Development and Testing of Occupancy Surveys for Sympatric Bighorn Sheep and Mountain Goats in Northern Yellowstone

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ABSTRACT

Using Occupancy Surveys to Assess Summer Resource Selection of Sympatric Bighorn Sheep and Mountain Goats in Northern Yellowstone

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Both bighorn sheep and mountain goats are generalist herbivores that overlap extensively in broad food and habitat requirements, but there have been few studies examining the potential for competition between sympatric populations. One area in which native bighorn sheep are living in sympatry with non-native mountain goats is the southern Gallatin Mountain range within and adjacent to the northwest boundary of Yellowstone National Park. Existing data of bighorn sheep and mountain goat observations for the area vary in spatial precision and records of areas where observers looked for but did not detect animals are not available. To gain a better understanding of the relationship between bighorn sheep and mountain goats and their habitat, it is necessary to understand resource selection and the extent of overlap in resource use among sympatric populations on fine spatial and temporal scales. In order to meet this need we designed and implemented formal, ground-based occupancy surveys during the summer of 2011. A crew of four spent 113 observer days in the field resulting in 240 hours of occupancy surveys and approximately 210 miles hiked. Observers recorded presence-absence data for both mountain ungulates. A total of 6,932 sample units were surveyed, with 68 bighorn sheep and 95 mountain goat groups detected. Proportions of bighorn sheep and mountain goat groups detected by both observers during double observer surveys were 76.9% and 54.5%, respectively. We summarize the objectives and field design of this project and report on our efforts to develop enhanced habitat models which will provide managers with additional ecological insights.
INTRODUCTION

An organism’s ecological niche is defined by its ecological role and the abiotic and biotic factors within its habitat that limit where it can survive, develop, and reproduce (Elton 1927, Hutchinson 1957). In the absence of competitors, an organism can occupy a larger ecological niche than when the use of some primary resource is restricted by individuals of another species. When two species have overlapping niches, interspecific competition will occur resulting in one species using limited resources more efficiently and reproducing faster. In some instances interspecific competition may lead to local elimination of the inferior competitor, which is known as competitive exclusion (Gause 1934, Begon et al. 2006). The extent of interspecific competition is reliant on the extent of niche overlap and is expected to lead to evolution towards niche divergence (Lack 1947, Schluter et al. 1985) allowing both species to coexist.

In some situations interspecific competition can be caused by intentional or accidental introduction of non-native species by human activities (Cox 1999). When occupying a niche similar to that of native species, non-native species may compete for resources indirectly through resource exploitation, or directly through interference by individuals (Pianka 1981, Noss and Cooperrider 1994, Poling and Hayslette 2006). Native species competing with exotics may be forced to modify their use of resources, resulting in decreased individual fitness and less abundant populations (Gause 1934, Hobbs et al. 1990, Mack et al. 2000). Non-native species may also serve as vectors for disease transmission (Reed and Green 1994, Daszak et al. 2000) which may further limit the fitness of native species. In some cases, competition with non-native species may lead to competitive exclusion of native species. When assessing potential competition between native and non-native species, it is important to consider other potential determinants of the distribution and abundance of a native species such as human exploitation, predator effects, climate change and disease outbreaks (Fritts and Rodda 1998).

In some parts of North America mountain goats (Oreamnos americanus) are not native causing concern about their potential impact on native plant and animal populations, particularly Rocky Mountain bighorn sheep (Ovis canadensis canadensis) (Laundre 1994, Varley and Varley 1996). Mountain goats are native to North America with historic ranges throughout British Columbia, Alberta, the Yukon Territories, southern Alaska and the northwestern United States, west of the Continental Divide (Chadwick 1983). Native populations in the United States are restricted to Alaska, northern Idaho, western Montana and western Washington (Guenzel 1980, Picton and Lonner 2008). Mountain goat habitat is frequently characterized by remote, mountainous, steep and cliffy terrain. In an effort to increase hunting opportunities in the early and mid-1900s, state wildlife agencies in the northwestern United States transplanted mountain goats to numerous mountain ranges outside their historical range (Picton and Lonner 2008). Introduced populations of mountain goats have expanded their range substantially making it critical to examine the potential effects of mountain goats on bighorn sheep.
Native populations of Rocky Mountain bighorn sheep are distributed throughout the mountainous regions of western North America from Alberta and British Columbia south as far as central Arizona and northern New Mexico. Bighorn sheep prefer areas of open landscape with stable plant communities, dominated by grasses and sedges in close proximity to steep, mountainous terrain. Both mountain goats and bighorn sheep are generalist herbivores that overlap extensively in broad food and habitat requirements (Laundre 1994). Although bighorn sheep and mountain goats are adapted to various habitats, it appears they most frequently overlap in subalpine and alpine areas. Similarities in foraging and habitat use could lead to competition between the two species (Pianka 1981, Noss and Cooperrider 1994, Mack et al. 2000, Poling and Hayslette 2006).

