of 77% (Table 4). The other best winter-spring model, which contained previous summer's cattle utilization, distance to improved roads, distance to ranch roads, and aspect, had a temporal model sensitivity of 78% and a temporospatial model sensitivity of 76% (Table 4). The resource selection functions for the best predictive models for winter, spring, and winter-spring are provided in Table 5.

Discussion

Model sensitivity greater than 60% indicates a good fit model (Burnham and Anderson 2002). Models with sensitivities that are ≥ 75% are considered excellent models. In each season (winter, spring, winter-spring), at least one model had both temporal and temporospatial validation sensitivities greater than 75%. These models appear useful for predicting mule deer feeding site selection on foothill and mountain rangeland in the Northern Rocky Mountain region.

Aspect was a strong predictor of mule deer feeding site selection in winter and spring, with mule deer selecting southerly aspects. Similar results have been reported from Colorado (Kufeld et al. 1988) and Montana (Mackie 1970; Wambolt and McNeal 1987; Guethner et al. 1987). In winter, snow depth is less on southern aspects, southern aspects receive more solar radiation, and southern aspects in the lower elevations of the northern Rocky Mountains are often dominated by shrubs such as big sagebrush (Oedekoven and Lindzey 1987). Big sagebrush provides mule deer with thermal cover and preferred forage in winter and early

Table 5. Resource selection functions for the best predictive models.

	Winter Model	Spring Model	Winter-Spring Models	
	IR[1], A[2]	IR, A, CG[3], RR[4], S[5]	IR, RR, S, A	IR, A, CG, RR
Optimal Cut point	0.34	0.44	0.39	0.40
Variable:				
Heavy Utilization	0	0.0789	0	-0.0582
Moderate Utilization	0	0.5027	0	0.2656
Light Utilization	0	-0.5542	0	-0.3168
Distance to Security Cover	0	0	0	0
Distance to Improved Roads	-0.00019	-0.00024	-0.00015	-0.00017
Distance to Ranch Roads	0	0	-0.00011	-0.00012
Slope	0	-0.0105	-0.0085	0
Aspect	-0.5331	-0.2667	-0.3415	-0.3363

[1]IR = Distance to improved roads
[2]A = Aspect
[3]CG = Cattle grazing utilization in previous summer
[4]RR = Distance to ranch roads
[5]S = Slope

spring in the Northern Rockies (Wambolt and McNeal 1987; Guethner et al. 1993; Torstenson et al. 2006). In spring, snow recedes earlier from southern aspects, making graminoids more accessible (Olson 1992). Mule deer in the Northern Rocky Mountains consume graminoid-dominated diets in spring (Beck and Peek 2005; Torstenson et al. 2006).

Mule deer selected feeding sites that were closer to roads (improved roads and ranch roads) in both winter and spring. Similarly, Johnson et al. (2000) reported that mule deer in late spring-early summer selected sites closer to roads, provided vehicular traffic was not heavy. Roads in my study area did not receive heavy vehicular traffic, especially during the morning crepuscular period when mule deer feeding site locations were recorded. The main reason that mule deer feeding sites were closer to roads in my study may have been that hayfields were located near many of the roads. For example, in the development data from Years 1 and 2 in Wyoming, distance to improved roads and distance to ranch roads were highly correlated with distance to agricultural fields ($|r| = 0.89$ and $|r| = 0.71$, respectively). In a companion study on the Wyoming study area, Torstenson et al. (2006) found that alfalfa comprised 18% of mule deer diets in both winter and spring. Mule deer apparently selectively foraged in and near hayfields despite the proximity of these fields to roads. Selting and Irby (1997) also reported that mule deer selected agricultural fields in early spring.

Cattle grazing intensity in the previous summer did not affect mule deer feeding site selection during winter. In spring, however, previous summer's cattle grazing at moderate and heavy intensities (31-60% utilization and > 60% utilization, respectively) positively influenced mule deer feeding site selection, whereas mule deer avoided feeding where

previous summer's cattle utilization was light. One possibility for this is that areas grazed moderately to heavily the previous summer may contain graminoid forage that is more conditioned in the spring than those areas lightly grazed. Mule deer prefer graminoid species from April through mid-May (Beck and Peek 2005). With a lack of old growth grass from the prior year, heavily and moderately grazed sites offer readily available spring growth that is easily accessible to mule deer. Similar to my results, Willms et al. (1979) observed mule deer in spring grazing in fields that were moderately grazed by cattle the previous fall (58% utilization).

Mule deer in winter and spring selected more gentle slopes for foraging. Mackie (1970) and Sheehy and Vavra (1996) also found that mule deer selected gentle slopes in winter and spring, and mule deer did not begin migrating to steeper slopes until summer (Sheehy and Vavra 1996).

Distance to security cover was a modest predictor of mule deer feeding sites in my study. Although Leckenby et al. (1982) reported that mule deer do not fully utilize forage areas more than 125 m from cover, mule deer feeding sites in my Wyoming study area (Years 1 and 2) averaged 1,160 m from security cover (Table 1). Mule deer in my study area apparently were less constrained to select feeding sites close to security cover. I attribute this to the fact that rangelands, forests, and agricultural fields in my Wyoming and Montana study areas were predominately privately owned ranchlands, where human disturbance levels were low, especially during winter and spring.

Management Implications

Predictive models developed and validated in this study can be used by land managers and wildlife managers to identify preferred mule deer foraging habitat and examine how potential management actions might affect the distribution and abundance of mule deer feeding sites on foothill and mountain rangelands. For example, resource managers could examine the potential effects of opening or closing specific roads. Resource managers also could examine the potential effects of increasing cattle utilization from light to moderate in some portions of the landscape. My results indicate that the effects of summer cattle grazing on mule deer foraging habitat likely depend on the season of interest for mule deer and the intensity of summer cattle grazing. Mule deer in spring will favor feeding sites where cattle grazing utilization in the previous summer was moderate to heavy (not severe), mule deer will avoid foraging in spring where summer cattle grazing utilization was light, and mule deer feeding site selection in winter is unlikely to be positively or negatively affected by light, moderate, or heavy cattle grazing intensities during the previous summer.

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