THESIS

HABITAT USE BY DALL SHEEP AND AN INTERIOR ALASKA MAMMAL COMMUNITY

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ABSTRACT

HABITAT USE BY DALL SHEEP AND AN INTERIOR ALASKA MAMMAL COMMUNITY

Anthropogenic disturbances are increasingly recognized for effects on the behavior and physiology of wildlife species. Military training, a potential source of disturbance, has shown mixed behavioral and physiological effects on wildlife, including mountain ungulates. Dall sheep (*Ovis dalli dalli*) are an important species for hunting and wildlife viewing in Alaska and have shown an aversion to some forms of human disturbance such as direct overflights. Military training is expanding into potential Dall sheep habitat on two training areas of Fort Wainwright, Alaska; Molybdenum Ridge and Black Rapids Training Area. I placed camera traps in expected optimal and sub-optimal Dall sheep habitat to estimate the spatiotemporal habitat use of sheep and to make training recommendations to the U.S. military. Then, I further explored the available data and estimated the habitat use of species in four different mammalian guilds and the co-occurrence of habitat use between apex predators and potential prey species.

In Chapter 1, I introduce the impetus for the study, the use of 54 camera traps in respect to mountain sheep, and the overall study design. My cameras captured over 8,000 images of sheep during the continuous 15-month sampling period. I successfully captured images of sheep traveling, foraging, resting, and interacting with other individuals. Occupancy models of detection-non-detection data suggest that abiotic covariates including slope, snow depth, and distance to escape terrain were the most important factors determining habitat use. Seasonal differences in habitat use suggested higher use of the Molybdenum Ridge study site during pre-rut, rut, winter, and lambing seasons with limited use during the summer, while habitat use estimates of Black Rapids were too imprecise to make broader inferences. Detection probabilities were temporally constant, but were positively correlated with cameras on a wildlife trail. From these results, I recommend that the U.S. Army concentrates training on Molybdenum Ridge during the early-July to early-September period and minimize training on both study sites during the lambing periods of May and June. If training were to occur on Molybdenum Ridge outside of this period, training should be concentrated around the easternmost valley/bowl of the ridge and the eastern half of the major south-facing slope of the ridgeline.

In Chapter 2, I expanded upon the analysis of Dall sheep habitat use and investigated the alpine habitat use of ten species within four mammalian guilds. I analyzed how spatial covariates and temporal patterns correlated with habitat use of these species within and between guilds. Further, I modeled two-species occupancy of grizzly bears and wolves with different prey species (e.g., caribou and sheep). My results suggest that small and large herbivore habitat use positively correlated with vegetation and rock ground coverages, while large herbivores also correlated with broader abiotic covariates. Meso- and apex predator detections were sparse possibly leading to imprecise estimates of habitat use and little support for most habitat covariates. Detection probabilities of Dall sheep and predators were improved by cameras on trails. Two-species models suggested co-occurrence of habitat use between grizzly bear/caribou and wolf/caribou and independence of habitat use between grizzly bear/squirrel and wolf/sheep.

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CHAPTER 1

HABITAT USE BY DALL SHEEP: AN OCCUPANCY MODELING APPROACH

Synopsis

Anthropogenic disturbances, such as military training, are increasingly recognized for potential effects on mountain ungulate populations. Dall sheep (*Ovis dalli dalli*) is an iconoclastic species that is important for hunting and wildlife viewing opportunities in Alaska and across the species range. Currently, military training is expanding into potential Dall sheep habitat within two training areas of Fort Wainwright, Alaska. Therefore, the U.S. Army requires a better understanding of the spatiotemporal habitat use of sheep to avoid disturbances to the population. Dall sheep have shown mixed behavioral and physiological effects of overflights and other human disturbances. Studies of these mountain ungulates often rely upon aerial surveys to assess population size and regional habitat use (Udevitz et al. 2006, Schmidt et al. 2011). Infrequently, camera traps have been employed to estimate population size and presence of mountain ungulates, but little use has been directed towards Dall sheep. I utilized an array of camera traps, taking triggered and hourly timelapse images, to determine the probability of Dall sheep habitat use based on seasonal and site covariates. Camera traps captured nearly 8,000 images of sheep during a continuous 15-month sampling period. Habitat use models suggest that abiotic covariates such as slope, snow depth, and distance to escape terrain are the most important factors determining habitat use. Seasonal differences in habitat use suggest higher use during winter and spring for the main study site (Molybdenum Ridge), and higher habitat use during the summer for the secondary training area (Black Rapids Training Area). Detection probabilities were constant temporally and were higher if the camera was positioned on wildlife trail versus not. My results suggest that the best training opportunities to avoid sheep habitat use is early-July to early-September, specifically in areas with less than a 50% slope and more than 500 m from escape terrain.