To date, there have been few studies examining the potential for competition between mountain goats and bighorn sheep. The majority of studies on these two species have examined feeding habits and habitat use of only allopatric populations and attempted to demonstrate the potential for competition based on broad use of similar resources. Resulting literature indicates possible competition between the two species as a result of dietary overlap in some seasons as well as dominance of mountain goats over bighorn sheep when direct interactions occur (Chadwick 1983, Reed 1986).

Both mountain goats and bighorn sheep have some distinctive physical adaptations which should allow them to successfully exploit different niches within alpine and subalpine habitats. Mountain goats have short, heavily muscled limbs and broad hooves with special traction pads that help grip on smooth surfaces, such as rock and ice. They are not well suited to outrun predators (Geist 1971, Adams et al. 1982, Chadwick 1983) and in many cases avoid predation by escaping to steeper, more rugged terrain. This requires mountain goats to forage alone or in small groups, where food resources are frequently patchy and/or sparse in cliff terrain (Adams et al. 1982). Bighorn sheep are morphologically well adapted to outrun predators over broken terrain (Geist 1971:257) with longer limbs and leaner bodies. As a result, they tend to feed in larger groups in areas of continuous, dense forage with unobstructed visibility and close proximity to open areas where they can outrun predators (Shannon et al. 1975, Adams et al. 1982). Bighorn sheep and mountain goats are naturally sympatric in some areas west of the Continental Divide and both species, in these areas seem to have partitioned their use of resources in such a manner that they are able to coexist. In other areas, bighorn sheep have persisted in the absence of competition from native mountain goat populations. The possibility exists that in these areas bighorn sheep have expanded their niche to encompass some of the resources that would typically be used by mountain goats in their native habitat. In these instances the potential for competition between the two species may be increased as a result of greater overlap in resource use. To gain a better understanding of the relationship between bighorn sheep and mountain goats and their habitat, it is necessary to understand resource selection and the extent of overlap in resource use among both allopatric and sympatric populations on a fine spatial scale.

Several types of data may be used to examine resource selection by animals; however, each has strengths and limitations. Most commonly, presence-only data are collected which
consist of animal locations from radio-telemetry collars, transect surveys or opportunistic sightings and do not include records for areas where observers looked for but did not detect animals. These data may be used to produce coarse spatial representations of animal distributions (Elith et al. 2006, Gormley et al. 2011) but do not allow for predictions or comparisons between places where the species of interest is present and absent (Hirzel et al. 2006). In these situations, where non-detection points do not exist, random “available” points may be generated for the study area and compared to points of use; however, this method is less likely than formal survey methods to identify sites of true absence (Loiselle et al. 2003, Keating and Cherry 2004). If available points are used instead of non-detection points, the intercept cannot be interpreted, and only a resource selection function (RSF) can be estimated. A RSF provides only relative probabilities that are proportional to the actual probabilities of use for an area. When true probabilities of use across a study area are very small, relative probabilities may be misleading. One area may appear to be strongly selected for relative to another, when in fact both areas have very small actual probability of use (Manly et al. 2002, Lele and Kleim 2006). Presence-only data are frequently not collected as part of systematic, standardized surveys and, as a result, are likely subject to spatial and detection biases (Hijmans et al. 2000, Reese et al. 2005, and Gormley et al. 2011).

A second type of data used to assess resource selection is presence-absence data. These data are most often collected as part of formal occupancy surveys, during which observers record areas of both detection and non-detection of animals, within defined survey units. These data may be used to estimate resource selection probability functions (RSPF) which allow for estimation of the actual probability that a species of interest will use a given resource, based on some combination of ecological variables, such as food or escape terrain.

The most effective type of data for examining resource selection is occupancy data which consists of presence-absence data combined with estimates of the probability that an animal will be detected when present in a survey unit. Animals will not always be detected by observers when present, so we cannot interpret non-detection of an animal as a true absence. Failure to account for imperfect detection will tell us more about the observer’s ability to find animals on the landscape rather than true occupancy (MacKenzie 2005) and can result in the underestimation of occupancy and false inferences about the relationship between actual occupancy and habitat characteristics. There is typically variation in the probability among survey units that an animal will be detected when present. By visiting survey units repeatedly over a short period of time and conducting multiple surveys it is possible to use patterns of detection and non-detection to estimate detection probabilities (MacKenzie et al. 2002).

Our study area represents a portion of the southern Gallatin Mountain range within and adjacent to the northwest boundary of Yellowstone National Park (Figure 1) which provides year-round habitat for native bighorn sheep and non-native mountain goats. Based on historical observation data, we know that bighorn sheep and mountain goats have been sympatric in the area since 1967; however existing animal location data have been collected in many different ways resulting in observations that vary greatly in spatial precision. Most of these observations
were recorded by managers during annual population surveys and are comprised of presence-only data.

The objectives of this study are to: 1) use existing management presence-only data to develop habitat models to define regions within the general study area to be intensively sampled during formal occupancy surveys; 2) intensively sample individual regions within the study area in an effort to develop, test and refine ground-based field methodology for collection of spatially explicit occupancy data for bighorn sheep and mountain goats in mountainous terrain; and 3) develop preliminary habitat selection models to predict distributions of bighorn sheep and mountain goats by including additional habitat covariates, multiple scales of selection, and spatially explicit occupancy and detection data obtained during the 2011 field season.

