A GIS-based approach to landscape habitat selection by bighorn sheep in the Missouri River Breaks, Montana
by Wayne Clayborne Hickey, III

A thesis submitted in partial fulfillment of the requirements for the degree of Masters of Science In Fish and Wildlife Management
Montana State University


Abstract:
Although reintroduction efforts for prairie/breaks bighorn sheep have met with limited success, the 1980 reintroduction of 28 RockyMountain bighorn sheep (Ovis canadensis canadensis) from the Sun River, Montana to the Stafford Ferry area of Fergus County appears to be successful while other nearby populations are stagnant or declining.

In an effort to find out why this population has been successful, 30 sheep where radio-collared in March 1998 and studied for 2 years. The objectives of this study were 2 fold: 1) to identify the distribution, movement patterns and estimate total numbers for the population on the north side of the river; and 2) to use a geographic information system (GIS) to develop a landscape level habitat selection model for the Missouri River Breaks. Ewes in the study population had mean home ranges of 4,265 ha, 5,416 ha, and 6,816 ha for winter, summer/spring, and fall, respectively, based on the 95% adaptive kernel method. Rams had mean home ranges of 11,751 ha, 13,610 ha, and 18,779 ha for winter, summer/spring, and fall, respectively. Overall, the radio-collared sheep showed no distinct seasonal home ranges and had an average of 75% overlap in individual seasonal home ranges. Estimates of total numbers of sheep within the study area varied from 326 to 403 individuals. I was unable to detect any population trends during the 2 years of my study. These estimates were too variable to tell if the population was growing, but total numbers counted indicated the population was stable during 1998 and 1999. My analysis of habitat selection was based on information from GIS data layers that provided slope, elevation, aspect, and type of vegetation at a 30 meter2 pixel resolution. I tested habitat selection at 4 separate scales: 0 (the individual pixel that contained the sheep location); 105m, 195m and 285m (dominant attributes encompassed in radius around the pixel that contained the sheep location). The habitat selection models at each of the 4 scales were investigated and compared using Akaike's information criteria (AIC). This allowed the models at different scales to be directly compared. All Models identified slope and cover type as being the most important variables for identifying use by bighorn sheep regardless of the scale. Estimates of coefficients for the individual cover types were too variable to put much faith in point estimates but did allow ranking of the relative importance of each cover type. Agricultural land was the least important cover type for bighorn sheep. Grassland, shrub, shrub-grass mosaic, and forest were all of the same importance, and all were used by sheep more than agricultural land. The cover type of water was more important in bighorn sheep selection than the previous variables. The most important cover type for bighorn sheep was the barren/badland cover type. The 285 m scale model had the lowest AIC scores, but the 195 m scale was selected as optimal because estimates of cover type coefficients were less variable. I concluded that the best habitat available for bighorn sheep in the study area were the steep badlands adjacent to the Missouri River with direct contact with native shrub and grasslands on the bench tops above slopes. However, this 2 variable model might be improved by the addition of other digital layers such as biomass estimates to improve predictions of sheep use within cover types. The effect of scale should be validated in other locations and habitat types. Delineation of this habitat complex at the 195-m scale was useful for eliminating patches of appropriate habitat that were too small for sheep to effectively

exploit.

# A GIS-Based Approach to Landscape Habitat Selection by Bighorn Sheep in the Missouri River Breaks, Montana.

By

Wayne Clayborne Hickey III

A thesis submitted in partial fulfillment

of the requirements for the degree

of

Masters of Science

In

Fish and Wildlife Management

MONTANA STATE UNIVERSITY-BOZEMAN
Bozeman, Montana

December 2000

APPROVAL

of a thesis submitted by

Wayne Clayborne Hickey III

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

Dr. Lynn Irby Lynn L. Irby 4 Dec 2000
(Signature) Date

Approved for the Department of Ecology

Dr. Jay J. Rotella Jay Rotella 12/4/00
(Signature) Date

Approved for the College of Graduate Studies

Dr. Bruce Mcleod Bruce R. McLeod 12-4-00
(Signature) Date

## STATEMENT OF PERMISSION TO USE

In presenting this thesis in partial fulfillment of the requirements for a Master's degree at Montana State University-Bozeman, I agree that the Library shall make it available to borrowers under the rules of the Library.

If I have indicated my intention to copyright this thesis by including a copyright notice page, copying is allowed only for scholarly purposes, consistent with "fair use" as prescribed in the U.S. Copyright law. Request for permission for extended quotation from or reproduction of this thesis in whole or in part may be granted only by the copyright holder.

Signature Wayne Clayborne Dickey III

Date 12/4/2006

## ACKNOWLEDGMENTS

I would like express my appreciation to the following individuals for their contributions to my study. First, I would like thank Dr. Lynn Irby for the supervision, technical support, and moral support he gave throughout this study. I would also like to thank Dr. Tom McMahon and Dr. Robert Garrott for their critical review of this thesis. I would also like to thank Al Rosgaard and Mark Sullivan of Montana Fish Wildlife and Parks for all their logistic support and other support throughout this study. I would also like to express my gratitude to Montana Fish Wildlife and Parks for funding this study. I would especially like to thank my wife Kim Hickey for all her support throughout all phases of this project.

# TABLE OF CONTENTS

TABLE OF CONTENTS—Continued

# LIST OF TABLES

LIST OF TABLES--CONTINUED

# LIST OF FIGURES

LIST OF FIGURES--CONTINUED

FIGURE PAGE

# ABSTRACT

Although reintroduction efforts for prairie/breaks bighorn sheep have met with limited success, the 1980 reintroduction of 28 Rocky Mountain bighorn sheep (*Ovis canadensis canadensis*) from the Sun River, Montana to the Stafford Ferry area of Fergus County appears to be successful while other nearby populations are stagnant or declining. In an effort to find out why this population has been successful, 30 sheep where radio-collared in March 1998 and studied for 2 years. The objectives of this study were 2 fold: 1) to identify the distribution, movement patterns and estimate total numbers for the population on the north side of the river; and 2) to use a geographic information system (GIS) to develop a landscape level habitat selection model for the Missouri River Breaks. Ewes in the study population had mean home ranges of 4,265 ha, 5,416 ha, and 6,816 ha for winter, summer/spring, and fall, respectively, based on the 95% adaptive kernel method. Rams had mean home ranges of 11,751 ha, 13,610 ha, and 18,779 ha for winter, summer/spring, and fall, respectively. Overall, the radio-collared sheep showed no distinct seasonal home ranges and had an average of 75% overlap in individual seasonal home ranges. Estimates of total numbers of sheep within the study area varied from 326 to 403 individuals. I was unable to detect any population trends during the 2 years of my study. These estimates were too variable to tell if the population was growing, but total numbers counted indicated the population was stable during 1998 and 1999. My analysis of habitat selection was based on information from GIS data layers that provided slope, elevation, aspect, and type of vegetation at a 30 meter$^2$ pixel resolution. I tested habitat selection at 4 separate scales: 0 (the individual pixel that contained the sheep location); 105m, 195m and 285m (dominant attributes encompassed in radius around the pixel that contained the sheep location). The habitat selection models at each of the 4 scales were investigated and compared using Akaike's information criteria (AIC). This allowed the models at different scales to be directly compared. All Models identified slope and cover type as being the most important variables for identifying use by bighorn sheep regardless of the scale. Estimates of coefficients for the individual cover types were too variable to put much faith in point estimates but did allow ranking of the relative importance of each cover type. Agricultural land was the least important cover type for bighorn sheep. Grassland, shrub, shrub-grass mosaic, and forest were all of the same importance, and all were used by sheep more than agricultural land. The cover type of water was more important in bighorn sheep selection than the previous variables. The most important cover type for bighorn sheep was the barren/badland cover type. The 285 m scale model had the lowest AIC scores, but the 195 m scale was selected as optimal because estimates of cover type coefficients were less variable. I concluded that the best habitat available for bighorn sheep in the study area were the steep badlands adjacent to the Missouri River with direct contact with native shrub and grasslands on the bench tops above slopes. However, this 2 variable model might be improved by the addition of other digital layers such as biomass estimates to improve predictions of sheep use within cover types. The effect of scale should be validated in other locations and habitat types. Delineation of this habitat complex at the 195-m scale was useful for eliminating patches of appropriate habitat that were too small for sheep to effectively exploit.

# INTRODUCTION

Bighorn sheep have a historic range that extends from southern British Columbia and Alberta to Mexico. In the 1700's, the total bighorn sheep population in North America may have been as high as 2 million sheep (Buechner 1960). By the early 1900's, sheep numbers had declined to approximately 20,000 over the same range. When Lewis and Clark first explored the Missouri River, they observed populations of sheep in prairies and breaks in what is now Montana (Buechner 1960). These sheep were later classified as *Ovis canadensis auduboni* or Audubon's bighorn sheep. This sub-species was driven to extinction in the early 1900's by over-hunting, disease, and competition from domestic livestock (Geist 1971). The decline in populations in the Missouri Breaks may have largely been due to anthrax introduced by domestic sheep in 1885 (Grinnell 1904:287 cited in Buechner 1960): "By 1897, no sheep remained in the Little Rocky, Bearpaw, Little Belt, Judith, Highwood, or Castle Mountains, according to L. V. Pirsson of Yale University" (Buechner 1960).

Currently, Montana has a total of 42 populations of Rocky Mountain bighorn sheep (Erickson 1999). Of these 42 populations, 39 are located in mountainous areas that vary from alpine to low montane environments. Sixteen of the 42 populations are native and the remaining are transplanted populations (Erickson 1999). Of the 16 native populations, 6 have required supplementation by transplants to remain viable.

Management agencies began using translocations to return bighorn sheep to parts of their historic range as early as the 1930's (Bleich et al. 1990, Dunn 1996). In 1947, the Montana Department of Fish, Wildlife and Parks (MDFWP) began efforts to reestablish sheep in the Missouri River Breaks region of Montana. Sixteen Rocky Mountain bighorn sheep (*Ovis canadensis canadensis*) from Colorado were relocated near Billy Creek in Garfield County, Montana. This population grew rapidly at first but by 1956 had begun to decline, and by 1963 had completely disappeared. Failure of this population has been attributed to competition for forage, disease, inter-breeding with domestic sheep, and social intolerance of domestic sheep in the area (Sullivan 1996). From 1958 through 1961, a series of reintroductions placed 43 Rocky Mountain bighorn sheep in the Two Calf area of Fergus County, south of the Missouri River and slightly east of the location of this study. Eventually this attempt failed as well. A series of weather events, disease, and competition with domestic livestock and deer were reported as responsible for the failure (Eihhorn and Watts 1972). However, some remnants of this introduction were probably present when additional sheep were released at Chimney Bend (Stafford Ferry population) in 1980. Another introduction into the Missouri River Breaks area occurred in 1974 in the Little Rockies when 21 sheep from the Sun River were released (McCarthy 1996). The population increased to approximately 100 individuals before declining in the mid 1990's. No sheep were sighted in helicopter or ground surveys in 1998. The cause for this die off has been attributed to disease (Sullivan, unpublished data).

In 1980, Rocky Mountain bighorn sheep from the Sun River area in Montana were again relocated to the Stafford Ferry area of Fergus County and to Mickey Brandon Buttes of Phillips County (McCarthy 1996). Twenty-eight animals were released in each location. The population introduced at the Stafford Ferry area has since grown and pioneered areas that include both sides of the Missouri River. In August 1998, this population had a minimum of 540 animals: 230 north of the Missouri River and 310 on the south side. The population at Mickey Brandon Buttes peaked at 88 individuals in 1994 but declined to 39 sheep by 1999. The Stafford Ferry population complex appears to be successful where other nearby prairie/breaks populations are stable or declining.

The mixed success of transplanted populations in the Missouri River Breaks may be due to inadequate habitat assessment at release sites (Smith et al. 1988, Dunn 1996). Suitable habitat for bighorns is superficially easy to define; open grassland in proximity to high relief escape terrain (Lawson and Johnson 1982), but the failure of many Missouri River Breaks transplants in areas of grassland adjacent to topographic relief suggested that a more sophisticated approach to habitat suitability was warranted.

My study included two primary objectives. The first objective was to generate information to describe population characteristics of bighorn sheep occupying MDFWP Hunting District 680 (HD 680) on the north side of the Missouri River. This objective involved; assessing population status by total enumeration, lamb-ewe ratios and demographic characteristics; use of home range calculations to identify winter and summer habitat; tracking movement and distribution to identify ewe and ram use areas as well as document interactions with sheep in other hunting districts; and assess the health of sheep in HD 680.

The second objective was to develop a model identifying suitable habitat for sheep in the Missouri Breaks. This was accomplished using a Geographic Information System (GIS) database, locations of radio-collared sheep, and logistic regression. My analysis was conducted at 4 spatial scales to identify the scale at which sheep are selecting habitat. This approach should allow managers to identify potential sheep habitat over large spatial expanses without expensive site reconnaissance or digitizing costs because it eliminates direct ground measurement and/or the need to digitize local databases. Results may improve planning for future sheep introductions and may be useful in determining if habitat is limiting for existing populations.

# STUDY AREA

My study area was located in southern Blaine County in north central Montana. The southern boundary of the study area was the Missouri River. The western boundary was a line running north from the junction of Birch Creek and the Missouri River, east of Montana State road 236. The eastern boundary was a line running north of the junction of Bullwacker Coulee and the Missouri River and followed the coulee. The northern boundary was an arbitrary line that roughly followed the edge of the breaks habitat. These boundaries encompassed an area of approximately 275 $km^2$ (Figure 1).

The study area was dominated by topography typical of the Missouri River Breaks and was characterized by rolling benches with many deeply dissected drainages (coulees) that have steep, sparsely vegetated slopes. These dendritic coulees become deeper and wider as they approach the Missouri River. Bench tops merge into a rolling plain north of the study area. Elevation within the study area varied from 690m to 1063m. See Hamlin and Mackie (1989) for a more detailed description of the breaks habitat.