Introduction

Analyzing the spatiotemporal habitat use of a wildlife species is increasingly important to assess if a population may be affected by human disturbances (e.g., Karanth et al. 2011). Anthropogenic disturbance of wildlife is a concern for the conservation of species as it has been shown to affect wildlife behavior and physiology (e.g., Walker et al. 2006). Military installations are often centers of large-scale human movements and disturbance, but have been increasingly recognized for the availability of wildlife habitat (Blair Joselyn 1965, Stein et al. 2008). The potential effects of military actions on wildlife is a growing point of concern and research interest (e.g., Krausman et al. 2004, Telesco and Van Manen 2006, Barron et al. 2012), especially in the United States, as the military lands under the U.S. Department of Defense must conform to federal environmental legislation (e.g., National Environmental Policy Act, Endangered Species Act). Research of mountain ungulates has shown a mix of no or negative impacts of military training with most of the work focused on effects of over-flights (Bleich et al. 1994, Cote 1996, Krausman et al. 1998, Lawler et al. 2004), with limited work on the effects of ground operations. Therefore, better understanding the spatiotemporal habitat use of mountain ungulates on military lands during ground operations is an important consideration for balancing the conservation of these species with military training operations.

My study focused on Dall sheep (*Ovis dalli dalli*), a mountain sheep species, inhabiting areas on and adjacent to Molybdenum Ridge (here on “Moly Ridge”) within Donnelly Training Area (DTA) and Black Rapids Training Area (BRTA) of Fort Wainwright, Alaska (**Figure 1.1**).

The U.S. Army has proposed the expansion of ground-based training with aerial support into areas where the knowledge of sheep habitat use is data-limited. Thus, a better understanding of the habitat use of Dall sheep within these training areas is important for planning of future training operations. Spiers and Heimer (1990) radio-collared 15 sheep and tracked their use on and adjacent to DTA (formerly Fort Greely). They concluded the presence of five separate subpopulations, one of which likely wintered (early-October to early-May) in areas of training on Moly Ridge.

Mountain sheep typically migrate between seasonal ranges throughout the year, due to the dynamic nature of the climate and habitat in which the sheep reside. Geist (1971) noted ewe bands had four different yearly ranges: winter, spring, lambing, and summer. Ram bands had up to six seasonal ranges: pre-rutting, rutting, midwinter, late-winter/spring, salt-lick range, and summer range (Geist 1971). Dall sheep spend the majority of the year on winter ranges, preferably on wind-swept slopes where snow depth is lighter and forage is more readily available. Migrations between seasonal ranges is often correlated with depth of snow, temperature, and plant phenology (Hoefs 1976, Walker et al. 2006).

Dall sheep rely upon steep mountainous slopes (> 60%) that provide escape terrain and montane meadows that provide available forage. Proximity to escape terrain, forage availability, and adequate visibility are the predominate features dictating preferred mountain sheep habitat (Risenhoover and Bailey 1985, Wakelyn 1987, Nichols and Bunnell 1999, Walker et al. 2007). Forage material includes grasses (e.g., *Festuca* spp. and *Poa* spp.), sedges (*Carex* spp.), a variety of forbs, and some small shrubs (Murie 1944, Hoefs 1984, Seip and Bunnell 1985). Murie (1944) examined stomach contents of sheep carcasses during winter in Mt. McKinley (Denali)

National Park and found grasses and sedges as the predominant food items in addition to *Artemisia* spp., *Dryas* spp., *Vaccinium* spp., *Salix* spp., and unidentified lichens.

Habitat occupancy is also affected by the physiology and demographics of the sheep. Rachlow and Bowyer (1998) found a significant difference between the habitat selected by ewes before and during the lambing period at a study site in Denali National Park, Alaska. Before lambing, female sheep selected areas of higher forage and lower snow cover. During lambing, pregnant females ascended to higher elevations with lower forage, but higher quality escape terrain. Therefore, it is important when constructing a sampling design of mountain sheep, to consider how seasonal movements and habitat selection may vary between demographic groups.

Conventional sampling techniques for mountain ungulates typically consist of aerial or on-foot surveys (Sumner 1948, Udevitz et al. 2006, Zhensheng et al. 2007, Schmidt et al. 2011). However, remotely activated cameras or “camera traps” are an increasingly utilized tool in the evaluation of wildlife presence and habitat use (Nichols et al. 2011) and may be advantageous in situations where conventional techniques are restricted or too expensive. While knowledge is increasing on the use of camera traps in ecological research (e.g., Jackson et al. 2006, Bhattacharya et al. 2012, Massara et al. 2015), mountain sheep research has seen limited application. Camera traps have effectively captured the diel use of water sources by Rocky Mountain bighorn sheep (*Ovis canadensis canadensis*) in northern Utah (Whiting et al. 2009), and have been used to obtain population size estimates for desert bighorn sheep (*O. c. mexicana*) in New Mexico, which were equally accurate to aerial and ground surveys (Perry et al. 2010). Cameras are also more likely to capture sheep when installed at human-made supplemental water features (Perry et al. 2010).