**METHODS**

**Study Area**

The general study area (1342 km$^2$) used for the presence-only habitat selection modeling effort was located in the southern portion of the Gallatin Range in Montana and Wyoming and encompassed areas east of the Yellowstone River (Figure 1). The area was chosen based on historic data which indicated local sympatry of native bighorn sheep and introduced mountain goats. The area was further broken down into four survey regions (Region 1, Region 2, Region 3 and Region 4) to be used for the development of field methods and data collection for formal occupancy surveys. These four survey regions extended from Fortress Mountain south to Sepulcher Peak and were restricted to areas west of the Yellowstone River (Figure 1). Regions were defined based on the results of presence-only habitat suitability models and maps, as well as the ability of an occupancy survey field crew to cover a given area with the resources available during three to four day backpacking trips.
Figure 1. Study area located in the southern Gallatin Range in Montana and Wyoming. The area is composed of four individual survey regions, each of which was surveyed for presence and absence of bighorn sheep and mountain goats during the summer of 2011.

Land ownership was a mosaic of U.S. Forest Service (Gallatin National Forest), National Park Service (Yellowstone National Park), Bureau of Land Management and private lands. Topography varied from rolling hills and flats with winding streams to abrupt, steep slopes. Elevations in the area ranged from 1,501 meters at the Yellowstone River to 3,334 meters on Electric Peak. The area experiences short summers and harsh long winters, snow frequently persisting in the higher portions of the study area into July. Average annual precipitation is 118.6 centimeters as measured at 2469 meters elevation by the Shower Falls weather station in the northern Gallatin Range, Montana. Mean annual temperature is 1.1 degrees Celsius.

**Presence-Only Modeling Effort**

**Management Point Data**

In order to determine the area to be sampled via formal occupancy surveys in the summer of 2011, summer season habitat selection modeling was conducted using a subset of existing bighorn sheep and mountain goat presence-only observation data which were previously compiled into a point database of all available bighorn sheep and mountain goat locations for the Greater Yellowstone Area (GYA). Data were collected by multiple agencies including Montana Fish, Wildlife and Parks, Yellowstone National Park, Montana State University, and private
wildlife consultants beginning in 1967 and continuing to the present. Animals were observed from various survey platforms including airplanes, helicopters and ground locations. Many of these data were not collected as part of structured surveys, resulting in various spatial resolutions of animal locations. Records considered for these analyses were restricted to observations in our general study area and with quarter section or finer spatial resolution, resulting in a total of 160 mountain goat locations and 377 bighorn sheep locations (Figure 2a). There were insufficient mountain goat data to examine habitat use in winter or lambing seasons, so we opted to focus analyses on summer and rut location data for mountain goats and summer location data for bighorn sheep. Bighorn sheep appeared to move into lower elevation habitat during the rut, however mountain goats appeared to inhabit similar areas during both summer and rut seasons (Figure 2a). As a result, mountain goat location data from these two seasons were combined and included for development of summer habitat models. A total of 1000 available points were randomly distributed (Figure 2b) within the study area to define characteristics of available habitat and to compare available to used habitat locations. This number was chosen as it provided reasonable coverage of the study area and was anticipated to capture heterogeneity in the landscape. The same set of available points was employed in modeling for both species.

Around each point, a 300-m radius buffer was created for data extraction from the related covariate layers to quantify habitat characteristics. The buffer size was selected because this is the best spatial resolution we felt was reasonable to assign to these data.
Covariate Development

All covariates used for the presence-only modeling effort were developed as part of preliminary analyses conducted in 2010 and were based on bighorn sheep and mountain goat biology, published literature and readily accessible GIS layers. Each of six habitat parameters (Table 1) was measured using 30-by-30 m grid-cell resolution, as this was the most common resolution of available data sources and allowed for reasonable spatial resolution and feasible data processing. All related layers were compiled and analyzed in a geographic information system (GIS). GIS analyses and modeling were completed using ESRI’s ArcMap Ver. 9.1 software (available from: http://www.esri.com). Hawth’s Analysis Tools extension was also used to allow extraction of statistics from various GIS layers concurrently.

Table 1. List of covariates considered in presence-only modeling effort.