Climate of the Missouri Breaks is semiarid, dominated by variable precipitation and prone to moderate to high winds and extremes in temperature. The 50-year average for precipitation is 37.9 cm per year. In 1998 a total of 44.9 cm of precipitation was recorded, with most of the above average precipitation falling in June and July. All reported weather information is from the weather station at Winifred, Montana. Annual

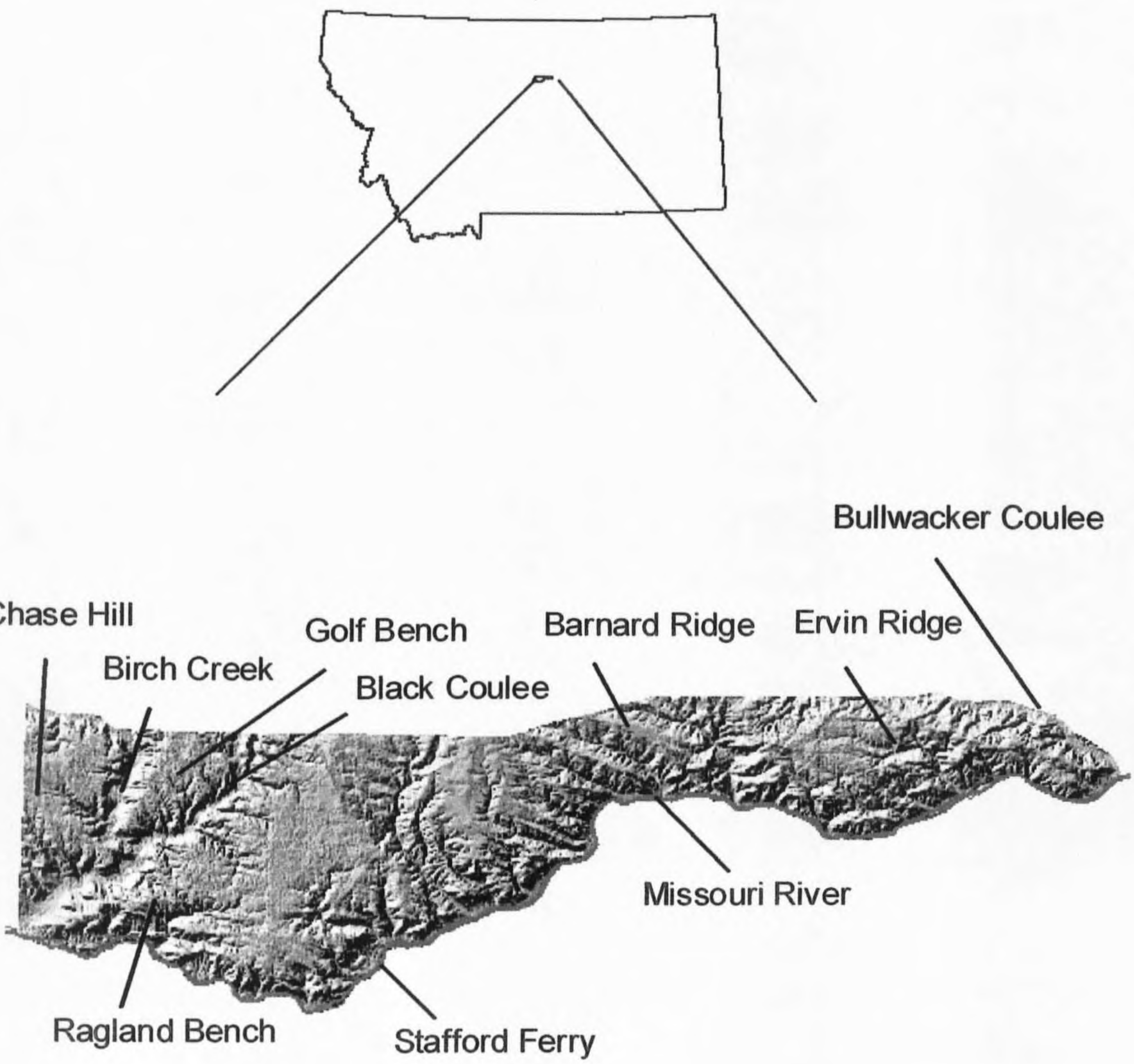
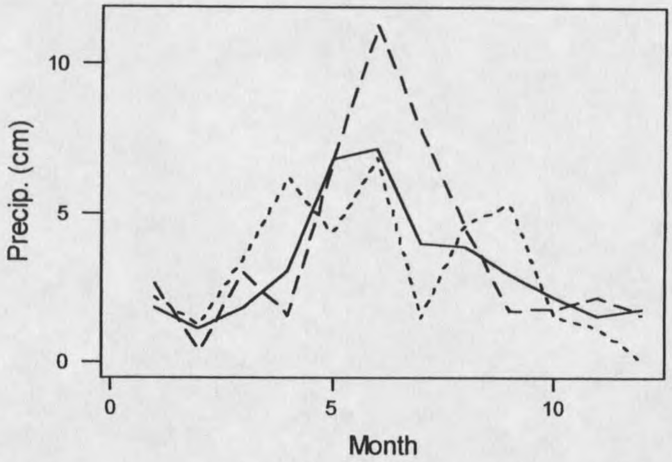



Figure 1. Map of study area with place names.

precipitation in 1999 was average (38.3 cm), but the spring and fall seasons had above average precipitation while the summer was below average (Fig. 2). Winter temperatures in 1998 and 1999 were milder than average (Fig. 3). Spring and summer temperatures were close to average in 1999 but warmer than average in 1998.

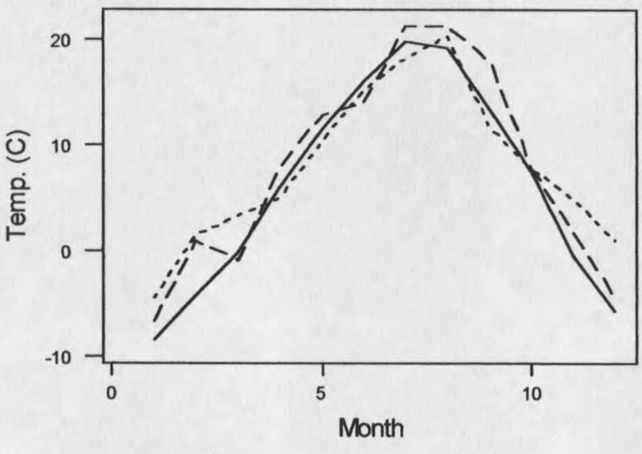
Soils in the Missouri Breaks are clay loam derived from the Bearpaw Shale Formation. The high clay content of these soils makes it relatively impermeable to water and helps contribute to the high rate of natural erosion. Many coulees in the study area had ephemeral water following rains. The only permanent water sources in the study area were the Missouri River and Birch Creek. An extensive system of stock tanks was present in the area. Most held water during 1998 and 1999 but would be dry in a drought year.

Land ownership was a mixture of private and Bureau of Land Management (BLM). Cattle ranching and dry land wheat farming were the dominant land uses at the time of this study. Cattle grazed throughout the study area, but wheat fields were located predominately at the west end of the study area. Agricultural fields in the study area were a mixture of untilled fields in the Conservation Reserve Program (CRP) and active fields. Many CRP contracts were scheduled to expire in 1999 – 2005, and many of the landowners were not planning to renew them. This suggested that agricultural acreage will increase in the future in the west end of the study area. Domestic sheep husbandry in the study area began in the late 1800's, but the last of these operations on the north side of the river was discontinued in the late 1970's.




Solid line = 50 year average precipitation
Dashed line = 1998 precipitation
Dotted line = 1999 precipitation

Figure 2. Monthly precipitation in the study area by year.




Solid line = 50 year average temperature
Dashed line = 1998 average temperature
Dotted line = 1999 average temperature

Figure 3. Monthly average temperature in the study area by year.

Potential predators of bighorn sheep within the study area included mountain lions (*Felis concolor*), bobcats (*Felis rufus*), coyotes (*Canis latrans*), and golden eagles (*Aquila chysaetos*). Possible competitors were domestic cattle (*Bos mcdonaldii*) and mule deer (*Odocoileus hemioneus*). Elk (*Cervus elephus*) and white-tailed deer (*Odocoileus virginianus*) were present but uncommon.

Hunting of bighorn sheep in Montana was not legal from the 1920's until the early 1950's. At that time specific populations were opened to regulated hunting when biologists concluded that populations could tolerate harvest. The population in my study area was first hunted in 1987. All the sheep on the north and south side of the Missouri River, in what are now hunting districts 482 and 680, were originally managed by Region 6 of MDFWP as hunting district 680. The area was split into 2 different administrative areas in 1996. The original hunting district had 15 either-sex permits and 10 ewe permits in 1996. By 1999, the quota had decreased to 10 either-sex permits and 10 ewe permits for HD 680 and 8 either-sex permits and 8 ewe permits in HD 482.

# METHODS

## Capture and Collaring

Sheep fitted with radios used in this study were captured in March 1998 by a professional wildlife capture service using net-guns mounted on a helicopter. Captures were spread over a large area in an effort to include 1 or 2 collars within several different bands of sheep. Radio-transmitters with mortality sensors and individually recognizable neckbands were fitted to each animal. At capture, blood was drawn to assess initial health and each animal was sexed and aged using tooth wear and irruption patterns (Lawson and Johnson 1982).

## Sampling

Ground radio-locations of sheep were collected using a systematic sampling scheme amongst the 8 zones in my study area (Figure 4). The 8 zones were established based on access into the area and were sized so that each could be sampled in a single day. Seven zones were accessible by vehicle. The eighth zone was the river corridor on the east half of the study area and was only accessible by boat. A random number generator was used to select a random zone among the 8 zones and the order zones were searched (increasing or decreasing order). For example if zone 2 was selected and the zone search order was decreasing the zones would be sampled 2, 1, 8, 7, 6, 5, 4, and 3. If the search direction was increasing the zones would be sampled 2, 3, 4, 5, 6, 7, 8 and 1. Each zone was alternately sampled starting at the opposite end (*i.e.* if a zone was sampled east to west one time it was sampled west to east the next time). The exception to this was zone 8, which was sampled from the river by boat; it was always sampled from upstream to downstream.

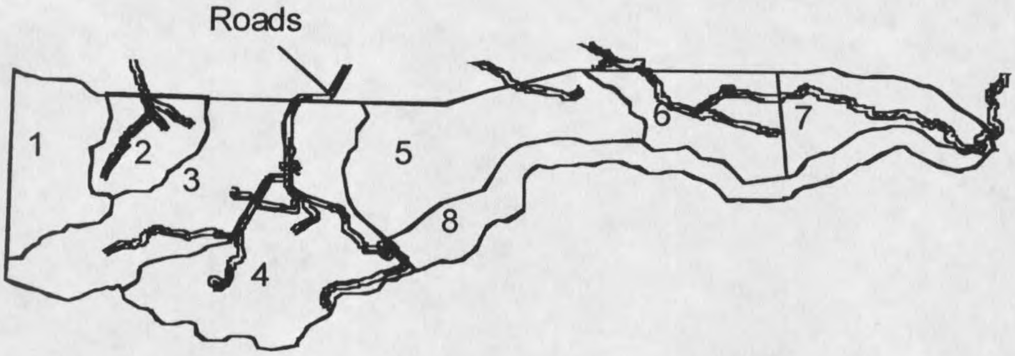



Figure 4. Map of sampling zones within the study area.

For each zone, I used radio telemetry to determine all collared sheep in the zone. Only animals actually observed were included in analysis using locations from the ground. Once an animal was located location co-ordinates, a brief site description, and group characteristics (number, gender, activity, etc.) were recorded. I used a non-correctable Global Positioning System (GPS) to identify my position in Universal Transverse Mercator (UTM) coordinates (WGS 84 Datum). Each animal's location was estimated using a compass bearing, estimated distance from the observer, and site descriptions. GPS data were converted to North American Datum (NAD) 27 datum using the program CORPSCON (U.S. Army Corps of Engineers 1997) and plotted on

7.5-minute USGS maps. The bearing, distance, and site description was then used to generate a sheep location on the map. These locations were then converted to North American Datum 1983 (NAD 83) using the CORPSCON program.

When locations were collected from a fixed-wing aircraft, the pilot circled the marked animal, if visible, or the area of strongest signal strength if the animal was not visible. This location was recorded with the same style GPS unit as used for locations from the ground. We attempted to locate all radio-collared animals on every flight even if animals were outside the defined study area. Flights occurred year round and employed the same pilot throughout the study. All flights were conducted using a Belanca Scout, model 8GCBC aircraft. Flights occurred at intervals of 10 days to 2 weeks.

## Population Status

I attempted complete (100% of the study area) counts of the population on 4 occasions over 2 years from a helicopter. On the day before or the morning of the flight, all collars were located using a fixed-wing aircraft to determine if marked animals were present in the census area. The study area was then flown at low speed in the helicopter using a systematic search pattern. All sheep were counted and classified and collars described. Only data from the last 3 surveys were used to estimate population size. The first helicopter survey was not included because a helicopter malfunction forced a week delay between counts of the east and west halves of the study area. The interval between partial surveys gave animals time to move and made total estimation unreliable.

The population size in the survey area was estimated using a modified Lincoln-Peterson estimate (Lancia et al. 1996). The assumptions of this model are:

1) population is closed
2) no marks are lost, gained or overlooked
3) all animals have equal capture probability.

The first assumption was met by attempting the surveys in 2 days. The second assumption was met and confirmed using radio telemetry. The last assumption is difficult to test. I used the program CAPTURE (White, no date) as an indirect test of the third assumption. If the capture probabilities I observed did not vary among collared individuals or between capture events, this would suggest the probability of being seen was relatively constant across individuals. The program CAPTURE compares fit of several models to a set of observed capture probabilities. The null model (constant capture probability) fit my data better than the heterogeneous model (where capture probabilities vary between individuals), the time model (where capture probabilities vary between capture events), or the behavior model (where the capture probabilities varied for individuals which were trap happy or trap shy).

In addition to total enumeration, individual estimates by gender were calculated using the same method. No lambs were marked; consequently, a robust method was not available to estimate numbers; therefore, I used the point estimate for ewes multiplied by the lamb-ewe ratio (lambs per 100 ewes). Confidence limits on lamb numbers were calculated by multiplying the confidence intervals for ewes by lamb-ewe ratio. The monthly ratios of lambs, rams, and yearlings to the number of ewes for ground locations were calculated directly from the monthly totals.

## Home Ranges

Home ranges were calculated in order to identify seasonal habitat such as winter and summer ranges. Home range calculations were done using CALHOME (Kie et al. 1994). This program was used to calculate both the minimum convex polygon (MCP) and adaptive kernel (ADK) home ranges for each individual. I have reported 95% home ranges using both techniques, but the percentages associated with these two methods have different meanings. Both methods employ an algorithm that calculates a center based on location data. This center is the point about which the home range is calculated. For the ADK method, the 95% percentile represents probabilities of containing the radioed animal and is plotted as a contour. The 95% percentile in the MCP method represents the percentage of the total locations used to create the polygon. For example, the 95% percentile of the MCP polygon would represent 95% of the points closest to the center point and eliminate the 5%.

Sheep locations used for home range calculations were the combination of ground and flight data from December 1998 through November 1999. Summer and fall data from 1998 were not included because, after stratification, sample sizes were too small. These data were divided into 3 seasonal strata. The first season was a spring/summer stratum from April 1999 through July 1999. This period covered the initiation of herbaceous plant growth to summer dormancy in the study area. The second stratum was fall, which extended from August 1999 through November 1999. Vegetation was generally dormant during this period, but weather was still reasonably mild and little or no snow had accumulated. The third seasonal stratum was winter and covered December 1998 through March 1999. This included the coldest weather events.

The Wilcoxon rank sum test was used (Mathsoft 1999) to test for differences in the sizes of average seasonal home ranges and differences between sexes by season. I used this test was used because samples were skewed toward values lower than the mean. Sample sizes were too small to apply the central limit theorem. The Wilcoxon rank sum test is also robust for samples that are not from a normal distribution (Mathsoft 1999).

## Movement and Distribution

The distribution of sheep within the study area and movements in and out of the study area were based on combined ground and flight locations. I used plots of locations to define population sub-units within the study area as well as areas used by ewes and rams.

## Health Indicators

Health of the sheep population was monitored by observing physical condition and examining fecal samples for lungworm (*Protostrongylus* spp.). Lungworm counts were made by the MDFWP wildlife lab in Bozeman, Montana using a modified Baermann technique (Beane and Hobbs 1983) to extract lungworm larvae. One visibly sick lamb was harvested and a necropsy performed by the same lab.

## Habitat Selection and Digital Data

Habitat provides essentials: food, water, cover and security that allows a population to survive and reproduce (White and Garrott 1990). Resource selection studies generally compare an animal's use of discretely classified habitats in a heterogeneous landscape to the availability of these habitats. A habitat is said to be preferred if it is used more frequently than available and avoided if used less frequently than its proportionate availability (White and Garrott 1990). Habitat types selected by use are often assumed to include the resources a species requires for survival and as potential limiting factors to population size and fecundity. These assumptions may not be true, but they allow biologists to identify categories that might limit population performance.