The low use of camera traps in relation to mountain sheep is likely a combined result of the difficult terrain that mountain sheep inhabit and, until recently, the lack of technology capable of operating in extreme climatic conditions. With the advent of technology capable of operating for multiple months in sub-freezing temperatures without servicing, researchers no longer must access camera traps on a weekly or monthly basis (e.g., Tobler et al. 2009, Pesenti and Zimmermann 2013). Freedom from constant maintenance allows researchers to avoid wasting resources accessing remote sites, decreases safety concerns, and allows for data collection when access is not feasible.

My objectives were to model the habitat use of Dall sheep across multiple seasons in both training areas using detection-non-detection data from an array of camera traps operating for 15 months. With this information, I used occupancy models to determine seasons and habitat covariates that correlated with sheep habitat use. I created maps from these models to inform the U.S. Army about the best times to conduct training as it relates to likely sheep habitat use. In addition, I further evaluated camera traps as an effective method for the study of mountain sheep, and offer recommendations for future utilization.

Materials & Methods

Study Site

Moly Ridge is located on the northern edge of the Alaska Range, approximately 50 km southwest of Delta Junction, Alaska. BRTA is adjacent to the Richardson Highway in the Delta River valley of the Alaska Range approximately 70 km south of Delta Junction, Alaska. Both locations are alpine habitats with prevalent graminoids, low growing forbs, dwarf shrubs, and unconsolidated rocky slopes. Elevations at Moly Ridge and BRTA ranged from 1,000 – 1,900 m and from 1,050 – 1,525 m, respectively, and slope percentages ranged from 0 – 272% (i.e., 0°–

70°). Both study sites are exposed to high wind conditions, especially during the winter ($\bar{x} =$ 19.3 km/h; NOAA 2015), leading to large windswept slopes ideal for sheep winter habitat. Moly Ridge is relatively isolated from the full extent of the mountain range and on the periphery of optimal mountain sheep habitat. In contrast, BRTA is in the center of the Alaska Range and is more dynamic topographically with large contiguous patches of escape terrain, while being bordered by a braided river valley.

Sampling Design: Camera Trap

Cameras were installed in Moly Ridge (n=45) and BRTA (n=9; **Figure 1.2 & 1.3**) during July and August 2013. I stratified the study sites by three classes of slope percentage, flat (≤ 15%), inclined (15% < slope ≤ 45%), and steep (slopes > 45%) which constituted 46.9%, 41.2%, and 11.0% of Moly Ridge and 7.8%, 61.1%, 38.2%, of BRTA, respectively. I utilized a sample size calculation in MacKenzie and Royle (2005) to proportionally allocate sampling effort for each stratum, using expected estimates of habitat use and detection and desired levels of precision. For the study design, I assumed use estimates of 0.1, 0.5, 0.8 and detection estimates of 0.2, 0.4, and 0.4 respectively for the flat, inclined, and steep strata (Gionfriddo and Krausman 1986, Rachlow and Bowyer 1998). For the Moly Ridge study site, this resulted in the allocation of effort as 5, 23, and 17 cameras for the flat, inclined, and steep strata, respectively, given my set sample size.

Camera locations were determined through a spatially balanced design. A spatially balanced survey is a probability-based survey generated via the Reversed Randomized Quadrant-Recursive Raster (RRQRR) algorithm (Stevens and Olsen 2004, Theobald et al. 2007), and was calculated using ArcGIS (ArcGIS v10.0; Environmental Systems Research Institute, Redland, California, USA). The RRQRR algorithm allows for varying numbers of sample site locations per strata by assigning relative inclusion probabilities to each stratum (Theobald et al. 2007). Using my sampling effort calculations, I developed inclusion probabilities that would adequately distribute the correct number of camera locations per strata.

Logistical issues such as timing of installation, scouting of camera locations, and safety of personnel were factors determining camera placement. Camera sites were chosen within 100 m of the identified coordinates that would provide the best opportunity to capture an image of sheep using the area. If I could not safely access the area of the chosen camera location (n=4) then a location was chosen which would capture an image of the predetermined camera coordinates. I used RECONYX PC800 and PC900 Professional Hyperfire Infrared cameras (RECONYX, Inc. Holmen, Wisconsin, USA 54636). Cameras were installed upon RECONYX t-post mounts, thunderbolt mounts, or within security boxes affixed to rock faces using a combination of construction adhesive and ratchet straps.

Moly Ridge and BRTA are active training areas of the U.S. Army, thus researcher access of the Moly Ridge site was when DTA was conducting “range cleanup”, a three-week period during late-July and early-August 2013 and 2014, in which no live fire training occurs. This period was long enough to conduct camera installation and vegetation sampling. Additionally, I conducted a shorter maintenance trip in October 2014 during a gap in training operations.