<table>
<thead>
<tr>
<th>Covariate List</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Distance to escape terrain</td>
<td>slope greater than 36 degrees</td>
</tr>
<tr>
<td>Elevation</td>
<td>meters</td>
</tr>
<tr>
<td>East/West Aspect</td>
<td>Gross et al. 2002</td>
</tr>
<tr>
<td>North/South Aspect</td>
<td>Gross et al. 2002</td>
</tr>
<tr>
<td>Percent tree</td>
<td>MODIS data re-sampled to 30 meters</td>
</tr>
<tr>
<td>Ruggedness</td>
<td>Poole et al. 2009</td>
</tr>
<tr>
<td>TCAP wetness</td>
<td>tasseled cap wetness (band 3), Landsat derivative (July 2000)</td>
</tr>
</tbody>
</table>
Habitat characteristics within the study area were represented using a Digital Elevation Model (DEM), Landsat Enhanced Thematic Mapper (ETM) satellite imagery and a MODIS scene. DEM layers were obtained from the Montana Natural Resource Information System (NRIS) (http://nris.mt.gov). Landsat imagery data were obtained from the Global Land Cover Facility website (www.landcover.org) and MODIS data were obtained from Montana State University’s Landscape Biodiversity Lab (http://www.montana.edu/hansen/). Distance to escape terrain (Escape), elevation (Elev), aspect (Asp) and ruggedness (Rug) were developed using DEM layers. Escape terrain has been defined in existing literature using a range of slopes from 27 degrees to greater than 40 degrees (Zeigenfuss et al. 2000, Gross et al. 2002, DeCesare and Pletscher 2006, Poole et al. 2009). For these analyses we defined escape terrain as slope greater than 36 degrees. A distance layer was created for the entire study area to determine the distance to the nearest escape terrain pixel. Two continuous covariates were derived from an aspect layer created for the study area. These covariates described N-S and E-W exposures and ranged from 0 to 180, with 0 indicating north or east, respectively, and 180 indicating south or west, respectively (Gross et al. 2002).

The data layer created from a MODIS scene covered the entire GYA and contained a percent tree cover (Tree) for each pixel. The original spatial resolution of the MODIS scene was 250 meters; however, it was resampled to 30 meters to ensure the resolution was comparable to other data layers used for analyses. Terrain ruggedness was calculated using the curvature function in ArcView 9.1. A curvature grid of 30 m resolution was generated and run through a moving window analysis for standard deviation within a 100 m radius of each grid cell. The result was a measure of the variability of the rate of change in slope for each grid cell. A high value was considered to be more rugged habitat as it would be indicative of a high degree of change in slope and complexity of surrounding cliffs (Poole et al. 2009).

Landsat data were converted from digital numbers to at-sensor reflectance values for normalization across scenes prior to use in data transformation and covariate creation. Landsat imagery for the study area consisted of three scenes collected in July of 2000. Image bands were downloaded individually in digital number format and were converted to at-sensor reflectance to be used for creating covariates. Preprocessing of Landsat imagery and creation of remotely sensed variables was done using Research System’s Inc. ENVI. v4.1. (personal communication: M. Zambon). The TCAP transformation was used to convert the original covariant Landsat data into new bands making up three unrelated indices: brightness, greenness and wetness which can reflect the condition of vegetation and soil (Sheng et al. 2011). Tasseled Cap Transformation Band 3 from Landsat ETM + imagery (Wet) was included as a surrogate for the amount of moisture found across the study area (lower values indicate wetter habitat) (Crist and Kauth 1986).
Statistical Modeling

Including two or more strongly correlated covariates in the same model may confound results and make interpretation difficult (Farrar and Glauber 1967). All pairwise correlations between covariates were explored to ensure highly co-linear covariates were not included in the same candidate models. The remaining covariates included in the global model were: \( \text{logit } \pi = \beta_0 + \beta_1 \text{(distance to escape terrain)} + \beta_2 \text{(elevation)} + \beta_3 \text{(east/west aspect)} + \beta_4 \text{(north/south aspect)} + \beta_5 \text{(percent tree)} + \beta_6 \text{(ruggedness)} + \beta_7 \text{(TCAP wetness)} \) which was used for subsequent modeling efforts.

Data were imported into program “R”. Density plots were created depicting the use and available location distributions for each of the seven covariates considered for mountain goat and bighorn sheep summer habitat models. These plots allow for easy interpretation of data distributions. If distributions of use and available points are comparable, it is unlikely the covariate in question represents a selection criterion. Where use and available distributions are different, there is evidence that the covariate may be influential to animal distributions.

We used logistic regression to relate the relative probabilities of use by bighorn sheep and mountain goats to the covariates of interest (Manly et al. 2002). Because these were exploratory analyses, all possible additive combinations of selected covariates were considered in modeling using the dredge function in program R. The strength of support that the data gave to each model was evaluated by ranking models with Akaike's Information Criterion and model weights (Burnham and Anderson 2002). Models within 4 ΔAIC units of the top model were considered to have received comparable support from the data. For each of the coefficient estimates resulting from top-models 95% confidence intervals were constructed.

Model outputs were in log odd units and were used for presentation of summer distribution maps. The ArcGIS raster calculator was used to apply regression coefficients from the top models to the covariates for the study area to create summer habitat suitability maps for mountain goats and bighorn sheep. The habitat suitability map constructed during this modeling exercise was used to identify regions within the general study area to be intensively sampled during formal occupancy surveys during the summer of 2011. Each survey area was stratified into four categories of species occurrence probability: very low (40%), low, medium and high (20%) probabilities of species occurrence. Due to the logistical and practical constraints of conducting ground surveys in mountainous terrain, occupancy survey sampling was limited to all areas predicted as high (20%) and medium (20%) suitability habitats and approximately half (10%) of the low suitability habitat defined by these models.