In any comparison of use and availability, the area accessible to use must be defined. These boundaries are difficult to identify in a 2 or 3 year study. So arbitrary boundaries are imposed in most studies. Depending on how the study area boundaries are created, there can be significant impact on what habitats are considered available and the proportion of each type available (Johnson 1980, Arthur et al. 1996). Boundaries may be further complicated because access to some habitats by individual animals may be compromised through the exclusion of some animals from preferred habitats by territorial animals, competing species, or human activities (White and Garrott 1990).

I used a Geographic Information System (GIS) to overlay several data bases and logistic regression to identify favored habitat features of sheep. GIS packages have been used to describe heterogeneity in complex habitats and the effects of scale in a wide array of situations (Johnson 1990, Lehmkuhl and Raphael 1993, Stow 1993, Baker et al. 1995). A GIS approach can be particularly effective given the importance of topography in bighorn sheep habitat selection and the ease with which a GIS can display slope over a large geographic area (Smith et al. 1990, Sweanor et al. 1994, Gudorf et al. 1996). A GIS can be a powerful, cost effective tool if data that are already publicly available can be used.

The currently favored approach for GIS habitat models is to apply buffers (areas of specified radius around a point or map feature, around "selected" habitats). Through a process of elimination, unsuitable habitat is "clipped" out. The area that remains within the buffers for all pertinent habitat attributes is then considered sheep habitat (Smith et al. 1990, Sweanor at al. 1994, Gudorf et al. 1996). However, this approach has the potential to systematically overestimate sheep habitat. Because this approach has no requirement for a specific level of important attributes (area, number of pixels, etc.), a single pixel that falls within all buffers can add > 0.25 $km^2$ habitat under the model proposed by Smith et al. (1990) and modified by Sweanor et al. (1994). Further, this error can be greatly magnified if this technique is applied to sparse marginal habitat where single pixels of suitable habitat might be widely dispersed.

I used public domain data from two sources, the GAP analysis for Montana (Redmond et al. 1998) and the 7.5-minute digital elevation model (DEM) from the United States Geologic Survey (USGS). The GAP analysis for Montana classified all of the state into 45 vegetative cover types based on a 30m by 30m pixel size. From the GAP analysis, the cover type classification and canopy cover data layers were used. These layers were created using a 2 step process. The first step was to do an unsupervised classification in order to define patch boundaries and spectral classes, using terrain-corrected landsat thematic mapper images. This automated process grouped patches based on specific spectral classes. The next step was a supervised classification; a person assigned cover types to specific spectral classes based on ground measurements to the same image. This 2 step process produced a complete cover type map of the state (Redmond et al. 1998).

The large number of cover type classes contained in the GAP data reduced the reliability of the habitat model by over powering the model with many low availability, low use types. To increase accuracy, I reduced the cover types in the GAP data set into 7 types. Classes in the GAP system also did not correspond to other more accepted community classification schemes and were too fine for a landscape approach. The reduced classification system included the 7 cover types: agricultural lands, grasslands, shrub land, shrub-grassland mosaic, forest, water and barren-badlands.

Accuracy assessments conducted by the University of Montana on the GAP analysis cover type layer yielded highly variable results for differnet cover types. State-wide accuracy varied from 4.4% for the Western Hemlock cover type to 93.2% for the

Missouri Breaks cover type (Redmond et al. 1998). The average for all 45 cover types was 61.4%. However, because vegetation structure should be more reliably classified by satellite imagery than species composition, and my classification system relied heavily on coarse differences in structure (grass vs. shrub), it should be more reliable than the fine classification specified by the GAP approach (Aronoff 1995).

The GAP data set also included elevation, slope, and aspect data layers. However, these appeared to systematically underestimate slope when compared to slope derived using the USGS 1:24,000 DEM. The GAP analysis also used the USGS 1:24000 DEM to derive slope and aspect, but the USGS had not completed all areas within Montana at this scale at the time the Montana GAP was constructed. Where the 30m X 30m DEM was unavailable, the 3 arc second data from the EROS data center that were available were converted to 30m X 30m pixels by re-sampling the approximately 100m X 100m pixels. This move from a coarse to a fine DEM by re-sampling caused the systematic underestimation of slope by the GAP data in the deeply dissected Missouri Breaks because detail was lost before the 30m X 30m data layer was created. The USGS 1:24000 DEM I used was based on primary sampling at a scale smaller than 30m x 30m pixels and scaled up. Slope and aspect were derived using functions provided in ESRI's SPATIAL ANALYSIS module for ARCVIEW 3.2 (Environmental Systems Research Inc. 1999).

To investigate the scale at which sheep may select habitat factors, 4 scales were analyzed: the individual 30m X 30m pixels (scale 1) that locations occurred and all the whole pixels falling within a 105m, 195m and 285m radius buffer around the animal's location (scales 2-4 respectively: Fig.5). Radii were selected based on how accurately an animal could be located. The single pixel corresponds to what has been traditionally done in wildlife work and is based on the assumption that I have identified animal locations with absolute precision. The 105-meter radius corresponds to errors of up to 100-meters in GPS accuracy resulting from selective availability (the error in positional accuracy the military induces for security reasons) associated with non-differentially corrected GPS (U.S. Department of Defense 1984). The 195-meter radius corresponds to locational accuracy associated with radio locations made using a GPS system in a fixed-wing aircraft. Carrel et al. (1997) found that a 95% confidence radius of 195.2-meter was required if the data were collected with a non-correctable GPS unit. The 285-meter radius was chosen because I felt a larger scale should be included to account for additional errors that possibly associated with the digital layers comprising my map of habitat availability.

Digital layers used to analyze habitat selection at different scales were created by using a program (Avenue script in the programming language used by ARCVIEW) that acted as a moving window. The moving window identified the dominant attribute from the surrounding pixels (the number of pixels varied with scale) from the base data layer in a cell and then moved over one pixel. This process was repeated until a new layer was created from the base layer. For example, the derived layer from cover type at the 105m scale would contain the dominant cover type for the surrounding 29 pixels as each cell value. The values for the sheep locations were then extracted from the resulting layers.

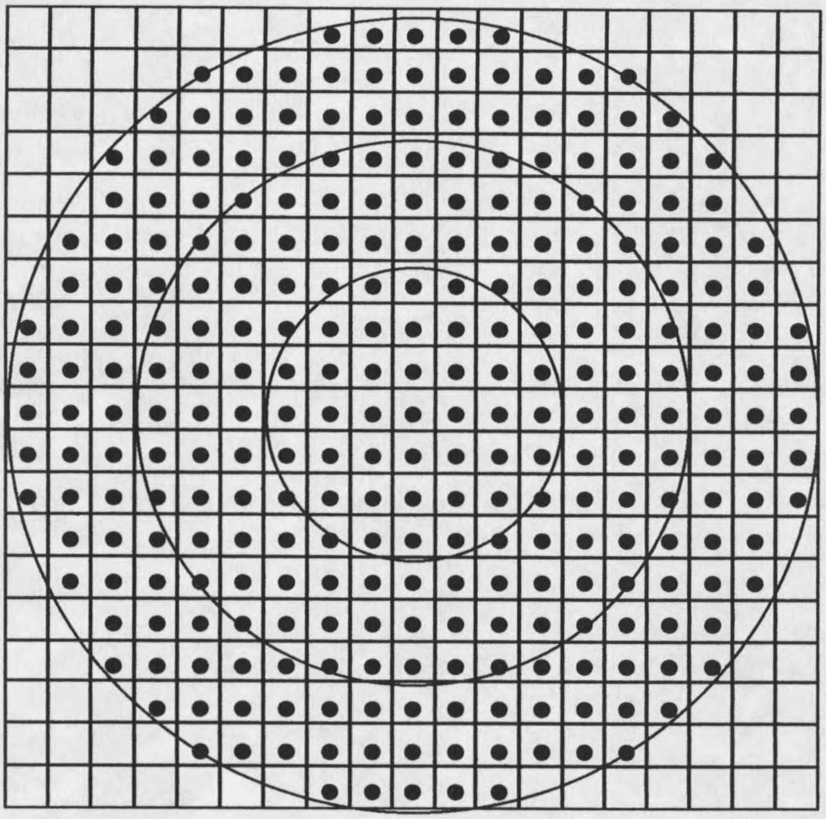


Figure 5. Layout of four scales used in habitat analysis. Each square represents a $30m^2$ pixel and each dot a single value for a pixel. Center-most pixel would be the zero scale or the pixel containing the actual location. The 3 concentric circles represent the area included in the 105m, 195m, and 285m scales.

I used logistic regression to analyze habitat selection by radio-collared sheep from a random pattern of habitat selection. Habitat use by sheep was derived from the combined flight and ground locations within the boundary of the study area for 1998 and 1999. The random set of habitat data was generated by drawing 10,000 points using a random generator in ARCVIEW. In order not to bias comparison of sheep locations with random location for factors such as sex, year, sub unit of the study area (east or west sub-population), and type of location (aerial or ground), the randomly generated data set was assigned these same attributes in exactly the same proportion as the data set of radio-collared sheep.

Prior to beginning modeling it was necessary to determine the appropriateness of inclusion of variables for appropriateness in a logistic regression model as well correlation between variables. The first of these tasks was accomplished graphically by plotting the observed probability of success (OPS) vs. level of the variable and the fitted logistic probability ($\pi(x)$) of success vs. level of the variable where:

$$\pi(x) = e^{\alpha+\beta(x)} / 1+e^{\alpha+\beta(x)}$$

when: $\alpha$ = the intercept term from the logistic regression

$\beta$ = the coefficient from the logistic regression for the variable in question

X = the level of the variable.

Correlations were between variables were analyzed by plotting the fitted line or logit ($\pi(x)$) vs. level of the variable where:

$$\text{logit}\ (\pi(x)) = \log\ (\pi(x) / 1 + \pi(x)$$

when $\pi(x)$ is defined as above.

I examined these plots and looked for specific patterns in the graphs. In the first 2 graphs, OPS vs. level and $\pi(x)$ vs. level, the expected pattern is that of an increasing or decreasing probability of success that approximates an "S" shaped curve or portion of an "S" curve. The third graph, logit ($\pi(x)$) vs. level, should be approximately linear and have either positive or negative slope depending on whether the variable has a positive or negative effect on success. These diagnostics were conducted for all scales investigated. Only results for the 105m scale are shown (Appendix B), but all other scales showed similar patterns.

The models presented in the results fall into 2 categories. The first set of models consists of *a priori* models where independent variables were included based on current literature and biological factors I considered important. The second set of models was created by manually applying a stepwise modeling procedure to the list of all potential independent variables. The "best" stepwise models were selected based on Akaike's information criteria (AIC). All models, *a priori* and stepwise, were ranked based on AIC (Burnham and Anderson 1998).

Because of missing values from the moving window technique applied to digital layers used in the habitat analyze the number of observations at each scale was different. This meant that AIC could not be used to compare models at different scales. These missing values represent ties or co-dominance of 2 levels of a variable when the moving window was run. In order to be able to directly compare the effect of scale, I used a subset of the data. This truncated data set included all observation where there were no missing values at any scale. Since all models were to be based on the exact same set of observations, AIC could be used to compare models at different scales.

# RESULTS

## Capturing and Collaring

A total of 31 adult bighorn sheep (19 females and 12 males) were captured. Young rams were selected (2-5 years of age with a mean = 3.6 yrs.) to avoid loss by harvest during the first hunting season. Ewes were not selected by age (2 – 10 years of age with a mean = 5 yrs.). Captures were made from 13 sheep groups over an area of approximately 170km$^2$. One ram died during the capture operation, and 1 ewe died shortly after the capture operation prior to starting field work in May 1998. This death might have been due to capture myopathy. Observations of habitat use and survival were based on the 29 animals alive in May 1998.

## Sampling

A total of 1,438 radio-collared sheep locations were collected in 1998 and 1999. Of these locations, 1,142 fell within the study area boundaries. A total of 245 sheep locations were collected from ground sampling and 1,193 locations were collected from aerial relocation of sheep.

## Population Status

Population estimates of for bighorn sheep in Hunting District 680 derived from helicopter surveys during 1998 and 1999 varied between 326 and 403 individuals (Table 1). The August 1998 and March 1999 surveys took place after the 1998 lambing season and before the 1999 breeding season. The observed lamb to ewe ratio from the

Table 1. Population estimates from helicopter surveys for 1998 and 1999.

| Survey date | Group | Collars observed[a] | N observed | N estimated[b] | Standard error | 95% CI[b,c] |
|---|---|---|---|---|---|---|
| Aug-98 | Total | 15 | 230 | 403 | 61.9 | (281,524) |
| Mar-99 | Total | 21 | 256 | 326 | 28.6 | (269,382) |
| Jul-99 | Total | 16 | 232 | 382 | 54.6 | (275,489) |
| Aug-98 | Ewes | 11 | 139 | 209 | 32.2 | (145,272) |
| Mar-99 | Ewes | 14 | 120 | 136 | 11.0 | (120,157) |
| Jul-99 | Ewes | 9 | 119 | 203 | 37.8 | (128,277) |
| Aug-98 | Rams | 4 | 32 | 78 | 22.7 | (33,122) |
| Mar-99 | Rams | 7 | 69 | 104 | 19.0 | (69,141) |
| Jul-99 | Rams | 7 | 47 | 71 | 12.6 | (47,95) |
| Aug-98 | Lambs | NA | 56 | 84 | 13.0 | (58,109) |
| Mar-99 | Lambs | NA | 67 | 76 | 6.1 | (67,88) |
| Jul-99 | Lambs | NA | 69 | 117 | 21.9 | (74,160) |

[a] Based on 27 collars in the study area at time of survey.

[b] Estimates and CI intervals have been rounded down to whole numbers.

[c] Intervals adjusted so that the lower estimate is not lower than actual number of animals seen.

flight data in 1998 (1998 lamb cohort) was 40 lambs per 100 ewes and the ram to ewe ratio was 23 rams per 100 ewes (Fig. 6). In 1999, the lamb to ewe ratio from the March survey (1998 lamb cohort) was 56 per 100 ewes and in July (1999 lamb cohort) was 58 per 100 ewes. The ram to ewe ratios from the same flights were 58 per 100 ewes in March and 40 per 100 ewes in July. Although, ratios from the ground data are more variable, monthly ratios of observed lambs, rams, and yearlings are included in Figures 7 and 8.

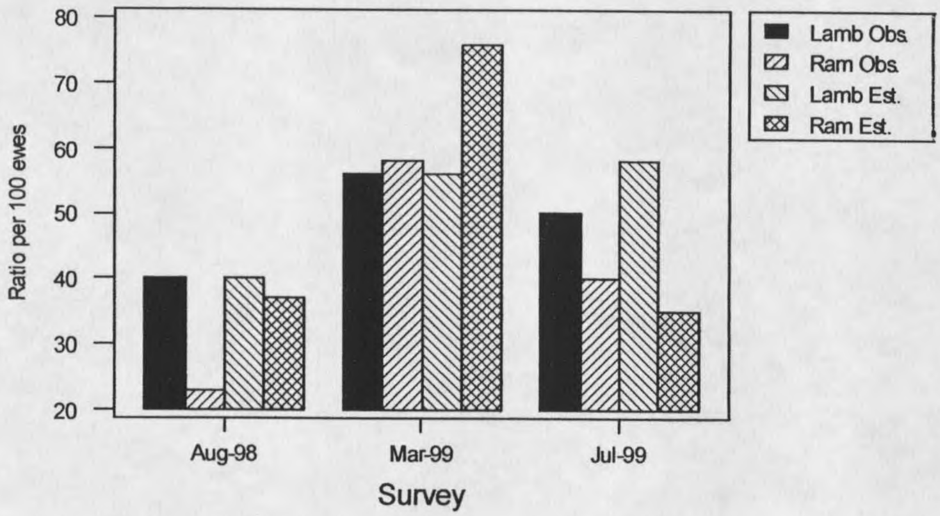



Figure 6. The observe and estimated ratio of lambs and rams per 100 ewes from helicopter survey data.