I programmed cameras to trigger by a combination of movement and infrared signature, as well as to record an image every hour. Once a trigger occurred, the camera captured three images in succession, with one second between images. The camera would then take no pictures for a 15-second “quiet period” to conserve digital memory. Following the first camera maintenance, and noting the amount of space still available on the memory cards, I removed the quiet period and decreased the time lapse from 1 hour to 30 minutes for the last three months of the study.

Sampling Design: Vegetation

I sampled vegetation during the summer 2014 field season at each camera site. I established 30, 0.5 m^2 quadrats every 5 m along a 50 m transect perpendicular to the camera face as well as at varying distances from the transect at each 5 m point (**Figure 1.4; Appendix I)**. I estimated aerial and ground coverage of 12 different abiotic (e.g., bare ground, gravel) and biotic (e.g., graminoid, dwarf shrub) coverage classes at each quadrat. Researchers identified all vascular plants in a quadrat to species; due to logistical reasons, species were only identified in quadrats each 10 m from the camera, out to 50 m (e.g., 10 m, 20 m; **Appendix II**).

Data Processing & Analysis

Due to the quantity of photos captured, I developed methods to increase the efficiency of photo analysis and cataloging. I placed all photos taken from a camera in order of capture into Windows Movie Maker (Microsoft Corp., Redmond, Washington, USA) and created two frame/second videos. This served a two-fold purpose. First, the videos provided a quick and seamless method of viewing thousands of photos. Second, I could detect wildlife in the back and middle ground of a photo that would likely be overlooked without the rapid succession of images.

All photos were uploaded into a Windows Access photo viewer interface (Ivan and Newkirk 2015) and sheep detections were recorded along with specific demographic (i.e., ewe-like, ram, or unknown) and behavioral details (i.e., moving/traveling, grazing, resting, vigilant, or unknown). Finally, sheep detections were truncated at approximately 500 m from the camera for analysis, due to decreased detection beyond this distance and changing habitat conditions. I binned these data into one-week occasions across the 64 weeks (15 months) of continuous sampling.

I analyzed my data using the single season occupancy model in Program MARK (White and Burnham 1999), but given the relatively large-scale movements of sheep throughout a season, the assumption of intra-seasonal closure was violated. Thus I interpreted occupancy estimates as habitat use (MacKenzie 2006). I defined two demographic groups (ewe-like and ram). I also treated each season as a separate group in my analysis rather than using a multi-season robust design model due to my low sample size, the increased number of parameters needed for the multi-season model, and difficulty interpreting immigration and emigration parameters when closure is violated (Kendall et al. 1995, MacKenzie et al. 2009, Falke et al. 2012). I defined ten biologically hypothesized seasons taking into consideration rutting, lambing, and potential differences in the movement patterns of ram and ewe-like groups (**Table 1.1**). Two weeks were censored between each season and when researchers were camped near cameras during July 2014. Finally, I treated study site (Moly Ridge vs BRTA) as a grouping variable resulting in 40 groups (i.e., 2 demographic groups x 10 seasons x 2 study sites). Given the large distance between the study sites and probable difference between sheep populations, study site difference was included in all models.

I estimated weekly snow depths for each camera location classifying the snow depth in sequential images into one of six categories (No snow/Trace, < 10 cm, 10 - < 20 cm, 20 - < 30 cm, 30 - < 40 cm, ≥ 40 cm). Snow posts with 20-cm sections of contrasting black and white paint were installed in front of four cameras, which aided in training observers at estimating the snow depth at all camera locations.

Abiotic covariates were determined from remote sensing data (U.S. Geological Survey, National Elevation Dataset [USGS NED]) using ArcGIS and included camera site elevation (m), mean slope (%), a camera's viewshed area (ha), surface distance of camera site to escape terrain (m), and surface distance of camera site to static military firing points (m; **Table 1.2**). Mean slope was calculated by clipping a slope raster with a 500 meter buffer radius around each camera site and averaging all the slope cells within that buffer. Distance from escape terrain was the surface distance from the camera site to a contiguous area > 1 ha of barren/rocky slopes greater than 60% grade (Wakelyn 1987, McKinney et al. 2003). Finally, I defined camera viewshed as the land area (ha) the camera was capturing an image of within 500 m of the camera location and was determined using the ArcGIS Viewshed tool. I tested for correlation between all covariates (abiotic and vegetation); one covariate was censored from any covariate pair with a |0.7| correlation coefficient.

I hypothesized individual covariate relationships and temporal structures that would best model sheep habitat use (ψ) and detection (p). I used a two-step *ad hoc* modeling approach used cumulative variable weights (w_i) to reduce unsupported covariates and determine the best model structures that explained ψ and p (Lebreton et al. 1992, Doherty et al. 2012, Bromaghin et al. 2013). First, holding p constant, I constructed a balanced set of all possible additive ψ models, with the addition of two hypothesized interactions between season and study site and between demographic group and distance to escape terrain. All group effects, covariates, and interactions with a w_i greater than 0.50 were retained for a second round of analysis. I repeated this procedure for p by maintaining ψ constant and varying p across variables of interest. All variables for ψ and p retained for the second round of analysis were combined into a global model. Final w_i's were calculated from a balanced model set of all additive combinations of these variables with and without the interaction terms. A predicting model that only contained all variables with a w_i greater than 0.50 was then chosen from this model set (Barbieri and Berger 2004). This procedure allowed me to handle a large number of variables efficiently, but also avoided possible spurious results (Doherty et al. 2012, Bromaghin et al. 2013).