Occupancy Modeling Efforts

Development of Formal Occupancy Surveys

In order to divide the landscape into discrete sampling units for occupancy surveys, a 100 x 100 meter grid cell system was placed over an aerial photo of each of the survey regions.
The grid cell system was designed to allow observers to record animal locations with fine spatial resolution (within 100 meters) and to record areas where they looked for, but did not detect animals.

The field computers used for data collection were the Geo Mesa by Juniper Systems. ArcPad was loaded onto each of four field computers and custom modifications were made to ArcPad software to allow observers to enter animal locations, group sex-age composition, and behavior data accurately and efficiently into field computers during surveys.

Observers conducted occupancy surveys within each of the four survey regions. A survey event consisted of three to four day backpacking trips in each of these regions. Travel routes were placed along trails and ridges, based on what was logistically feasible and safe for observer travel, while affording observers a reasonable field of view. Observation points were systematically placed every three kilometers along travel routes using ArcGIS. A random number generator was used to select a starting point within the first three kilometers of the intended travel route. Observation points were then systematically selected every three kilometers from the starting point, as this distance allowed the survey crew to traverse a reasonable amount of the survey area during a three to four day trip.

Figure 3. Screen shot of ArcPad in Juniper Systems Geo Mesa field computers. Grid overlay is made up of 100x100 meter cells, which define the individual units surveyed for bighorn sheep and mountain goat presence-absence. Green dots indicate grid cells where observers looked but did not detect bighorn sheep or mountain goats, blue triangles indicate bighorn sheep observations and red triangles indicate mountain goat observations.
A 500 meter radius buffer was placed around each observation point to allow observers to select a site for conducting an occupancy survey that afforded maximum visibility of the landscape.

The surrounding viewsheds were surveyed and observations recorded into field computers. If there were multiple options for survey travel routes (i.e., a fork in the trail) direction of travel was based on logistics. Upon arrival at each systematically selected observation point, a coin was flipped to determine which observers would survey a given viewshed (i.e., east or west side of a ridgeline) from the observation point. The exception was when an observer had already surveyed parts of the adjacent area. In order to avoid confusion about which areas were previously surveyed by another observer the original observer surveyed the aforementioned adjacent area. Observers attempted to visit each predetermined observation point during a survey event. Certain pre-selected observation points were not visited, due to logistical constraints in the field (i.e., weather, challenging terrain, etc). Observers made every attempt to visit these points and survey visible viewsheds on subsequent visits.

Animals will not always be detected when they are present in a sampling unit. Patterns of detection and non-detection accrued through repeat surveys in a short period of time may be used to estimate detection probabilities (MacKenzie et al. 2002, 2003, Mackenzie and Royle 2005, Mackenzie et al. 2006). In an effort to accrue adequate animal detections for estimation of detection probabilities, observers alternated between double and single observation methods. During double observer surveys, the observers determined the most effective way to conduct one independent survey per team member. All communication regarding visual observation of presence or absence of animals ceased. Observers positioned themselves on opposite sides of a natural barrier (i.e., rock, vegetation) when possible and did not view the field computer of the other observer once a survey period had begun. These measures helped to ensure that data collected by each observer were independent. After surveys at selected observation points were completed, team members reconvened and determined which animals were detected by both observers and which animals were only detected by one observer. Data were recorded onto detection probability worksheets. Observers then traveled together to the next systematically selected observation point until all possible observation points had been visited and the associated visible viewsheds had been surveyed. Efforts were focused on visiting more sampling units rather than conducting more visits per sampling unit during a survey period, as additional visits do not always notably increase the accuracy of detection probability estimates (MacKenzie and Royle 2005). If previously surveyed grid cells were visible on a future trip, those grid cells were re-surveyed.

Before scanning grid cells within a viewshed for animals, observers agreed on a reasonable topographic boundary defining the area to be surveyed. This was done at the start of both single and double observer surveys to ensure observers were covering a comparable amount of land so survey duration was not drastically different. Date, survey point ID, survey start and end times and observer location (UTM, WGS-1984) were recorded. Average wind-speed (meters/second) over a ten-second period and temperature (degrees Fahrenheit) were measured.
using a Kestrel 2000 Pocket Weather meter at the beginning and end of each survey period. Data were recorded into field notebooks. Observers then scanned all grid cells within the viewshed for mountain goats and bighorn sheep using 10x42 binoculars and 20x60 spotting scopes. When animals were detected, the predominant behavior of the group at first observation (feeding, resting, traveling, or other) was recorded and each group was assigned a unique number for the day. A group was considered a single animal or individuals of a species within approximately 250 meters of each other. Animals separated by more than 250 meters at first detection were considered separate groups. Group numbers allowed us to record animals as they traveled through multiple grid cells and minimize the chance of animals being counted multiple times. Animals were counted before any attempt at age/sex classification was made in an effort to increase the likelihood of recording all visible animals before they moved out of sight. Counts and point locations of detected animals were recorded directly into the field computers.