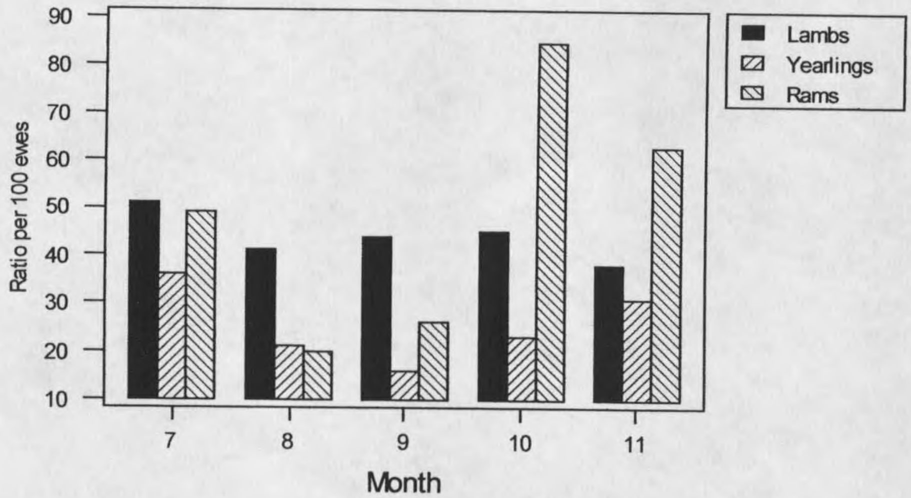



Figure 7. Ratio of lambs, yearlings, and rams per 100 ewes by month from 1998 ground data.

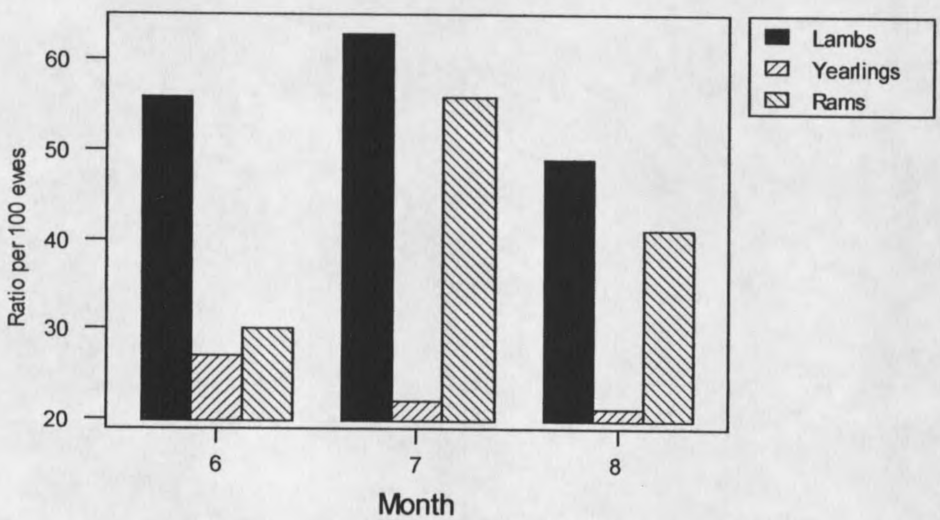



Figure 8. Ratio of lambs, yearlings, and rams per 100 ewes by month from 1999 ground data.

Little mortality was documented during the study. Two radio-collared ewes died during the study; 1 of unknown causes in June 1998, and 1 was harvested in September 1998. The 2 deaths of radio-collared ewes resulted in a monthly survival rate of 91.7% and an overall survival of 88.9% for the 24 months of the study. The radio-collared rams had a 100% monthly survival rate as well as 100% overall survival for the duration of the study. Although little mortality was documented in marked animals, at least 20 sheep died in the study area between June 1998 and August 1999. There were 10 either-sex permits and 10 ewe permits. Ten rams (all available permits) and at least 6 ewes (including 1 collared ewe) were harvested during the 1998 hunting season. Two lambs and 1 ewe were killed by a mountain lion in September 1998, and 1 ill lamb was collected for necropsy in August 1999.

## Home range

Individual seasonal home ranges varied by 2 orders of magnitude (585 to 38,390 ha) using the ADK method and 1 order of magnitude (275 to 12,610 ha) using the MPC method. Individual seasonal home ranges using ram and ewe locations showed no significant difference between seasons using the ADK method. However, the individual fall home range was significantly larger than spring (P=0.02) using the MPC method.

When home ranges are calculated for ewes and rams separately (Table 2, Appendix A Table 12), rams had significantly larger home ranges than ewes for each season (P< 0.01). Ewes showed no significant differences in seasonal home range size between seasons for ewes under the ADK method. However, fall home ranges were significantly larger than spring and summer (P=0.02 for each) using the MCP method. The average number of points per individual included in each seasonal home range were; spring/summer = 14.6 (minimum=12, maximum=18), fall = 11.6 (minimum=12, maximum=14), and winter = 11.7 (minimum=10, maximum=12).

Table 2. Average home ranges calculated by program CALHOME by sex and season.

| Season[c] | Method[b] | Mean area females[a] | Mean area males[a] | Ratio (M/F) |
|---|---|---|---|---|
| Winter | ADK 95% | 4265.3 | 11750.5 | 2.8 |
| Spr./Sum. | | 5415.9 | 13609.8 | 2.5 |
| Fall | | 6815.5 | 18779.4 | 2.8 |
| Winter | MCP 95% | 1981.1 | 5557.4 | 2.8 |
| Spr./Sum. | | 2646.2 | 5715.8 | 2.2 |
| Fall | | 3654.0 | 8642.8 | 2.4 |

[a] Area is in hectares.

[b] ADK is adaptive kernel method, MCP is minimum convex polygon method.

[c] Winter includes data from December 1998 through March 1999. Spring/Summer includes the data from April 1999 through July 1999. Fall includes the data from August 1999 through November 1999.

The high percentage of overlap (70% or more for most sheep) among individual seasonal home ranges (Table 3, Appendix A Table 13) indicates that bighorn sheep in this area did not have distinct winter and summer home ranges but used the same general geographic area in all seasons (Table 3). Figure 9 shows a typical set of spatial relationships of seasonal home ranges for this population. Ewe 1452 had the most distinct separation of home range (Figure 10). Her winter and spring/summer home ranges overlapped little but the fall home range overlapped both to a high degree.

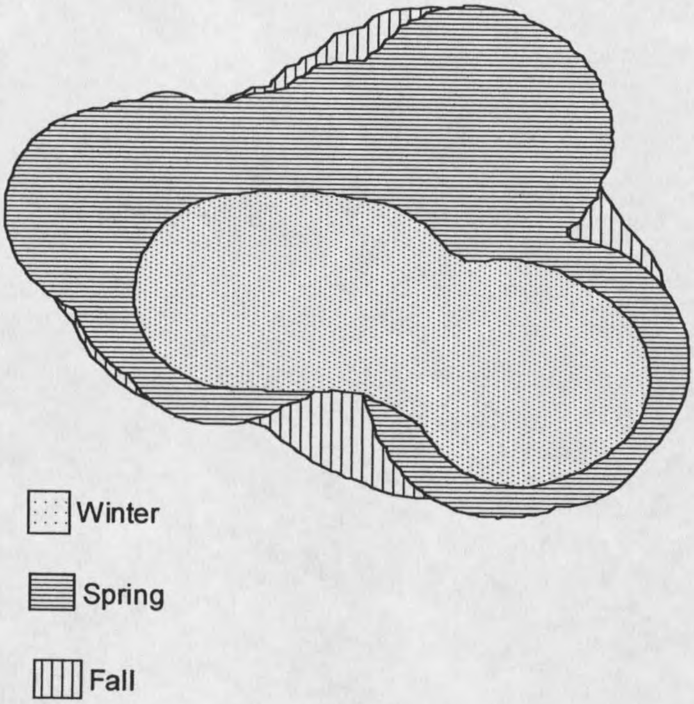



Figure 9. Diagram of seasonal home ranges of individual 1020.

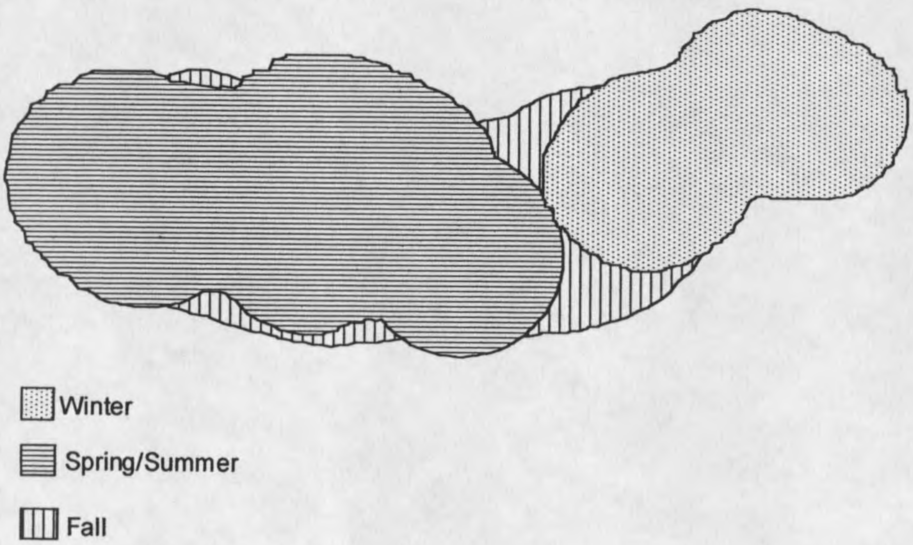



Figure 10. Diagram of seasonal home ranges of individual 1452.

Table 3. The average percentage of individual home range[a] overlap[b] by season.

| Group | Season | Mean % Overlap |
|---|---|---|
| All Sheep | Spring/Summer | 79.1 |
| | Fall | 67.1 |
| | Winter | 78.5 |
| Ewes | Spring/Summer | 75.1 |
| | Fall | 65.8 |
| | Winter | 76.4 |
| Rams | Spring/Summer | 84.8 |
| | Fall | 69.0 |
| | Winter | 81.5 |

[a] Home ranges used for percent overlap were the 95% adaptive kernel method.

[b] Home range overlap describes how much of a seasonal home range is contained in the other 2 seasonal home ranges.

## Movement and Distribution

Ewes and older rams tended to stay segregated except during the rut. Younger rams (1 to 2 years of age) were common in ewe groups. Ram and ewe groups used the same spatial area but usually did not use the same sites at the same time. Areas used exclusively by only 1 group occurred in the northwest corner (Chase Hill area) of the study area and the area west of the Stafford Ferry (Figure 11, 12, 13). Ewes used the northwest corner in all seasons, but I rarely saw any rams in the area. The area west of the Stafford Ferry was almost exclusively used by rams. Another of these areas was an area north of the east end of Bullwacker Coulee (out of the study area) that rams used extensively in 1999 but did not use it at all in 1998. Segregation of the sexes was greatest in spring/summer (Figure 12).


Figure 11. Map of all sheep locations from winter (Dec. 98-Mar. 99).

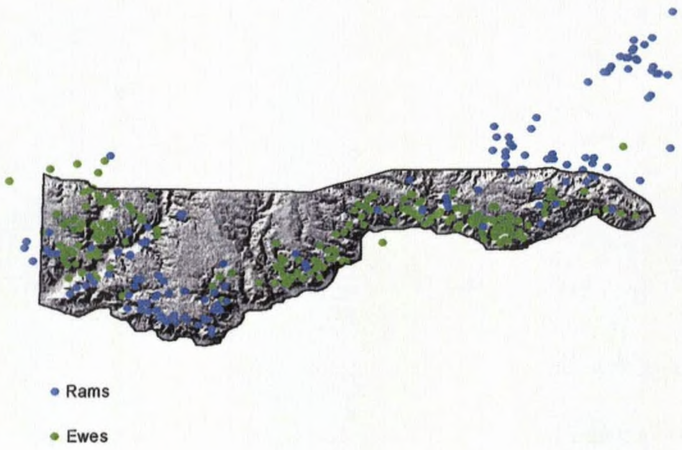



Figure 12. Map of all sheep locations from spring/summer (Apr. 99-Jul 99).

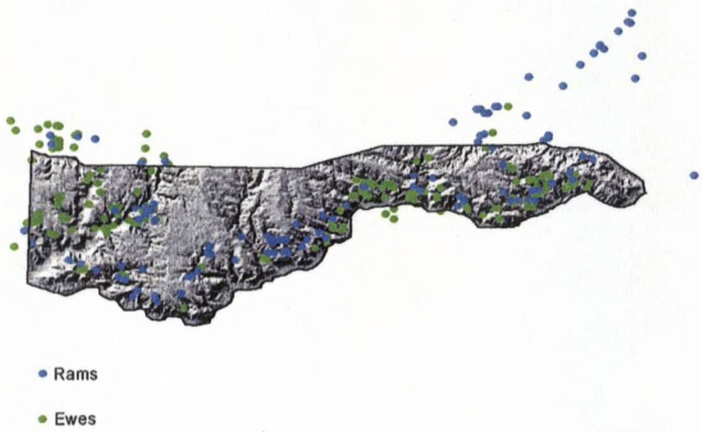



Figure 13. Map of all sheep locations from fall (Aug. 99-Nov. 99).

Radio relocations indicated the population on the north side of the Missouri River is made up of 2 sub-populations. I only located sheep captured in the west half of the study area in the east half 31 times (8 individuals, 2.5% of the total locations for sheep). Of these locations, only 11 were more than 2 km east of my boundary defining these units (Figure 14). There were only 20 locations of east-end sheep recorded in the west end of the study area (7 individuals, 1.6% of the total of sheep locations). Of these locations, only 10 occurred more than 2 km west of the boundary between units. However, animals from the west half did not occupy the 4 km boundary zone between the 2 geographical units at the same time as animals from the east half.

The Missouri River was not an impenetrable barrier to movement for bighorn sheep. Twenty-seven out of 1,438 (1.9%) locations were collected south of the river. Of these, 19 were from 1998 and represented 14 individual animals. The 8 locations from 1999 represented 7 individuals and included 2 individuals that had not crossed in 1998. Of the 16 individuals that crossed the Missouri River, 11 crossed only once. All collared sheep that crossed the river returned to the study area, usually by the next sampling cycle. One young ram remained on the south side of the river almost 3 months.