Habitat Use Maps

I used remote sensing, vegetation, and snow depth data in conjunction with my chosen prediction model to create habitat use maps for the Moly Ridge study site. I created raster layers of slope percentage, distance from escape terrain (m), and elevation (m) in ArcGIS using USGS NED digital elevation model layers. Then I created interpolative cokriging or ordinary kriging raster layers of mean seasonal snow depth and all vegetation covariates supported in my occupancy prediction model.

Cokriging, as with ordinary kriging, uses point estimates and the spatial autocorrelation of a variable to interpolate values of that variable across a surface. However, cokriging can include other spatial variables (e.g., elevation, slope) to increase predictive abilities of the model (Xu et al. 2015). To examine spatial cross-correlation I calculated Mantel's test in R (R Core Development Team 2015) between supported ground coverage covariates and remotely sensed abiotic data. Then, I created cokriging layers of ground coverages and any significantly cross-correlated abiotic variable. Finally, I created habitat use maps using the ArcGIS v10.0 raster calculator utilizing my occupancy prediction model, including important temporal and demographic effects and spatial covariates.

Predictions

I hypothesized that habitat use would vary by demographic group, seasonally, and by habitat type across both Moly Ridge and BRTA (**Table 1.2**). Given the lower elevation than the adjacent mountains and the windswept slopes of Moly Ridge and BRTA, I predicted that pre-rut through lambing season habitat use would be higher than summer and late-summer habitat use. In addition, I predicted that ewe-like habitat use would remain constant during the post-rut, winter, and lambing seasons, while ram habitat use would decrease, since ewe-like groups are known to persist on rutting ranges through the winter (Hoefs and Bayer 1983). I predicted that the habitat use would be temporally similar between the two study sites, but that there would be higher magnitude of difference between the seasonal estimates on the topographically isolated Moly Ridge versus BRTA, which is better integrated into the mountain range. Therefore, I included an interaction between season and study site. I thought direct integration into the mountain range would allow for more movement in and out of BRTA, likely creating higher variability in the estimates. I predicted that increased military training would negatively affect the habitat use of sheep due to the aversion of some mountain sheep to anthropogenic disturbances. Additionally, I expected abiotic factors including slope percentage, distance to escape terrain, and snow depth to be the strongest correlates of sheep habitat use (Geist 1971, Nichols and Bunnell 1999). In addition, I expected an interaction between escape terrain and demographic group. Ewe-like groups stay closer to escape terrain than ram groups (Gionfriddo and Krausman 1986, Nichols and Bunnell 1999), therefore, I expected ewe-like groups to have a stronger negative relationship with the distance to escape terrain. I hypothesized that higher graminoid, forb, and dwarf shrub cover and vegetation richness would moderately increase sheep habitat use. I predicted that detection probability would vary by study site, but not temporally, because I did not expect sheep behavior to change in such a way that would increase or decrease detections. Finally, I expected positive correlation of detection with cameras placed on wildlife trails and with a camera's viewshed area (**Table 1.2**).

Results

Camera Data

During the first year of sampling, the 54 camera traps captured 629,392 photos, over approximately 15,393 camera-trap days. At different points of the first sampling year, 19 of the Moly Ridge cameras were either severally altered in orientation or destroyed by grizzly bears (*Ursus arctos*) or caribou (*Rangifer tarandus*). Additionally, two cameras stopped operating for unknown reasons. In total, this constituted a loss of ~ 25% camera-trap days versus if the cameras had continued operating. However, only one SD card was lost from these damaged cameras and there was no evidence of camera alteration or destruction from human activities. I then conducted maintenance in October 2014. During the three-months prior to this maintenance, the cameras captured 196,331 photos over approximately 3,809 camera trap days. Four of the cameras had severe animal damage with one lost SD card and 18 had disabling card read errors at different points during the three-month period. Cameras affixed to rock faces were not damaged. In total, over 825,000 photos were captured over the 15-month sampling period.

A total of 7,837 images of sheep were captured across the 15-month sampling period. Of these, 1,952 images were censored between seasons resulting in 2,652 and 3,233 images from Moly Ridge and BRTA, respectively, for habitat use analysis. The raw number of images was higher for Moly Ridge in the winter and lambing seasons, while for BRTA more images were in the summer season (**Figure A3.1**). A second examination of the images from the first four cameras that I processed found only one missed sheep image, increasing confidence in the photo processing methodology.