Using binoculars and spotting scopes, observers attempted to classify individual animals within a group by age and sex classes, including mature male, young male, female, yearling or young of year. Bighorn sheep classes were determined using methods described by Geist (1971, 1979) and were based on a combination of possible identifying features including horn size, body size and positive identifying features, including urination posture and external genitalia. It is frequently difficult to differentiate between yearling males and ewes. If an observer was unable to differentiate between the two, the animal was classified as a female. Methods described by Chadwick (1983) were used to classify mountain goats and were based on a combination of possible identifying features including horn mass and shape, body size, rump cleanliness and positive identifying features, including external genitalia and urination posture. If it was not possible to determine the age or sex of an animal, it was recorded as unknown.

Each grid cell surveyed by an observer was assigned a ranking from 1-4 based on the percentage of the grid cell visible to the observer: 1-1%-25%, 2-26%-50%, 3-51%-75% and 4-76%-100%. This ranking system was based on topography (i.e. a cell going over a ridgeline or in a draw) and was not affected by cover or ruggedness. Due to high snow levels in 2011 and our inability to quantify snow cover using a GIS layer, we did not survey large areas of the landscape fully covered in snow. These areas would not be truly representative of the landscape features available at the time of the survey.

All surveyed grid cells where no bighorn sheep or mountain goats were detected were identified and recorded in the field computer by placing a non-detection point in approximately, the middle of the grid cell. If a group of animals moved into a previously unoccupied grid cell during a survey, the observer changed the status of the grid cell and included relevant animal information. If groups of animals were encountered while observers were traveling between the pre-determined observation points, they were counted and classified and their point location recorded as an opportunistic sighting. Surveys were not conducted during periods of extreme inclement weather (i.e., high winds, heavy rain) due to a decrease in observer ability to locate animals on the landscape. Upon returning from the field, all supplementary data recorded in field
Notebooks was logged onto data sheets to ensure consistency of recorded data and to streamline data entry.

**Survey Data Entry**

Data from field computers were downloaded after each field data collection event, upon return to the office. The Access database designed for this study consisted of four main tables to store the point and demography data for bighorn sheep and mountain goat observations (Figure 4). The first table, Field Computer, stored all of the survey data downloaded from field computers. The second table, Notebook, stored all of the survey information not recorded directly into field computers. The third table, Detection Probability, stored survey data related to groups of animals detected during double observer surveys. The fourth table, Opportunistic, stored the attribute data and the demography data associated with each opportunistic animal point location recorded outside of a survey event. The Field Computer table was linked to the Notebook table through the Survey ID, a unique ID code generated for each survey conducted. The Detection Probability table was also linked to the Notebook table through the Survey ID.

![Diagram of database tables](image)

Figure 4. A screenshot of three of the four main tables (Field Computer, Notebook Data and Detection Probability) are displayed as well as the relationships between them. The Opportunistic table was not related to the other tables in the database.
Development of Additional Covariates

Species distributions and habitat selection depend on various biological processes, many of which are affected by solar radiation. For example, Keating et al. (2007) demonstrated high concentrations of ungulates during the winter in locations receiving relatively high levels of solar radiation. Frequently, habitat studies include covariates such as aspect as a proxy for solar radiation, rather than including it as a distinct covariate (Keating et al. 2007). We found it difficult to determine the biological significance of the aspect covariates as used in previous modeling efforts and as a result, we decided to exclude these covariates from further modeling efforts and instead we examined other indices of solar radiation. We used equations developed by McCune and Keon (2002) that were easily executed in a spreadsheet to estimate direct incident radiation and an index of heat load using slope, aspect and latitude. Although potential direct incident radiation is symmetrical around a north/south axis the same is not true for heat load. A slope receiving afternoon sun will likely be warmer than an equivalent slope receiving morning sun. To account for this McCune and Keon rescaled aspect so that a value of zero represents the coolest aspect (NE) and a value of one represents the warmest aspect (SW). There is no way to convert the results into a collective measure of temperature so the output must be considered a unit-less index of heat load (McCune and Keon 2002). Although it appears a useful way to examine relative heat load across the study area, this method fails to take into account cloud cover and adjacent topography. As a result, we also decided to examine solar radiation as calculated using the Solar Radiation toolset in ArcGIS 9.3 Spatial Analyst Extension based on methods developed by Fu and Rich (2002). The tools available allow the user to process a huge amount of information including atmospheric effects, site latitude, elevation, slope, aspect, daily sun angle shift and adjacent topographical shading, which would otherwise be too time consuming. The related calculations can be performed for individual points or over large geographic areas and are carried out in a multi-step process. The process begins with calculation of an upward-looking hemispherical viewshed and is calculated based on topography. This viewshed is then laid over a direct sunmap and a diffuse skymap, allowing for estimation of direct radiation and diffuse radiation, respectively. This process is then repeated for every point or area of interest and used to produce a map of insolation (Huang and Fu 2009). Our hope is that inclusion of these site specific features may help capture some of the factors affecting spatial distribution patterns of air and soil temperatures, patterns of snow melt, moisture content of soil and the amount of light available to enable plant productivity at a small scale.