Only 4 marked animals from the west sub-population crossed the river, and 3 of these crossed on the same day. In contrast, 75% of the collared animals from the east unit crossed the river during the study. The majority of all sheep crossings took place from April through November with 1 each in March and December. One ewe crossed

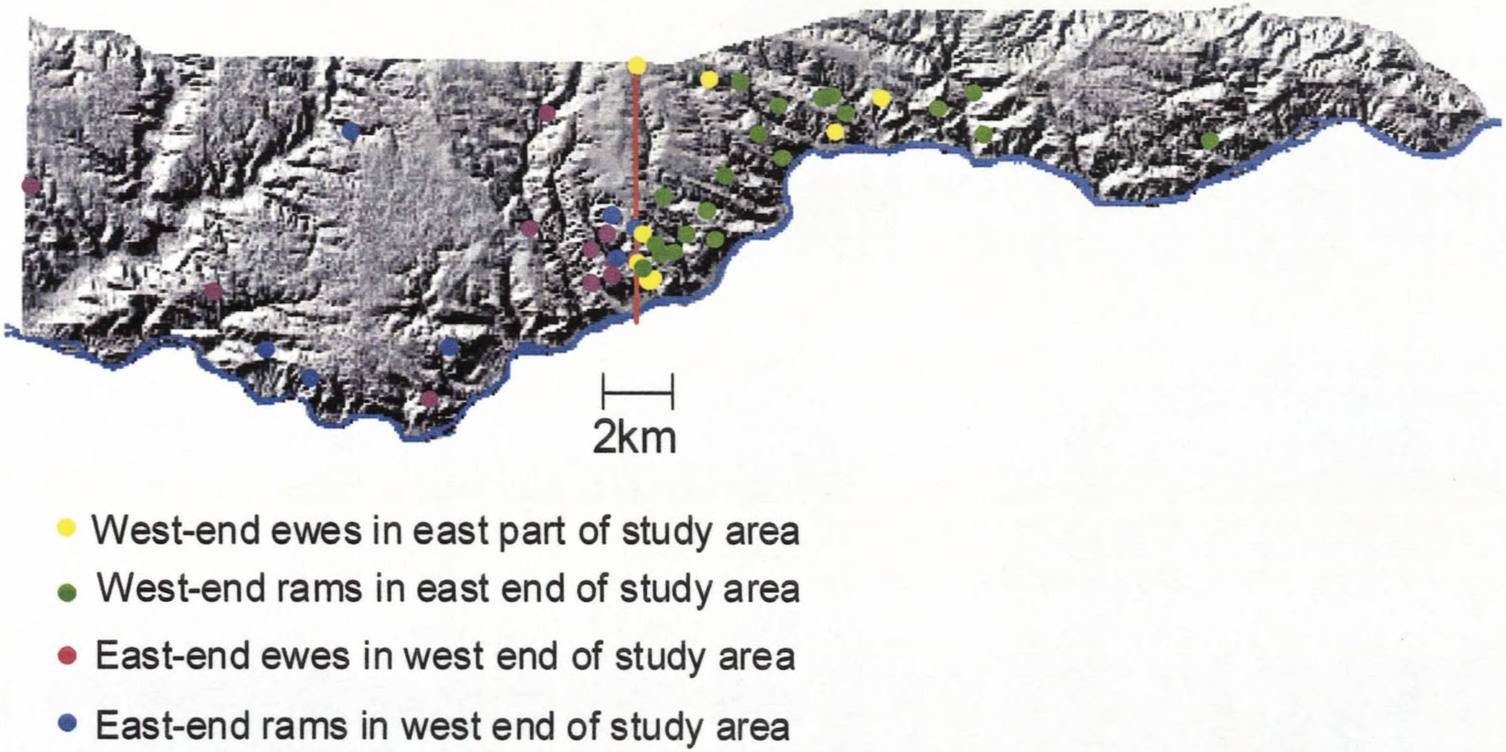



Figure 14. Map of bighorn sheep locations showing crossover between sub-populations (west and east study area units) during 1998 and 1999.

at peak run off in late May 1998 when the Missouri River was running in excess of 708 cubic meters per second (25,000 cubic feet per second).

Bighorn sheep appeared to avoid domestic livestock. Of 245 ground observations, only 2 (0.8%) occurred within 300m of domestic livestock (cattle) that were not separated from the sheep by some form of barrier, usually escape terrain.

## Health Indicators

Overall the bighorn sheep in HD 680 were healthy. Lamb-ewe ratios (indices of survival and population growth) were relatively high through the study (Figure 7 and Figure 8). I observed 1 lamb and no adults with visible health problems. Fecal samples from 5 ewes, 8 rams, and 1 lamb were collected. Lungworms were undetectable in 9 (69%) of 13 samples. In the samples where lungworms were detected, the average was 7.96 larvae per gram. The range from infected samples varied from 0.8 larvae per gram to 23.4 larvae per gram. The sample from a visibly sick lamb that was harvested tested negative for lungworms. The necropsy indicated the lamb had pneumonia consistent with aspiration of rumen contents as well as a viral infection (contagious ecthyma).

## Habitat Selection and Digital Data

The total amount of individual variables available to bighorn sheep did vary with scale but not substantially (Tables 4 and 5). There were, however, differences in availability between the west and east sub-units of the study area. The most notable of these was level 1 of cover type (agricultural land). Virtually all agricultural land was

Table 4. The number of pixels for each category of dominant cover type at each scale.

| Scale | Level[a] | West | East | Total | Scale | Level[a] | West | East | Total |
|---|---|---|---|---|---|---|---|---|---|
| Zero | 1 | 10,339 | 31 | 10,370 | 195m | 1 | 11,197 | 13 | 11,210 |
| | 2 | 45,680 | 24,289 | 69,969 | | 2 | 43,772 | 23,874 | 67,646 |
| | 3 | 60,587 | 35,936 | 96,523 | | 3 | 60,542 | 34,045 | 94,587 |
| | 4 | 7,169 | 4,847 | 12,016 | | 4 | 5,337 | 3,452 | 8,789 |
| | 5 | 8,367 | 14,929 | 23,296 | | 5 | 6,497 | 14,023 | 20,520 |
| | 6 | 4,455 | 6,701 | 11,156 | | 6 | 5,152 | 7,787 | 12,939 |
| | 8 | 43,444 | 36,594 | 80,038 | | 8 | 46,490 | 39,563 | 86,053 |
| 105m | 1 | 10,603 | 25 | 10,628 | 285m | 1 | 11,509 | 3 | 11,512 |
| | 2 | 44,338 | 23,789 | 68,127 | | 2 | 41,872 | 23,881 | 65,753 |
| | 3 | 59,988 | 35,094 | 95,082 | | 3 | 63,373 | 33,598 | 96,971 |
| | 4 | 6,609 | 4,465 | 11,074 | | 4 | 3,812 | 2,445 | 6,257 |
| | 5 | 7,697 | 14,460 | 22,157 | | 5 | 6,520 | 13,121 | 19,641 |
| | 6 | 4,735 | 7,079 | 11,814 | | 6 | 3,615 | 6,734 | 10,349 |
| | 8 | 44,118 | 36,962 | 81,080 | | 8 | 48,817 | 43,345 | 92,162 |

[a] Level of categorical variable of cover type where: 1 = agricultural land, 2 = grassland, hrub 4 = shrub-grassland mosaic, 5 = forest, 6 = water, 7 = barren/badland .

Table 5. The number of pixels for each category of dominant slope at each scale.

| Scale | Level[a] | West | East | Total | Scale | Level[a] | West | East | Total |
|---|---|---|---|---|---|---|---|---|---|
| Zero | 1 | 58,122 | 42,225 | 100,347 | 105m | 1 | 62,049 | 18,593 | 80,642 |
| | 2 | 38,547 | 36,056 | 74,603 | | 2 | 30,663 | 18,595 | 49,258 |
| | 3 | 27,614 | 35,668 | 63,282 | | 3 | 24,393 | 27,222 | 51,615 |
| | 4 | 20,037 | 27,658 | 47,695 | | 4 | 16,682 | 19,894 | 36,576 |
| | 5 | 14,505 | 17,374 | 31,879 | | 5 | 12,029 | 10,884 | 22,913 |
| | 6 | 11,021 | 11,255 | 22,276 | | 6 | 10,452 | 7,915 | 18,367 |
| | 7 | 7,487 | 6,578 | 14,065 | | 7 | 8,104 | 5,193 | 13,297 |
| | 8 | 3,314 | 3,045 | 6,359 | | 8 | 3,243 | 2,760 | 6,003 |
| | 9 | 668 | 813 | 1,481 | | 9 | 412 | 375 | 787 |
| | 10 | 111 | 113 | 224 | | 10 | 52 | 4 | 56 |
| | 11 | 16 | 15 | 31 | | 11 | 2 | 0 | 2 |
| | 12 | 3 | 5 | 8 | | | | | |
| | 13 | 0 | 6 | 6 | | | | | |
| 195m | 1 | 70,794 | 20,843 | 91,637 | 285m | 1 | 78,256 | 22,991 | 101,247 |
| | 2 | 30,228 | 17,961 | 48,189 | | 2 | 30,461 | 17,356 | 47,817 |
| | 3 | 25,874 | 32,644 | 58,518 | | 3 | 26,391 | 36,458 | 62,849 |
| | 4 | 16,359 | 21,625 | 37,984 | | 4 | 16,394 | 22,622 | 39,016 |
| | 5 | 11,359 | 10,544 | 21,903 | | 5 | 9,758 | 9,332 | 19,090 |
| | 6 | 10,943 | 7,201 | 18,144 | | 6 | 10,029 | 6,094 | 16,123 |
| | 7 | 7,579 | 4,570 | 12,149 | | 7 | 5,576 | 3,323 | 8,899 |
| | 8 | 1,632 | 2,004 | 3,636 | | 8 | 607 | 1,292 | 1,899 |
| | 9 | 152 | 126 | 278 | | 9 | 20 | 86 | 106 |

[a] Level of slope refers to a 5° change for each unit of change starting with zero degree of slope.

found in the west end of the study area. Bighorn sheep were observed in almost all levels of each variable. The exceptions were the highest level of slope, which was quite rare (< 8 pixels at the zero scale and not present in other scales). The highest level of canopy cover appeared to be avoided; no locations were collected in canopy cover greater than 70%. CRP was not defined as a separate cover type but instead was included in grassland because it had characteristics similar to native grasslands.

Agricultural land was used only where steep slopes were located at the edge of fields. Although many sites had this configuration, sheep were only observed in 4 sites in wheat fields.

The results of individual variable diagnostics indicated that 7 variables were not highly correlated and were appropriate for logistic regression. Details of the individual variable diagnostic results are presented in Appendix B. I identified 5 potential independent habitat variables (cover type, slope, canopy cover, aspect and elevation) that were available from the GAP and DEM data layers, as well as 4 other variables (sex, year, study area sub-unit [west/east] and data type [aerial or ground]). I eliminated elevation from all consideration in any models because elevation was highly confounded with slope. The total variation in elevation was less than 370 meters, and pixels with high or low elevations were likely to be flat (river bottom or bench top). Most mid-elevation pixels were on slopes.

Although other studies have found aspect an important variable in predicting use by bighorn sheep, particularly for seasonal habitat use and for predicting lambing areas (Smith et al. 1990, Sweanor et al. 1994, Gudorf et al. 1996), I was unable to include it.

Aspect was eliminated because it was highly variable within pixels at the scales available. My diagnostic analysis showed an unstable pattern of rise and drop in probability of success (use by sheep) which made this variable unsuitable for logistic regression. Adding a seasonal variable and or an aspect-season interaction term did little to fix the instability associated with this variable.

When I used the full data set available at each scale, the most parsimonious of the *a priori* models ranked by AIC (Table 6) was a model incorporating cover type, sex (gender), slope and a variable identifying study area halves or units (west/east) at all scales. The second ranked model at all scales included cover type, sex and, slope and gender.

The results of stepwise analysis (Table 7) varied with scale, but cover type and slope were included at all scales. The most parsimonious zero scale stepwise model contained only slope and cover type but the 105m and 285m scale models also included the sub-unit variable west/east (Table 8). At the 195m scale, the most parsimonious model also included a fourth variable, canopy cover.

Gender was not a good explanatory variable in the *a priori* models (Table 9) despite spatial segregation of sexes in bighorn sheep. The coefficient for sex varied between 0.0011 and -0.0153, depending on scale, and the odds ratio varied from 0.98 (95% CI (0.86,1.13)) to 1.0 (95% CI (0.88,1.14)), depending on scale. The impact on AIC (AIC= -2log-likelihood [from regression] + 2K, where K=the number of parameters in the regression equation) was equivalent to the penalty for adding another

Table 6. The *a priori* models ranked by AIC for each scale investigated for the complete data set.

| Scale of model | Variables in model | AIC | Δ AIC |
|---|---|---|---|
| Zero scale | Cover Type+Sex+Slope+W/E | 7568.67 | 0.00 |
| | Cover Type+Sex+Slope | 7569.95 | 1.28 |
| | Cover Type | 7621.23 | 52.56 |
| | Cover Type+Sex | 7623.22 | 54.55 |
| | Slope+Sex+Canopy Cover | 7706.41 | 137.74 |
| | Slope | 7713.75 | 145.07 |
| | Slope+Sex | 7715.70 | 147.03 |
| 105m scale | Cover Type+Sex+Slope+W/E | 6711.74 | 0.00 |
| | Cover Type+Sex+Slope | 6713.93 | 2.19 |
| | Slope+Sex+Canopy Cover | 6889.79 | 178.05 |
| | Slope | 6891.22 | 179.48 |
| | Slope+Sex | 6893.21 | 181.47 |
| | Cover Type | 7545.98 | 834.24 |
| | Cover Type+Sex | 7547.92 | 836.18 |
| 195m scale | Cover Type+Sex+Slope+W/E | 7086.85 | 0.00 |
| | Cover Type+Sex+Slope | 7090.99 | 4.14 |
| | Slope+Sex+Canopy Cover | 7253.62 | 166.77 |
| | Slope | 7257.00 | 170.15 |
| | Slope+Sex | 7259.00 | 172.15 |
| | Cover Type | 7520.06 | 433.22 |
| | Cover Type+Sex | 7521.98 | 435.13 |
| 285m scale | Cover Type+Sex+Slope+W/E | 7216.08 | 0.00 |
| | Cover Type+Sex+Slope | 7224.50 | 8.42 |
| | Slope+Sex+Canopy Cover | 7386.34 | 170.26 |
| | Slope | 7391.63 | 175.54 |
| | Slope+Sex | 7393.58 | 177.49 |
| | Cover Type | 7501.27 | 285.19 |
| | Cover Type+Sex | 7503.13 | 287.05 |

variable (Table 5). The penalty for adding another variable is 2. The actual change in AIC varied from 1.9 to 2.0, the log-likelihood portion of the formula changed by < 0.1.

Table 7. The most parsimonious model from stepwise logistic regression for each scale and comparison to the most parsimonious *a priori* model for the full data set.

| Scale of model | Variables in model | AIC | AIC from *a priori* model | Δ AIC |
|---|---|---|---|---|
| Zero Scale | Slope+Cover Type | 7566.7 | 7568.7 | -2.0 |
| 105m Scale | Slope+Cover Type+W/E | 6709.8 | 6711.7 | -1.9 |
| 195m Scale | Slope+Cover Type+Can. Cov.+W/E | 7078.5 | 7086.8 | -8.3 |
| 285m Scale | Slope+Cover Type+W/E | 7214.1 | 7216.1 | -2.0 |

The results of the logistic modeling on the truncated data made up of sheep locations without missing values were similar for the most parsimonious models (Table 10). The most parsimonious model for the truncated data set at all scales was the same, containing the parameters of cover type, slope, and study area unit. Direct comparison of models of different scales based on AIC (Table 11) indicated that as scale increased in area the AIC decreased. This implies that larger scales provided better discrimination of habitat selection between random points and sheep locations.