I detected ewe-like groups with lambs in May and June 2014 (i.e., lambing 2014) on both Moly Ridge and BRTA, which indicated sheep, may use these areas as lambing ranges.

Additionally, despite four times more BRTA military training days (**Table 1.3**) over double the sheep images were captured during the late-summer 2014 compared to the late-summer 2013. However, I note that the number of sheep images does not account for imperfect detection or if the same animal was photographed multiple times.

Both triggered and timelapse programing captured images of sheep. Triggered images predominately featured one or more sheep walking or grazing in the image foreground, however, some triggered images captured sheep in the background in addition to the individual that likely triggered the camera. Time lapse images captured images of animals in close proximity of the camera and up to approximately 1,200 m from the camera location. Approximately 1,000 timelapse images recorded sheep. This technique was the sole form of sheep detection for 17% of the camera locations that captured sheep images.

Nocturnal images of sheep moving, foraging, and resting outside the hours of civil twilight (i.e., an hour before and after sunrise and sunset) were captured at both study sites. Triggered photos captured (n=44) instances of ewes and rams moving and/or grazing. Timelapse photos detected few nocturnal images (n=6), of these instances five were of sheep resting and one of a ewe-like group grazing. The vast majority of nocturnal detections (82.4%) were between 11/01/2013 – 3/01/2014 when daylight hours were the fewest of the sampling period.

Model Results

The first step in my *ad hoc* modeling approach culled five variables (i.e., elevation, dwarf shrub coverage, vegetation species richness, viewshed, and military training days) for ψ and study site for p. Retained ψ covariates included an interaction between demographic group and distance to escape terrain, slope percentage, snow depth, and graminoid coverage. In addition, use varied seasonally and by study site (**Table 1.4 & Table A3.1**). Distance from firing point was retained, but exhibited unexpected positive beta results, possibly indicating biases between covariate values and the study design. Finally, study site difference was discarded from modeling detection probability while trail and viewshed were retained (**Table 1.4 & Table A3.2**).

My second round of modeling focused on a final model set consisting of all possible combinations of the variables retained during the first round. My prediction model included seasonal, site, and demographic differences for sheep habitat use (**Tables 1.5 & 1.6**). The prediction model included differences between the 10 seasons, except for constant habitat use of ewes during the winter, late-winter, and lambing seasons. While sheep habitat use of Moly Ridge was highest during the pre-rut to winter seasons, BRTA had very low use during the pre-rut and rut season, and the highest use in the post-rut and late-summer season. Habitat use was positively correlated with slope percentage and graminoid cover, and negatively correlated with distance to escape terrain and snow depth (**Table 1.6**). Detection was constant temporally and was higher if the camera was on wildlife trail and negatively correlated with viewshed size.

Temporal use estimates of Moly Ridge were higher during the rut, winter, and lambing seasons for both ewe-like and ram groups (**Figure 1.5**). However, ram groups showed a steady decline in habitat use following the rut period; this differed from ewe-like use, which was best supported by constant use through the winter and lambing seasons (**Figure 1.5**). Seasonal habitat use estimates of BRTA found support for higher use in post-rut/early winter 2013 and within the summer 2014 seasons (**Figure 1.6**), however, precision was low in part due to the relatively small sample size of camera locations.

Model results indicated support for abiotic factors including slope percentage, snow depth, and distance to escape terrain as the most important covariates predicting sheep habitat use (**Tables 1.5 & 1.6**). Slope percentage ($\hat{\beta}$ = 0.08 SE 0.02) showed a positive relationship with sheep use for both study sites (**Figure 1.7**). Moly Ridge summer habitat use was minimal and thus only the steepest slopes were predicted to have any habitat use (**Figure 1.7a**). Winter habitat use for both sites (**Figure 1.7b & 1.7d**) and summer habitat use for BRTA (**Figure 1.7c**) was ≥ 0.50 on slopes ≥ 60% when within 500 m of escape terrain. Snow depth showed a negative relationship ($\hat{\beta}$ = -0.90 SE 0.19) with sheep habitat use on both study sites. Results indicated that habitat use on Moly Ridge dropped below 0.50 between 10-20 cm of snow, and habitat use approached zero once snow depths were ≥ 40 cm (**Figure 1.8**). Sheep use of BRTA followed a stronger negative relationship; use dropped below 0.1 with greater than 20 cm snow depth (**Figure 1.8**). In addition, results indicated an interaction between demographic group and escape terrain ($\hat{\beta}$ = -0.003 SE 0.001), indicating support for ewe-like habitat use concentrated closer to escape terrain versus ram use (**Figure 1.9**). Finally, my prediction model had some support for the cover of graminoids ($\hat{\beta}$ = 0.12 SE 0.06) predicting sheep habitat use (**Table 1.6**).