The ruggedness measure used in previous presence-only modeling included only the variability of the rate of change in slope for each grid cell. When examining landscape ruggedness and how it may affect resource selection by animals it is important to include changes in both aspect and gradient of slope to truly capture features of surrounding topography important to animals. It is likely that bighorn sheep and mountain goats perceive ruggedness and slope differently when assessing escape and forage terrain and therefore it seems logical to
quantify heterogeneity in both aspect and slope (Sappington et al. 2007). Using layers previously generated in ArcView 9.3 including slope, aspect and contour and an ArcView Script developed by Sappington et al. (2007) we created a new layer of vector ruggedness measures which combined variation in aspect and slope into a single measure (script available online from the Environmental Systems Research Institute ArcScripts website: www.esri.com/arcscripts). This method may capture more heterogeneity in the landscape than indices based only on changes in slope or elevation.

Animals select landscape features at various spatial scales ranging from geographic areas to individual plants (Johnson 1980). Scale is defined here as spatial extent or area as opposed to grain or resolution of measured landscape features (Kie et al 2002). The scale at which an animal selects a resource is dependent on vulnerability to predation, the cost of foraging and the spatial distribution of the resource (Senft et al. 1987, Gustafason 1998, Johnson et al. 2002, Kie et al. 2002). Our ability to capture differences in resource selection and to make associations between animals and their habitat will vary along with scale (Boyce 2006). If data are not explored at the scales that are important to animals, we are likely to misinterpret the results of habitat suitability analyses (Wiens 1989). Examining too large of an area may preclude detection of habitat heterogeneity and examining too small of an area may cause under sampling of variance in local habitat characteristics (Boyce et al 2006). In an effort to account for heterogeneity of the habitat and local variation of habitat characteristics, we decided to examine habitat selection at two different spatial scales by placing a buffer with 100 meter radius and 500 meter radius around observation points for both detection and non-detection records and examining landscape features within each buffer.

RESULTS

Presence-Only Modeling Effort

The use versus available covariate distributions for mountain goats during the summer season suggested mountain goats selected for areas closer to escape terrain in drier, rugged, higher elevation terrain than what was available. There was also some evidence for selection of areas with greater tree-cover. Interpretations of the density plot patterns were supported by results of model selection. The two top-models accounted for nearly all of the model weight (Table 2). Both of these models included five of the seven covariates, with only east/west aspect not appearing in both models. Coefficient estimates were similar for both models and the only coefficient confidence interval that spanned zero was wetness, in one of the two top-models (Table 3). The use versus available covariate distributions for bighorn sheep during the summer season suggested bighorn sheep and mountain goats selected for similar locations in rugged habitat, closer to escape terrain and at high elevations. Bighorn sheep also appeared to select for wetter areas with fewer trees compared to areas selected by mountain goats. Model comparisons resulted in one top model receiving 100% of the model weight (Table 2). The top model included six of the seven covariates considered in models. Point estimates and associated 95% confidence
intervals for the six covariate coefficients appearing in the model did not span zero (Table 3). The resulting habitat suitability maps were very similar for both species so we only present the bighorn sheep suitability map in this document (Figure 5). A total area of 250km², comprised of four regions, was identified for conducting occupancy surveys in the summer of 2011.

Table 2. Model selection results for resource selection probability function models examining the effects of 7 landscape covariates on bighorn sheep and mountain goat summer and rut habitat selection. All models are presented along with the number of parameters (K), ΔAICc value and Akaike weight (ωi).

<table>
<thead>
<tr>
<th>Bighorn Sheep</th>
<th>Model ID</th>
<th>Model</th>
<th>AIC</th>
<th>K</th>
<th>AICc</th>
<th>ΔAICc</th>
<th>ωi</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1</td>
<td>Escape + Elev + EWAsp + NSAsp + Rug + Wet</td>
<td>3508</td>
<td>7</td>
<td>3494</td>
<td>0</td>
<td>0.91</td>
</tr>
<tr>
<td>2</td>
<td>2</td>
<td>Escape + Elev + EWAsp + NSAsp + Tree + Rug + Wet</td>
<td>3515</td>
<td>8</td>
<td>3499</td>
<td>5.196</td>
<td>0.07</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Mountain Goat</th>
<th>Model ID</th>
<th>Model</th>
<th>AIC</th>
<th>K</th>
<th>AICc</th>
<th>ΔAICc</th>
<th>ωi</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1</td>
<td>Escape + Elev + EWAsp + Tree + Rug + Wet</td>
<td>1537</td>
<td>7</td>
<td>1523</td>
<td>0</td>
<td>0.52</td>
</tr>
<tr>
<td>2</td>
<td>2</td>
<td>Escape + Elev + Tree + Rug + Wet</td>
<td>1535</td>
<td>6</td>
<td>1523</td>
<td>0.174</td>
<td>0.48</td>
</tr>
<tr>
<td>3</td>
<td>3</td>
<td>Escape + Elev + Tree + Rug + Wet</td>
<td>1544</td>
<td>8</td>
<td>1528</td>
<td>5.047</td>
<td>0.04</td>
</tr>
</tbody>
</table>
Table 3. Coefficient estimates of all models within 4 AIC units of the top model for bighorn sheep and mountain goat summer habitat selection. Coefficient estimates in bold font include confidence intervals that do not span zero.