Interpretation of these multiple logistic regression equations is complex and differs from interpretation of linear regression results. The coefficient ($\beta_i$) for a parameter in the logistic regression equation is defined as the effect that the level of the variable ($x_i$) has on the odds ratio (or log odds) that Y=1 (where Y=1 refers to a success or use by bighorn sheep), where all other parameters are fixed. Put more simply, the

Table 8. The details of the most parsimonious stepwise models based on AIC for each scale on the full data set.

| Scale of Model | Variable | Level of categorical variables | Coefficients for variable(s) | P-value | Odds ratio | 95% CI for odds ratio |
|---|---|---|---|---|---|---|
| Zero Scale | Cover Type | 1 (Agricultural land) | | | | |
| | | 2 (Grassland) | 0.96 | 0.01 | 2.62 | (1.28,5.39) |
| | | 3 (Shrub) | 0.90 | 0.01 | 2.46 | (1.2,5.04) |
| | | 4 (Shrub-Grass Complex) | 0.77 | 0.06 | 2.16 | (0.98,4.73) |
| | | 5 (Forest) | 0.68 | 0.07 | 1.98 | (0.94,4.19) |
| | | 6 (Water) | 1.19 | 0.00 | 3.28 | (1.49,7.21) |
| | | 8 (Barren/Badlands) | 1.60 | 0.00 | 4.94 | (2.42,10.09) |
| | Slope | NA | 0.12 | 0.00 | 1.12 | (1.09,1.16) |
| 105m Scale | Slope | NA | 0.15 | 0.00 | 1.16 | (1.13,1.2) |
| | Cover Type | 1 (Agricultural land) | | | | |
| | | 2 (Grassland) | 1.08 | 0.01 | 2.94 | (1.36,6.35) |
| | | 3 (Shrub) | 1.05 | 0.01 | 2.87 | (1.33,6.17) |
| | | 4 (Shrub-Grass Complex) | 0.99 | 0.02 | 2.69 | (1.16,6.23) |
| | | 5 (Forest) | 0.97 | 0.02 | 2.65 | (1.19,5.90) |
| | | 6 (Water) | 1.41 | 0.00 | 4.08 | (1.77,9.41) |
| | | 8 (Barren/Badlands) | 1.72 | 0.00 | 5.60 | (2.61,12.05) |
| | West/East | NA | -0.14 | 0.04 | 0.87 | (0.77,0.99) |

Table 8. Continued

| Scale of model | Variable | Level of categorical variables | Coefficients for variable(s) | P-value | Odds ratio | 95% CI for odds ratio |
|---|---|---|---|---|---|---|
| 195m Scale | Slope | NA | 0.17 | 0.00 | 1.18 | (1.14,1.22) |
| | Cover Type | 1 (Agricultural land) | | | | |
| | | 2 (Grassland) | 0.84 | 0.02 | 2.33 | (1.17,4.61) |
| | | 3 (Shrub) | 0.79 | 0.02 | 2.21 | (1.12,4.37) |
| | | 4 (Shrub-Grass Complex) | 0.81 | 0.04 | 2.25 | (1.03,4.94) |
| | | 5 (Forest) | 0.57 | 0.16 | 1.77 | (0.80,3.88) |
| | | 6 (Water) | 1.11 | 0.00 | 3.04 | (1.43,6.47) |
| | | 8 (Barren/Badlands) | 1.52 | 0.00 | 4.58 | (2.32,9.05) |
| | Canopy Cover | NA | 0.10 | 0.41 | 1.10 | (0.88,1.38) |
| | West/East | NA | -0.16 | 0.01 | 0.85 | (0.75,0.97) |
| 285m Scale | Slope | NA | 0.17 | 0.00 | 1.19 | (1.15,1.23) |
| | Cover Type | 1 (Agricultural land) | | | | |
| | | 2 (Grassland) | 1.16 | 0.00 | 3.17 | (1.47,6.85) |
| | | 3 (Shrub) | 1.07 | 0.01 | 2.91 | (1.35,6.25) |
| | | 4 (Shrub-Grass Complex) | 0.70 | 0.15 | 2.00 | (0.77,5.20) |
| | | 5 (Forest) | 0.96 | 0.02 | 2.60 | (1.16,5.85) |
| | | 6 (Water) | 1.43 | 0.00 | 4.19 | (1.80,9.77) |
| | | 8 (Barren/Badlands) | 1.86 | 0.00 | 6.43 | (3.00,13.81) |
| | West/East | NA | -0.21 | 0.00 | 0.81 | (0.72,0.92) |

Table 9. The details of the most parsimonious of the *a priori* models for each scale on the full data set.

| Scale of Model | Variable | Level of Categorical Variables | Coefficients for Variable(s) | P-Value | Odds Ratio | 95% CI for Odds Ratio |
|---|---|---|---|---|---|---|
| Zero Scale | Cover Type | 1 (Agricultural land) | | | | |
| | | 2 (Grassland) | 1.01 | 0.01 | 2.75 | (1.34,5.66) |
| | | 3 (Shrub) | 0.95 | 0.01 | 2.59 | (1.26,5.32) |
| | | 4 (Shrub-Grass Complex) | 0.82 | 0.04 | 2.27 | (1.03,5.00) |
| | | 5 (Forest) | 0.76 | 0.05 | 2.15 | (1.01,4.56) |
| | | 6 (Water) | 1.27 | 0.00 | 3.55 | (1.61,7.83) |
| | | 8 (Barren/Badlands) | 1.66 | 0.00 | 5.23 | (2.56,10.72) |
| | Sex | NA | 0.00 | 0.99 | 1.00 | (0.88,1.14) |
| | Slope | NA | 0.12 | 0.00 | 1.13 | (1.09,1.16) |
| | West/East | NA | -0.11 | 0.07 | 0.89 | (.79,1.01) |
| 105m Scale | Cover Type | 1 (Agricultural land) | | | | |
| | | 2 (Grassland) | 1.08 | 0.01 | 2.94 | (1.36,6.35) |
| | | 3 (Shrub) | 1.05 | 0.01 | 2.87 | (1.33,6.17) |
| | | 4 (Shrub-Grass Complex) | 0.99 | 0.02 | 2.69 | (1.16,6.23) |
| | | 5 (Forest) | 0.97 | 0.02 | 2.65 | (1.19,5.90) |
| | | 6 (Water) | 1.40 | 0.00 | 4.07 | (1.76,9.40) |
| | | 8 (Barren/Badlands) | 1.72 | 0.00 | 5.60 | (2.61,12.05) |
| | Sex | NA | -0.02 | 0.82 | 0.98 | (0.86,1.13) |
| | Slope | NA | 0.15 | 0.00 | 1.16 | (1.13,1.20) |
| | West/East | NA | -0.14 | 0.04 | 0.87 | (0.76,0.99) |

Table 9. Continued

| Scale of Model | Variable | Level of Categorical Variables | Coefficients for Variable(s) | P-Value | Odds Ratio | 95% CI for Odds Ratio |
|---|---|---|---|---|---|---|
| 195m Scale | Cover Type | 1 (Agricultural land) | | | | |
| | | 2 (Grassland) | 0.85 | 0.02 | 2.33 | (1.17,4.62) |
| | | 3 (Shrub) | 0.79 | 0.02 | 2.21 | (1.12,4.37) |
| | | 4 (Shrub-Grass Complex) | 0.81 | 0.04 | 2.26 | (1.03,4.95) |
| | | 5 (Forest) | 0.70 | 0.06 | 2.02 | (0.98,4.17) |
| | | 6 (Water) | 1.11 | 0.00 | 3.05 | (1.43,6.47) |
| | | 8 (Barren/Badlands) | 1.53 | 0.00 | 4.61 | (2.34,9.11) |
| | Sex | NA | -0.01 | 0.87 | 0.99 | (0.87,1.13) |
| | Slope | NA | 0.17 | 0.00 | 1.18 | (1.14,1.22) |
| | West/East | NA | -0.16 | 0.01 | 0.85 | (0.75,0.97) |
| 285m Scale | Cover Type | 1 (Agricultural land) | | | | |
| | | 2 (Grassland) | 1.16 | 0.00 | 3.17 | (1.47,6.85) |
| | | 3 (Shrub) | 1.07 | 0.01 | 2.91 | (1.35,6.25) |
| | | 4 (Shrub-Grass Complex) | 0.70 | 0.15 | 2.00 | (0.77,5.20) |
| | | 5 (Forest) | 0.96 | 0.02 | 2.60 | (1.16,5.85) |
| | | 6 (Water) | 1.43 | 0.00 | 4.19 | (1.80,9.77) |
| | | 8 (Barren/Badlands) | 1.86 | 0.00 | 6.43 | (3.00,13.81) |
| | Sex | NA | 0.00 | 0.99 | 1.00 | (0.88,1.14) |
| | Slope | NA | 0.17 | 0.00 | 1.19 | (1.15,1.23) |
| | West/East | NA | -0.21 | 0.00 | 0.81 | (0.72,0.92) |

Table 10. The details of the most parsimonious models based on AIC for each scale on the truncated data set.

| Scale of model | Variable | Level of categorical variables | Coefficients for variable(s) | P-value | Odds ratio | 95% CI for odds ratio |
|---|---|---|---|---|---|---|
| Zero Scale | Cover Type | 1 (Agricultural land) | | | | |
| | | 2 (Grassland) | 1.27 | 0.00 | 3.57 | (1.56,8.16) |
| | | 3 (Shrub) | 1.18 | 0.01 | 3.24 | (1.42,7.40) |
| | | 4 (Shrub-Grass Complex) | 0.98 | 0.03 | 2.65 | (1.07,6.55) |
| | | 5 (Forest) | 0.97 | 0.03 | 2.63 | (1.11,6.23) |
| | | 6 (Water) | 1.61 | 0.00 | 5.01 | (2.05,12.20) |
| | | 8 (Barren/Badlands) | 1.93 | 0.00 | 6.91 | (3.03,15.76) |
| | Slope | NA | 0.13 | 0.00 | 1.13 | (1.01,1.17) |
| | West/East | NA | -0.11 | 0.12 | 0.90 | (0.78,1.03) |
| 105m Scale | Cover Type | 1 (Agricultural land) | | | | |
| | | 2 (Grassland) | 1.06 | 0.01 | 2.89 | (1.34,6.24) |
| | | 3 (Shrub) | 0.98 | 0.01 | 2.66 | (1.23,5.74) |
| | | 4 (Shrub-Grass Complex) | 0.99 | 0.02 | 2.69 | (1.16,6.26) |
| | | 5 (Forest) | 0.89 | 0.03 | 2.42 | (1.08,5.42) |
| | | 6 (Water) | 1.43 | 0.00 | 4.18 | (1.81,9.67) |
| | | 8 (Barren/Badlands) | 1.67 | 0.00 | 5.34 | (2.48,11.50) |
| | Slope | NA | 0.17 | 0.00 | 1.18 | (1.14,1.22) |
| | West/East | NA | -0.13 | 0.05 | 0.87 | (0.76,1.0) |

Table 10. Continued

| Scale of model | Variable | Level of categorical variables | Coefficients for variable(s) | P-value | Odds ratio | 95% CI for odds ratio |
|---|---|---|---|---|---|---|
| 195m Scale | Cover Type | 1 (Agricultural land) | | | | |
| | | 2 (Grassland) | 1.09 | 0.01 | 2.96 | (1.37,6.40) |
| | | 3 (Shrub) | 0.99 | 0.01 | 2.69 | (1.25,5.80) |
| | | 4 (Shrub-Grass Complex) | 0.92 | 0.04 | 2.51 | (1.04,6.08) |
| | | 5 (Forest) | 0.95 | 0.02 | 2.58 | (1.15,5.83) |
| | | 6 (Water) | 1.41 | 0.00 | 4.09 | (1.76,9.47) |
| | | 8 (Barren/Badlands) | 1.83 | 0.00 | 6.2 | (2.88,13.36) |
| | Slope | NA | 0.16 | 0.00 | 1.18 | (1.14,1.22) |
| | West/East | NA | -0.16 | 0.02 | 0.85 | (0.74,0.97) |
| 285m Scale | Cover Type | 1 (Agricultural land) | | | | |
| | | 2 (Grassland) | 1.47 | 0.00 | 4.36 | (1.77,10.75) |
| | | 3 (Shrub) | 1.34 | 0.00 | 3.83 | (1.56,9.40) |
| | | 4 (Shrub-Grass Complex) | 0.97 | 0.08 | 2.65 | (0.89,7.90) |
| | | 5 (Forest) | 1.27 | 0.01 | 3.55 | (1.38,9.14) |
| | | 6 (Water) | 1.91 | 0.00 | 6.77 | (2.56,17.92) |
| | | 8 (Barren/Badlands) | 2.2 | 0.00 | 8.98 | (3.66,22.07) |
| | Slope | NA | 0.18 | 0.00 | 1.19 | (1.15,1.24) |
| | West/East | NA | -0.2 | 0.00 | 0.81 | (0.71,0.93) |

odds ratio refers to the multiplicative effect on the probability of success for 1 unit increase in the $x_i$ for a parameter at fixed levels for the parameters in the equation.

Table 11. The most parsimonious model from stepwise logistic regression for the truncated data set at each scale compared to the most parsimonious model (285m scale).

| Scale of model | Variables in model | AIC | Δ AIC |
|---|---|---|---|
| 285m Scale | Cover Type+Slope+W/E | 6053.17 | 0.00 |
| 195m Scale | Cover Type+Slope+W/E | 6090.98 | -37.81 |
| 105m Scale | Cover Type+Slope+W/E | 6138.23 | -85.06 |
| Zero Scale | Cover Type+Slope+W/E | 6174.10 | -120.90 |

The interpretation for specific variables in the most parsimonious model from the truncated data set (no missing values) at the 285m scale (Table 10) would be as follows:

1) slope: The effect of a 1-unit increase in slope (an ordinal variable in which a change of 1 unit is equal to a 5 degree increase), with the levels of cover type and study area unit fixed, would be to increase the odds of success (use by sheep) by 19%.

2) cover type: Because cover type is a categorical variable, the effect of cover type 1 (agricultural land in this model) is included in the $\alpha$ (y-intercept term) term of the equation. This means that all interpretations of effect of cover type are relative to agricultural lands. The cover type with the greatest difference from agricultural land was the barren/badlands cover type. Sheep were 8.98 times more likely to be found in barren/badlands as they were agricultural lands given all other parameters are fixed.

3) The net effect of study area unit (west/east), a dichotomous variable, is that sheep were 0.81 times as likely to be found in the east end of the study area as the west end.

# DISCUSSION

## Population Status

Population estimates for sheep in HD 680 during 1998 and 1999 were too variable to identify population trends. However, total numbers counted during surveys conducted for this study and those conducted by MDFWP in the years prior to this study (Sullivan unpublished data 1995,1996 and 1997) indicate the population in HD 680 was stable.

Lamb-ewe ratios and minimum total lamb counts for the 1998 breeding season indicate that this population was reproductively successful. Comparison between lamb-ewe ratios I observed and those reported in other studies have limited utility because lamb-ewe ratios are difficult to compare when reporting techniques are inconsistent due to inconsistencies in reporting techniques (Festa-Bianchet 1992). Dates and actual numbers surveyed are normally not reported and papers seldom mention if the survey included only reproducing ewes (> 2.5 years of age) or all ewes. Authors seldom indicate the timing of lambing seasons and length and seasonality of lambing can vary by up to 2 months between populations, sub-species and geographic region. Patterns of lamb mortality (early, constant or late) associated with the surveyed population are often ignored. However, summer helicopter surveys in 1998 and 1999 indicated moderate early survival of lambs in 2 annual cohorts (≥40 lambs per 100 ewes). The March 1999 survey suggested the 1998 lamb cohort had good survival through winter (lamb-ewe ratio Aug. 1998 = 40/100 and Mar. 1999 = 56/100).