Detection probability was best determined by if a camera was positioned on a wildlife trail ($\hat{\beta}$=1.46 SE 0.19; **Table 1.6; Figure 1.10**). I found evidence that detection decreased with the increasing camera viewshed area ($\hat{\beta}$= -0.07 SE 0.04; **Figure 1.11**), however, the confidence interval of the beta included zero and the negative relationship is suspect.

Habitat Use Maps

Mantel's test results found significant correlation between graminoid cover and slope percentage (p < 0.001), but not between graminoid cover and elevation (p = 0.757). I did not find significant cross-correlation between seasonal snow depths and slope (p = 0.882 [pre-rut 2013]) or elevation (p = 0.267 [pre-rut 2013]). Therefore, I created a cokriging map of graminoid with slope percentage data and an ordinary kriging map of snow depth (Gong et al.

2014, Xu et al. 2015). Habitat use maps then included graminoid and seasonal snow depth layers and varied between seasonal and demographic differences.

Habitat use maps of Moly Ridge during the pre-rut 2013 season show the highest concentration of habitat use for both ewe-like and ram groups in areas surrounding the northwestern face, western-most bowl, and northern most arm of the ridgeline (**Figure 1.12a & 1.12b**). In addition, there was high probability of habitat use for the easternmost peak of Moly Ridge for both ewe-like and rams (**Figure 1.12a**). Several ram groups were detected in this area throughout the study period, but no ewe-like groups were detected in this region.

The habitat use of Moly Ridge during the late-summer 2014 season is a sharp contrast to habitat use of the pre-rut season (**Figure 1.13a & 1.13b**). Habitat use is still concentrated in the northwestern portions of Moly Ridge, but is generally estimated for ewe-like and rams groups as < 0.30 for even the most optimal sheep habitat. Only rams were detected during this season on the westernmost slopes of Moly Ridge and the areas around the easternmost peak of Moly Ridge. However, rams show a lower probability of use than ewe-like groups.

It appears that the movement of sheep from the broader Alaska Range to Moly Ridge likely occurs from western aspects of Patton Mountain (small mountain to the southwest of Moly Ridge), to the southwestern aspects of Moly Ridge. This corridor is the shortest distance between escape terrain, is predicted, by the habitat use map, to have some use by ram individuals, and is highlighted with red lines on the map (**Figure 1.12b**).

Habitat use maps of BRTA display different temporal use relationships than Moly Ridge. During the pre-rut 2013 season, habitat use of BRTA was low for both ewe-like (**Figure 1.14a)** and ram groups (**Figure 1.14b**). Use by either group was concentrated around the steepest sections of eastern BRTA. Habitat use increased into late-summer 2014 and was very high for the majority of higher elevation areas of eastern BRTA for both demographic groups (**Figure 1.15a & 1.15b**). However, these maps do not demonstrate the large imprecision of BRTA estimates, therefore, any inferences from BRTA habitat use maps should be taken with caution.

Discussion

Habitat Use and Detection

Cameras successfully captured thousands of sheep images within both study sites throughout the 15-month sampling period. Habitat use varied by season, site, and sheep demographic group. Ewe-like and rams used Moly Ridge the most with the onset of rut in 2013 and likely due to deeper snow conditions at higher elevations of the Alaska Range (**Figure 1.5**). While ram use declined in the months following the rut, ewe-like use remained constant throughout the winter and lambing seasons, matching my *a priori* temporal hypothesis. Habitat use for all sheep declined after early-June, probably when sheep migrated off the military installation, to higher elevations of the Alaska Range for better foraging and mineral lick opportunities (Spiers and Heimer 1990). Ewe bands might occupy winter ranges for up to nine months of the year (Hoefs and Bayer 1983), which would be consistent with my results of presence from mid-September 2013 to early-June 2014. Sheep use of Moly Ridge during the late-summer was minimal, detections were scant and mostly consisted of single or pairs of rams **(Figure A3.1)**. Geist (1971) notes that young rams in western Canada are frequently observed “wandering,” traveling longer distances into more novel territories than ewe groups, which could explain some of these unexpected results. This leads to the interpretation that low levels of Moly Ridge habitat use during the summer and late-summer were mostly the result of a few ram individuals while the high levels of habitat use during the pre-rut through lambing seasons likely coincided with the highest densities of ewe and ram individuals.

Estimates for BRTA habitat use were less precise than Moly Ridge, in part due to lower sample size. Sheep presence on BRTA was detected across most of the sampling period with notable increases during the post-rut 2013 and summer 2014 seasons and notably absent during the 2013 pre-rut and rutting season (**Figure 1.6)**. Unlike Moly Ridge, BRTA is within a contiguous range of optimal sheep habitat, presumably allowing for a greater movement of sheep groups in and out of the training area and likely constitutes a small portion of both ewe and ram group seasonal ranges. However, estimates of habitat use are very imprecise, leading to only weak inferences about temporal habitat use patterns.