<table>
<thead>
<tr>
<th>Model ID</th>
<th>Bighorn Sheep</th>
<th>Mountain Goat</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>Covariate</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Intercept</td>
<td>17.3</td>
<td>-23.07</td>
</tr>
<tr>
<td></td>
<td>(-18.9, -15.7)</td>
<td>(-37.96, -18.35)</td>
</tr>
<tr>
<td>Escape</td>
<td>-0.006</td>
<td>-0.005</td>
</tr>
<tr>
<td></td>
<td>(-0.009, -0.005)</td>
<td>(-0.008,-0.003)</td>
</tr>
<tr>
<td>Elev</td>
<td>0.003</td>
<td>0.003</td>
</tr>
<tr>
<td></td>
<td>(0.003,0.004)</td>
<td>(0.002,0.004)</td>
</tr>
<tr>
<td>EWAsp</td>
<td>0.008</td>
<td>0.002</td>
</tr>
<tr>
<td></td>
<td>(0.005,0.011)</td>
<td>(-0.004,0.008)</td>
</tr>
<tr>
<td>NSAsp</td>
<td>-0.005</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td>(-0.009,-0.002)</td>
<td>-</td>
</tr>
<tr>
<td>Tree</td>
<td>-</td>
<td>0.027</td>
</tr>
<tr>
<td></td>
<td>-</td>
<td>(0.018,0.039)</td>
</tr>
<tr>
<td>Rug</td>
<td>2.66</td>
<td>3.856</td>
</tr>
<tr>
<td></td>
<td>(2.02,3.24)</td>
<td>(3.093,4.685)</td>
</tr>
<tr>
<td>Wet</td>
<td>122.6</td>
<td>-17.56</td>
</tr>
<tr>
<td></td>
<td>(122.5,138.7)</td>
<td>(-31.82, 18.72)</td>
</tr>
</tbody>
</table>
Figure 5. Bighorn sheep relative habitat suitability map for the study area, resulting from application of regression coefficients from the top models to the covariates for the study area. Also depicted are the four survey regions within the area (Region 1, Region 2, Region 3, and Region 4) that were sampled during occupancy surveys during summer 2011.

Formal Occupancy Field Surveys

From 8th of July to the 20th of September 2011 the total number of observer days in the field was 113 resulting in approximately 240 hours of occupancy survey effort. Fifty-seven viewsheds were surveyed by a single observer and an additional 77 viewsheds were surveyed by two, independent observers. A total of 6,909 100x100 meter grid cells were surveyed (Figure 6) on at least one occasion with 3,392 of those grid cells visited on multiple occasions during the season. Fifteen groups of bighorn sheep were detected during occupancy surveys with an average group size of 10.3 individuals, a median group size of 7.0 individuals, and a group size range of 44.0 individuals with a SD of 10.9 individuals. One hundred fifty four individual bighorn sheep were observed and classified during occupancy surveys with 81 females, 57 young of the year, 1 mature male, 9 yearlings, and 6 unknown. Fifty grid cells were occupied by bighorn sheep during surveys and observers recorded bighorn sheep in an additional 18 grid cells while traveling between surveys.

Thirty-four groups of mountain goats were detected during surveys with an average group size of 2.3 individuals, a median group size of 1.0 individual, and a group size range of
17.0 individuals with a SD of 3.2 individuals. Seventy-nine individual mountain goats were observed and classified during occupancy surveys with 17 females, 13 young of the year, 1 mature male, 5 yearlings and 43 unknown. Fifty-nine grid cells were occupied by mountain goats during surveys and observers recorded mountain goats in an additional 36 grid cells while traveling between surveys.

A total of 13 groups of bighorn sheep were detected during double observer surveys and 10 of these groups were detected by both observers (76.9%). A total of 22 groups of mountain goats were detected during double observer surveys and 12 groups were detected by both observers (54.5%).
Figure 6. Maps of each individual survey region (Region 1, Region 2, Region 3 and Region 4) and the observations recorded in each, during 2011 field season. Green dots indicate neither bighorn sheep nor mountain goats were observed, blue triangles indicate a bighorn sheep observations and red triangles indicate mountain goat observations.
Figure 6 (continued).
FUTURE EFFORTS

We are currently preparing the data collected during the summer of 2011 as well as the new covariate GIS layers for analyses. The results of these efforts will be presented in a final thesis product in August of 2012. Occupancy surveys will be continued for another two years by a new master’s student, Jesse DeVoe, and his crew beginning in the summer of 2012. By increasing the data available for analyses we hope we will be able to construct habitat models for both bighorn sheep and mountain goats and validate these models in additional study areas.

ACKNOWLEDGEMENTS

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LITERATURE CITED