Yearling to ewe ratios based on ground sightings in July 1998 suggested that the 1997 cohort was successfully recruited into the population. Lower ratios from ground observations in June and July 1999 may indicate that recruitment of yearlings from the 1998 lamb cohort was low.

Adult survival was high in 1998 and 1999. Only 2 radio-collared animals (<10%) died during the study. Known hunting mortality in 1998 was 3% of the estimated ewe population and approximately 10% of the estimated ram population. I was unable to measure the impact of emigration, but no radio-collared animals migrated permanently from the study area.

## Home Range

The large seasonal home ranges (average ADK 95% seasonal home range for ewes varied from 4,265ha to 6,815ha and rams varied from 11,750ha to 18,779ha) exhibited by bighorn sheep in HD 680 indicate that sheep were highly mobile within their home ranges. Direct comparison to other populations is difficult because many show distinct summer and winter ranges. In these studies, the amount of area reported may correspond to an area clear of snow and not a probability-based home range calculation. However, Lewis (1998) reported average home ranges (95% ADK) for ewes, corresponding to the same approximate seasonal time frame I used, of 22.3 ha for winter, 22.6 ha for spring/summer and 30.7 ha for fall. Rams for the same period had home ranges of 43.6 ha, 42.0 ha and 24.3 ha. This amount of area differs by 2 and almost 3 orders of magnitude compared to home ranges of sheep in HD 680. In another study (Semmens 1996), home ranges calculated not by individuals but of 3 sub-populations (ewes only) that had summer home ranges of 600 ha to 3,100 ha and winter home ranges from 2,000 ha to 3,200 ha. These sub-populations had home ranges that were more similar to the pattern exhibited by ewes in HD 680. The summer home ranges I observed for ewes were 3 to 5 times larger and winter home ranges were similar to 3 times as large as those reported by Semmens (1996).

The pattern of habitat use I observed in my study allowed sheep to avoid potential competition with domestic livestock and exploit local variation in forage quality. Other studies in prairie environments have shown bighorn sheep often use small areas of preferred habitats to excess (Lewis 1998, Hobbs 1996, Kissel 1996, Cook 1990). Cook (1990) hypothesized that low elevation sheep tend to group and overuse limited high quality sites leaving only low quality forage available for lambs at weaning. The sheep in HD 680 moved around enough that I seldom found signs of forage use when they vacated a site. Having a large contiguous area with a mix of heterogeneous cover types interspersed with high levels of escape terrain may allow the sheep of HD 680 to follow phenology and potentially avoid reduced forage quality associated with desiccation and/or maturation of vegetation.

## Habitat Model

The most parsimonious habitat selection models indicated that 3 parameters were important: cover type, slope and study area unit. This was true for the full data set as well as the truncated data set. Since the truncated data set allows comparison across scales, I will discuss models based on that data set.

The first variable to enter all models at all scales in stepwise procedures was cover type. Odds ratios for individual cover type classes differed among models at different scales, but at all scales agricultural land was the least important cover type. Relative to agricultural land: presence of grassland, shrub, shrub-grass mosaic and forest in a pixel were 1.2 to 6.0 times as likely to predict the presence of sheep than presence of agricultural land. Pixels with water, which included the Missouri River and adjacent riparian vegetation, were 1.8 to 9.4 times more likely to predict presence of sheep than agricultural land. This implies water was a better predictor than the cover types of grassland, shrub, shrub-grass mosaic, forest and agricultural land (odds ratios of 1.8 to 9.4 relative to agricultural land). The barren/badland cover type was the best predictor of sheep use with odds ratios of 2.9 to 13.4 greater than agricultural land.

Slope, or more specifically escape terrain, has been well documented as a key feature in bighorn sheep habitat selection (Smith et al. 1990, Sweanor et al. 1994, Gudorf et al. 1996). Estimates for odds ratio for slope showed low variability at all scales. As scale increased, the odds ratio of slope increased slightly, indicating that bighorn sheep are more likely to use larger contiguous areas of escape terrain than smaller patches of escape terrain.

The odds ratio of the study area unit was similarly affected by scale. This variable most likely represents the differences in availability between cover types and slope between the west and east portions of the study area. Values < 1.0 suggest that habitat in the western half of the study area was better than that in the eastern half.

The model most widely used to define sheep habitat is one created by the National Park Service (NPS). The NPS model of Johnson and Swift (1995) has been applied in 7 study areas in and around 9 National Parks (Sweanor et al. 1996). This model defines bighorn sheep habitat based on: escape terrain, vegetation density, distance to water, proximity to domestic livestock, barriers, and human use areas. Escape terrain is a buffered area of 300m radius around areas of slope > 27° and < 85°. Vegetation density is defined as an area that has > 55% visibility as measured from ground transects (these transects are used to assign values to vegetation communities on a vegetation map). The distance to water is quantified as a 3.2-km buffer around water sources. Proximity to domestic livestock removes all habitat within a 16-km radius around areas used by domestic sheep. Barriers were defined as natural and man-made features that excluded animals from areas (rivers > 2000 cfs, areas with visibility < 30% that are at least 100 m wide, cliffs with > 85° slope, major highways, human use areas, wildlife-proof fences, aqueducts and canals).

My model shares similarities with the NPS modeling efforts but differs in several important ways. Slope was an important variable in my model as it was in the NPS model. However, cover type was the first variable to enter my model (*i.e.* had the most impact on AIC) at all scales. This implies that cover type is a better predictor of sheep use than slope alone, regardless of scale. The NPS model only uses vegetation to describe visibility. The nearest equivalent in my model was canopy cover. Canopy cover was not a good predictor of sheep use in HD 680. The vegetation variable in the NPS model requires direct ground measurement of vegetation, a vegetation map of the area being modeled, and that these 2 data sources be digitized to be evaluated in the model.

The NPS model may have also been too conservative in its definition of barriers to bighorn sheep, since individuals of HD 680 crossed the Missouri River at flows more than 12 times the volume listed as a barrier in the NPS model. Although I was unable to test the domestic livestock filter in the NPS model because there were no domestic sheep near my study area, the propensity for transmission of disease from domestic to wild sheep (Foreyt 1990, Foreyt and Jessup 1982) indicates this requirement should be added to my model.

The NPS model also included criteria for delineating winter range and lambing habitat. The sheep in HD 680 showed no different habitat selection in winter than any other time of year. This could mean that the NPS model has the potential to underestimate winter range when sheep do not show seasonal selection as the sheep in HD 680 did. I did not collect data on lambing and was unable to evaluate how the lambing habitat criteria performed.

Habitat Selection

My analysis of habitat selection in the Missouri Breaks indicated that desirable sites for bighorn sheep consist of barren/badlands cover with steep slopes adjacent to other native cover types. Access to a large dependable water source appears to be important. Isolated pockets of steep terrain, barren/badlands, or water are insufficient to provide habitat that will support a population. I was unable to identify a preferred mix of forest, shrub, and grassland for sheep, but lands used for row crop production appeared to be poor alternatives to any native cover types. The exception to this would be wheat grown in close proximity to escape terrain. In some of these areas, but not all, I observed sheep using wheat; predominately rams, although ewes did use them early in spring. Given that most wheat fields in the breaks are only planted every other year and only have vegetation on them 4 months out of every 2 years, this may not be an important cover type for sheep. However, conversion of CRP fields to wheat in the west unit of the study area may eliminate important habitat in the west unit sub-population.

I believe a 2 factor model (cover type and slope) at a 195m scale will yield the best results in predicting habitat suitability for sheep in the Missouri Breaks for sheep. I selected the 195m scale primarily because the odds ratios for cover type were slightly more stable than those at the zero and 285m scales (Table 8). The odds ratios for the 105m scale were similar, but the 195m scale allowed consideration of a larger area and still had a lower AIC.

Using a larger area for assessing suitability decreases the need for accuracy in digital layers and decreases the effects of locational errors in data used to develop the model. All digital land cover classification systems are plagued by accuracy problems in boundaries for vector-based data layers and pixel edge effects in raster-based layers. Unfortunately, the ability to produce digital land cover classifications far exceeds the ability to meaningfully quantify their accuracy (Lillesand and Kiefer 1994). Variability of spatial scales in land cover classification can also be a problem. Most classification systems do not classify on an individual pixel basis; they have minimum map units of approximately 100 m. This prevents small inclusions of cover types (microsites important to animals) from being included in cover type maps. Larger patches of desirable habitat may be missed because they cross pixel boundaries and are eliminated as small inclusions in each individual pixel.

Locational accuracy of data layers and animal locations can add additional uncertainty. Accuracy of geo-referencing satellite images, variability in land cover classification, and limits on accuracy of ground truthing introduce errors of tens to hundreds of meters in GIS layers. Accuracy in estimating animal positions and limits to GPS accuracy (satellite wobble, atmospheric effects and selective availability) limit the reliability of locational coordinates of animals used to develop models and can introduce errors of several to hundreds of meters. Assessing habitat use remotely at relatively coarse scales is the best available answer until new technologies such as better image rectification, better software, and land cover classifications based on smaller pixels, become available.

# CONCLUSIONS

## Population Status

The population in HD 680 was stable during 1998 and 1999. Counts of yearling animals were more variable than other classes. I was unable to determine what caused these variations, but further research on yearling survival and movements might help explain this variability.

## Habitat

The best sheep habitat in my study area consisted of steep badlands adjacent to the Missouri River with bench tops of native shrub and grassland above the slopes. Although CRP and wheat fields were used by sheep, further research is needed to see if agricultural lands are adequate habitat for bighorn sheep.

Bighorn sheep in my study area were very mobile and made use of large areas in 1998 and 1999; 2 years of average or above average rainfall. In dry years, water could potentially limit this population's ability to be highly mobile. Many ranchers in the area with BLM leases along the Missouri River do not graze cattle on land adjacent to the Missouri River except in dry years. This is due to difficulties of getting cattle in and out and the difficulty maintaining drift fences along the river. In dry years this has the potential to concentrate cattle and bighorn sheep in a small area and put them in direct competition for resources.

## Model Suitability

The 2 variable model derived from my study calculates the likelihood sheep will use an area based on cover type and slope. Other digital or remotely sensed data layers, such as multi-spectral radiometry (MSR) should be explored to see if they would improve on the cover type and slope model I defined. MSR would allow biomass to be compared to sheep use and might capture phenology. Biomass and phenology could influence sheep distribution and improve prediction of sheep use within cover types. The scale effect should also be validated in other locations and habitat types to verify that the relationship holds.

# LITERATURE CITED

Aronoff, S. 1995. Geographic information systems: a management perspective. WDL Publications. Ottawa, Canada. 294pp.

Arthur, S. M., B. F. Manly, L. L. McDonald, and G. W. Garner. 1996. Assessing habitat selection when availability changes. Ecology 77:215-227.

Baker, B. W., B. S. Brian, W. L. Mangus and J. L. McMillen. 1995. Spatial anaylsis of sandhill crane nesting habitat. Journal of Wildlife Mangement. 59(4):752-758.

Beane, R. D., and N. T. Hobbs. 1983. The Baermann technique for estimating *Protostrogylus* infection in bighorn sheep: Effect of laboratory procedures. Journal of Wildlife Diseases. 19:7-9.

Bleich, V. C., J. D. Wehausen, and S. A. Holl. 1990. Desert-dwelling mountain sheep: Conservation implications of a naturally fragmented distribution. Conservation Biology. 4:383-390.

Buechner, H. K. 1960. The bighorn sheep in the United States, its past, present and future. Wildlife Monographs 4:174.

Burnham, K. P., and D. R. Anderson. 1998. Model selection and inference: a practical Information-theoretic approach. Springer-Verlag, New York. 353pp.

Carrel, W. K., R. A. Ockenfels, J. A. Wennerlund and J. C. Devos. 1997. Topographic mapping, LORAN-C, and GPS accuracy for aerial telemetery locations. Journal of Wildlife Management. 61(4):1406-1412.

Cook, J. G. 1990. Habitat, nutrition, and population ecology of two transplanted bighorn sheep populations in southcentral Wyoming. Ph.D. dissertation, University of Wyoming. 311pp.

Dunn, W. C. 1996. Evaluating bighorn habitat: A landscape approach. Technical note 395. New Mexico Dept. Game and Fish. 41pp.

Eichhorn, L. C., C. R. Watts. 1972. Bighorns in the breaks. Montana outdoors. 3(3)32-34.

Environmental Systems Research Inc. 1999. ARCVIEW version 3.2. Environmental Systems Research institute. Redlands, CA.

Erickson, G. pp 86-91. (in) ed. D. E. Toweill, V. Geist. 1999. Return to royalty: wild sheep of North America. Boone and Crockett Club and Foundation for North American Wild Sheep. Missoula, MT. 214pp.

Festa-Bianchet, M. 1992. Use of ratios to predict bighorn sheep population dynamics. Biennial Symposium Northern Wild Sheep and Goat Council. 8:227-236.

Foreyt, W. J. 1990. Pneumonia in bighorn sheep: Effects of *Pasterurella haemolytica* from domestic sheep and effects on survival and long-term reproduction. Biennial Symposium Northern Wild Sheep and Goat Council. 7:92-101.

_____, and D. A. Jessup. 1982. Fatal pneumonia of bighorn sheep following association with domestic sheep. Journal of Wildlife Diseases. 18:163-168

Geist, V. 1971. Mountain sheep, a study in behavior and evolution. Univ. Chicago Press. Chicago. 383pp.

Grinnell, G. B. 1904. American big game in its haunts. New York: Forest and Stream Publishing Co. 497pp.

Gudorf, M., P. Y. Sweanor, J. Singer. 1996. Bighorn sheep habitat assessment of the greater Bighorn Canyon National Recreation Area. National Park Service and National Biological Service cooperative report. Bighorn Canyon National Recreation Area, Lowell. WY. 43pp.

Hamilin, K. L., R. J. Makie. 1989. Mule deer in the Missouri River Breaks, Montana – a study of population dynamics in a fluctuating environment. Montana Department of Fish, Wildlife and Parks. pp 401

Hobbs, N. T. 1996. Modification of ecosystem by ungulates. Journal of Wildlife Management. 60:695-713.

Johnson, D. H. 1980. The comparison of usage and availability measurements for evaluating resource preference. Ecology 61:61-71.

Johnson, L. B. 1990. Analyzing spatial and temporal phenomena using geographical information systems. Landscape Ecol. 4:31-43.

Johnson, T., and M. Swift. 1995. A test of a Rocky Mountain bighorn sheep habitat evaluation procedure. Rocky Mountain National Park report. Rocky Mountain National Park, Estes, CO.

Kie, J. G., Baldwin, J. A., Evans, C. J. 1994. CALHOME: home range analysis program-electronic user's manual. Report M-904. United States Forest Service. 19pp.

Kissel, R. E. 1996. Population dynamics, food habits, seasonal habitat use, and spatial relationships of bighorn sheep, mule deer, and feral horses in the Pryor Mountains, Montana/Wyoming. M.S. Thesis, Montana State University, Bozeman. 153pp.

Lancia, R. A., J. D. Nichols and K. H. Pollack. (in) ed. T. A. Bookhout, 1996. Research and management techniques for wildlife and habitats. Fifth ed., rev. The Wildlife Society, Bethesda, Md. 740pp.

Lawson, B. and R. Johnson. 1982 Mountain sheep. Pp 1036-1055 in Chapman, J. A. and G. A. Feldhammer eds. Wild mammals of North America; biology management, and economics. Johns Hopkins University Press.

Lehmkuhl, J. F., and M. G. Raphael. 1993. Habitat pattern around northern spotted owl locations on the Olympic Peninsula, Washington. Journal of Wildlife management. 57:302-315.

Lillesand, T. M., and R. W. Kiefer. 1994. Remote sensing and image interpretation. 3rd ed. John Wiley and sons, Inc. New York, NY. 750pp.

Lewis, S. T. 1998. Evaluation of habitat use by transplanted bighorn sheep herd in Theodore Roosevelt National Park. M.S. Thesis, Montana State University, Bozeman. 65pp.

Mathsoft. 1999. S-PLUS 2000, Guide to statistics, volume 1. Data analysis products Division, Seattle, WA. 637pp

McCarthy, J. J. History of transplanting mountain goats and mountain sheep-Montana. Biennial Symposium Northern Wild Sheep and Goat Council. 10:176-183.

Redmond, R.L., M.M. Hart, J.C. Winne, W.A. Williams, P.C. Thornton, Z. Ma, C.M. Tobalske, M.M. Thornton, K.P. McLaughlin, T.P. Tady, F.B. Fisher, S.W. Running. 1998. The Montana Gap Analysis Project: final report. Unpublished report. Montana Cooperative Wildlife Research Unit, The University of Montana, Missoula. 136 pp.

Semmens, W. J. 1996. Seasonal movements and habitat use of the Highland/Pioneer Mountains bighorn sheep herd of southwest Montana. Biennial Symposium Northern Wild Sheep and Goat Council. 10:35-44.

Smith, T. S., J. T. Flinders, and D. W. Olsen. 1988. Status and distribution of Rocky Mountain bighorn sheep in Utah. Biennial Symposium Northern Wild Sheep and Goat Council. 6:5-12.

______., J. T. Flinders, and D. S. Winn. 1990. Habitat evaluation procedure for rocky mountain bighorn sheep in the western rocky mountains and great basin region. Biennial Symposium Northern Wild Sheep and Goat Council. 7:210-229.

Sweanor, P. Y., M. Gudorf, F. J. Singer, R. Andrascik, W. F. Jensen, C. W. McCarty, M. Miller, D. Reed and R. Schiller. 1994. Bighorn sheep habitat assessment of The Greater Theodore Roosevelt National Park area. National Park Service and National Bioological Survey cooperative report. Theodore Roosevelt National Park, Medora, ND. 55pp.

________, P. Y., M. Gudorf, and F. J. Singer. 1996. Application of a GIS-based bighorn sheep habitat model in Rocky Mountain region National Parks. Biennial Symposium Northern Wild Sheep and Goat Council. 10:118-125.

Stow, D. A. 1993. The role of geographical information systems for landscape ecological studies. Pages 11-21 in Haines-Young, D. R. Green, and S. Cousins, eds. Landscape ecology and geographical information systems. Taylor and Francis, Bristol, Pa.

Sullivan, M., 1996. Return of the bighorns. Montana outdoors. Vol. 27, #6, Pages 2-7.

US Army Corps of Engineers. 1997. CORPSCON version 5.x. US Army Corps of Engineers Topographic Engineering Center. Alexandria, Va.

US Department of Defense. 1984. Federal radio navigation plan. DoD-4650.4, Department of Defense and Department of Transportation, Washington, D.C. 204pp.

White, G. C., and R. A. Garrott. 1990. Analysis of wildlife radio-tracking data. Academic Press. San Diego, California, USA. 383pp.

______., (no date). Program Capture [Online]. Available: ftp://ftp.cnr.colostate.edu/pub/capture/capture.zip

# APPENDICES

# APPENDIX A

Individual Home Ranges and Percent Overlap Tables

Table 12. Individual home ranges calculated with program CALHOME.

| Individual | Sex | Season[a] | Method[b] | Area(ha) | Individual | Sex | Season[a] | Method[b] | Area(ha) |
|---|---|---|---|---|---|---|---|---|---|
| 10 | F | Spr./Sum. | ADK 95 | 3,474 | 120 | M | Spr./Sum. | ADK 95 | 9,806 |
| | | | MCP 95 | 2,216 | | | | MCP 95 | 3,571 |
| | | Fall | ADK 95 | 876 | | | Fall | ADK 95 | 26,540 |
| | | | MCP 95 | 306 | | | | MCP 95 | 9,379 |
| | | Winter | ADK 95 | 4363 | | | Winter | ADK 95 | 10,340 |
| | | | MCP 95 | 1,357 | | | | MCP 95 | 6,259 |
| 131 | F | Spr./Sum. | ADK 95 | 3,511 | 231 | F | Spr./Sum. | ADK 95 | 5,595 |
| | | | MCP 95 | 2,824 | | | | MCP 95 | 2,781 |
| | | Fall | ADK 95 | 3,234 | | | Fall | ADK 95 | 5,809 |
| | | | MCP 95 | 1,240 | | | | MCP 95 | 3,318 |
| | | Winter | ADK 95 | 5,912 | | | Winter | ADK 95 | 1,775 |
| | | | MCP 95 | 1,767 | | | | MCP 95 | 1,050 |
| 251 | M | Spr./Sum. | ADK 95 | 12,810 | 330 | M | Spr./Sum. | ADK 95 | 7,763 |
| | | | MCP 95 | 7,183 | | | | MCP 95 | 5,230 |
| | | Fall | ADK 95 | 6,003 | | | Fall | ADK 95 | 15,690 |
| | | | MCP 95 | 4,508 | | | | MCP 95 | 7,234 |
| | | Winter | ADK 95 | 14,377 | | | Winter | ADK 95 | 10,520 |
| | | | MCP 95 | 5,624 | | | | MCP 95 | 6,841 |
| 341 | M | Spr./Sum. | ADK 95 | 38,390 | 420 | F | Spr./Sum. | ADK 95 | 4,130 |
| | | | MCP 95 | 10,410 | | | | MCP 95 | 2,394 |
| | | Fall | ADK 95 | 25,940 | | | Fall | ADK 95 | 5,512 |
| | | | MCP 95 | 11,670 | | | | MCP 95 | 4,112 |
| | | Winter | ADK 95 | 3,842 | | | Winter | ADK 95 | 5,125 |
| | | | MCP 95 | 1,475 | | | | MCP 95 | 2,164 |
| 440 | M | Spr./Sum. | ADK 95 | 10,680 | 480 | F | Spr./Sum. | ADK 95 | 4,472 |
| | | | MCP 95 | 5,427 | | | | MCP 95 | 2,552 |
| | | Fall | ADK 95 | 8,530 | | | Fall | ADK 95 | 5,617 |
| | | | MCP 95 | 4,408 | | | | MCP 95 | 2,780 |
| | | Winter | ADK 95 | 6,149 | | | Winter | ADK 95 | 3,067 |
| | | | MCP 95 | 4,482 | | | | MCP 95 | 1,410 |
| 700 | F | Spr./Sum. | ADK 95 | 1,830 | 800 | F | Spr./Sum. | ADK 95 | 2,631 |
| | | | MCP 95 | 871 | | | | MCP 95 | 1,499 |
| | | Fall | ADK 95 | 3,603 | | | Fall | ADK 95 | 3,539 |
| | | | MCP 95 | 1,539 | | | | MCP 95 | 1,449 |
| | | Winter | ADK 95 | 7,540 | | | Winter | ADK 95 | 4,688 |
| | | | MCP 95 | 3,711 | | | | MCP 95 | 1,511 |
| 900 | F | Spr./Sum. | ADK 95 | 4,292 | 1020 | M | Spr./Sum. | ADK 95 | 19,100 |
| | | | MCP 95 | 2,148 | | | | MCP 95 | 9,466 |
| | | Fall | ADK 95 | 7,783 | | | Fall | ADK 95 | 18,300 |
| | | | MCP 95 | 2,708 | | | | MCP 95 | 12,450 |
| | | Winter | ADK 95 | 4,783 | | | Winter | ADK 95 | 8,163 |
| | | | MCP 95 | 2,160 | | | | MCP 95 | 5,417 |

Table 12. Continued

| Individual | Sex | Season | Method* | Area(ha) | Individual | Sex | Season | Method* | Area(ha) |
|---|---|---|---|---|---|---|---|---|---|
| 1130 | M | Spr./Sum. | ADK 95 | 7,525 | 1137 | F | Spr./Sum. | ADK 95 | 11,960 |
| | | | MCP 95 | 4,626 | | | | MCP 95 | 4,550 |
| | | Fall | ADK 95 | 23,880 | | | Fall | ADK 95 | 6,236 |
| | | | MCP 95 | 11,620 | | | | MCP 95 | 4,472 |
| | | Winter | ADK 95 | 28,130 | | | Winter | ADK 95 | 8,795 |
| | | | MCP 95 | 12,610 | | | | MCP 95 | 6,194 |
| 1380 | M | Spr./Sum. | ADK 95 | 6,311 | 1390 | F | Spr./Sum. | ADK 95 | 6,573 |
| | | | MCP 95 | 2,884 | | | | MCP 95 | 1,939 |
| | | Fall | ADK 95 | 20,040 | | | Fall | ADK 95 | 6,595 |
| | | | MCP 95 | 8,744 | | | | MCP 95 | 2,543 |
| | | Winter | ADK 95 | 3,359 | | | Winter | ADK 95 | 6,481 |
| | | | MCP 95 | 1,904 | | | | MCP 95 | 2,054 |
| 1452 | F | Spr./Sum. | ADK 95 | 2,921 | 1584 | F | Spr./Sum. | ADK 95 | 5,731 |
| | | | MCP 95 | 999 | | | | MCP 95 | 3,466 |
| | | Fall | ADK 95 | 3,222 | | | Fall | ADK 95 | 2,563 |
| | | | MCP 95 | 1,213 | | | | MCP 95 | 1,533 |
| | | Winter | ADK 95 | 1,482 | | | Winter | ADK 95 | 585 |
| | | | MCP 95 | 275 | | | | MCP 95 | 325 |
| 1600 | F | Spr./Sum. | ADK 95 | 4,616 | 1660 | F | Spr./Sum. | ADK 95 | 15,210 |
| | | | MCP 95 | 2,997 | | | | MCP 95 | 4,974 |
| | | Fall | ADK 95 | 8,886 | | | Fall | ADK 95 | 5,622 |
| | | | MCP 95 | 4,823 | | | | MCP 95 | 3,097 |
| | | Winter | ADK 95 | 5,687 | | | Winter | ADK 95 | 2,758 |
| | | | MCP 95 | 3,228 | | | | MCP 95 | 1,722 |
| 1780 | F | Spr./Sum. | ADK 95 | 5,813 | 1810 | F | Spr./Sum. | ADK 95 | 4,330 |
| | | | MCP 95 | 2,362 | | | | MCP 95 | 3,256 |
| | | Fall | ADK 95 | 20,730 | | | Fall | ADK 95 | 21,030 |
| | | | MCP 95 | 9,545 | | | | MCP 95 | 12,320 |
| | | Winter | ADK 95 | 19,690 | | | Winter | ADK 95 | 2,053 |
| | | | MCP 95 | 6,833 | | | | MCP 95 | 1,336 |
| 1880 | F | Spr./Sum. | ADK 95 | 5,379 | 1890 | M | Spr./Sum. | ADK 95 | 13,500 |
| | | | MCP 95 | 2,873 | | | | MCP 95 | 3,676 |
| | | Fall | ADK 95 | 18,920 | | | Fall | ADK 95 | 18,110 |
| | | | MCP 95 | 11,010 | | | | MCP 95 | 9,637 |
| | | Winter | ADK 95 | 3,150 | | | Winter | ADK 95 | 13,105 |
| | | | MCP 95 | 1,434 | | | | MCP 95 | 5,793 |
| 1990 | M | Spr./Sum. | ADK 95 | 18,010 | | | | | |
| | | | MCP 95 | 8,039 | | | | | |
| | | Fall | ADK 95 | 22,810 | | | | | |
| | | | MCP 95 | 5,876 | | | | | |
| | | Winter | ADK 95 | 11,580 | | | | | |
| | | | MCP 95 | 3,893 | | | | | |

Table 12. Continued

[a] Spring/summer covers the time period from April 1999 through July 1999. Fall covers the time period from August 1999 through November 1999. Winter covers the time period from December 1998 through March 1999.

Table 13. The percentage of individual home ranges[a] overlap by season, where overlap describes how much of a seasonal home range is contained in the other 2 seasonal home ranges.

| Individual | Sex | Season | % Overlap | Individual | Sex | Season | % Overlap |
|---|---|---|---|---|---|---|---|
| 10 | F | Winter | 49.63 | 1130 | M | Winter | 47.08 |
| | | Spring/summer | 49.89 | | | Spring/summer | 85.68 |
| | | Fall | 100 | | | Fall | 65.15 |
| 120 | M | Winter | 98.34 | 1137 | F | Winter | 79.66 |
| | | Spring/summer | 99.47 | | | Spring/summer | 49.86 |
| | | Fall | 52.72 | | | Fall | 40.1 |
| 131 | F | Winter | 45.97 | 1380 | M | Winter | 92.52 |
| | | Spring/summer | 92.5 | | | Spring/summer | 98.55 |
| | | Fall | 86.34 | | | Fall | 36.09 |
| 231 | F | Winter | 100 | 1390 | F | Winter | 89.33 |
| | | Spring/summer | 64.9 | | | Spring/summer | 70.88 |
| | | Fall | 57.1 | | | Fall | 79.79 |
| 251 | M | Winter | 69.88 | 1452 | F | Winter | 43.22 |
| | | Spring/summer | 74.83 | | | Spring/summer | 74.84 |
| | | Fall | 99.04 | | | Fall | 87.73 |
| 330 | M | Winter | 51.99 | 1584 | F | Winter | 100 |
| | | Spring/summer | 78.02 | | | Spring/summer | 31.72 |
| | | Fall | 58.99 | | | Fall | 87.66 |
| 340 | M | Winter | 60.52 | 1600 | F | Winter | 81.65 |
| | | Spring/summer | 91.26 | | | Spring/summer | 96.01 |
| | | Fall | 88.87 | | | Fall | 48.9 |
| 420 | F | Winter | 52.03 | 1660 | F | Winter | 100 |
| | | Spring/summer | 81.85 | | | Spring/summer | 37.92 |
| | | Fall | 64.38 | | | Fall | 65.6 |
| 440 | M | Winter | 92.14 | 1780 | M | Winter | 87.36 |
| | | Spring/summer | 81.85 | | | Spring/summer | 100 |
| | | Fall | 64.38 | | | Fall | 54.94 |
| 480 | F | Winter | 72.08 | 1810 | F | Winter | 91.35 |
| | | Spring/summer | 81.29 | | | Spring/summer | 100 |
| | | Fall | 60.01 | | | Fall | 21.3 |
| 700 | F | Winter | 32.39 | 1880 | F | Winter | 99.37 |
| | | Spring/summer | 100 | | | Spring/summer | 100 |
| | | Fall | 74.73 | | | Fall | 28.44 |
| 800 | F | Winter | 86.65 | 1890 | M | Winter | 98.79 |
| | | Spring/summer | 85.05 | | | Spring/summer | 59.19 |
| | | Fall | 97.42 | | | Fall | 80.55 |