As hypothesized, abiotic covariates best explained variations in habitat use. Distance from escape terrain, slope percentage, and snow depth were highly supported for predicting habitat use; further, the probability of use in relation to the distance to escape terrain varied by demographic group. Ewe-like individuals were more likely to concentrate closer to escape terrain, while rams were less predictable and had a higher probability of using areas further from escape terrain. Ram groups may spatially segregate from ewe groups to areas further from escape terrain (Geist 1971, Corti and Shackleton 2002). In addition, during lambing, ewe use is highly associated with steep escape terrain and predator avoidance (Rachlow and Bowyer 1994, 1998). However, caution should be taken when making broader inferences given the imprecise estimates of ram habitat use beyond ~500 m from escape terrain (**Figure 1.9**). The spatially balanced weighting skewed the camera sites resulting in over 55% of cameras occurring within 500 m of escape terrain, greatly reducing the precision of estimates beyond that distance.

Habitat use declined with increasing snow depths. Dall sheep are presumed to avoid areas with deep snow due to increased energy loss from movement through the snow, digging to find forage, and being slowed down when pursued by a predator (Burles and Hoefs 1984, Hoefs et al. 1986). Dall and Stone's sheep (*O. d. stonei*) have been observed avoiding areas with snow depth greater than 30 cm (Seip and Bunnell 1985, Nichols 1988), a finding further supported by my model results. Sheep occupying both study sites exhibited the same negative relationship; however, sheep detected on BRTA showed a stronger relationship. Both study sites have relatively high wind conditions creating slopes of exposed forage ideal for sheep winter ranges. BRTA has steeper topography resulting in more areas of exposed forage and greater connectivity with the Alaska Range allowing sheep to move into other winter habitats, possibly explaining the stronger relationship with increasing snow depth.

As hypothesized, I found moderate support for graminoid coverage positively influencing habitat use and no support for vegetation species richness or forb coverage effecting habitat use. Sheep habitat use has been documented to be predominately restricted to areas near escape terrain and windswept slopes, thus finding a lack of support for biotic factors predicting use was expected. Previous studies have recorded the importance of graminoids, forbs, and dwarf shrub species on the diets of thinhorn sheep (Murie 1944, Hoefs 1976, Rachlow and Bowyer 1998, Walker et al. 2007), but my study design only found moderate support for one of these classes of vegetation. Habitat use as a factor of plant biota could potentially be more decipherable with a larger sample size and much shorter occasion durations.

Detection was best determined by a camera being on a wildlife trail and the size of the cameras viewshed. Positioning a camera on an obvious wildlife trail greatly improved the chances of detecting a sheep; however, this came with the trade-off that sheep were typically detected traveling through the area rather than interacting with the habitat. Time lapse photos of non-trail areas had lower detection probabilities, but allowed for sampling of larger habitat areas and captured more images of sheep grazing or resting. Finally, the size of a camera's viewshed was negatively related to detection probability, opposite of my prediction. A possible explanation is that the human observer missed more detections in images of larger viewsheds compared to smaller viewsheds. A double-observer approach during photo processing could calculate if the probability of detecting a sheep, given that a sheep appeared in an image, was negatively correlated with viewshed size.

The cameras were a novel item in the treeless study sites, possibly prompting sheep to interact and investigate the cameras and camera mounts. Time lapse images captured sheep grazing near cameras immediately before triggered images of sheep investigating the camera, indicating that sheep may not have been attracted to an area because of the camera. It is possible that detection probabilities were biased slightly high by conspicuous cameras, but this is difficult to assess without further research.

Nocturnal Activity

Mountain sheep are considered diurnal animals and little direct evidence is available recording nocturnal activities (Geist 1971, Hoefs 1976). I have provided evidence that Dall sheep move and graze during the night and that these events appear concentrated during seasons with the lowest daylight hours. Observations of domestic hill sheep have shown nocturnal activity is common during winter months when daylight is limited and then ceases soon after the spring equinox (Wallace 1889). A study of desert bighorn sheep assessed differences in radio collar signal strengths and determined that nocturnal activity was common with this species across the entire year (Alderman et al. 1989). Dall sheep appear active during nocturnal periods, increasing foraging time, especially during long periods of darkness.

Camera Traps and Mountain Sheep

Research of mountain sheep typically involves direct human observation via aircraft or ground tracking, both of which can cause disturbances to sheep individuals (Frid 2003, Zhensheng et al. 2007, Stankowich 2008). These methods are often cost intensive, hazardous, and restricted by inclement weather. My study has shown that modern camera traps can effectively operate in mountain sheep terrain and produce data to estimate sheep habitat use, while reducing biases caused by human presence and climatic conditions. Data collected throughout the year allows for estimation of seasonal habitat use and detection, including the winter, a season when data collection is often difficult.

Camera traps are not a panacea for the study of mountain sheep or, for that matter, other mammals that reside in mountainous terrain. Though effective at distinguishing important temporal trends and habitat covariates, without having to capture individuals, these data cannot fluidly track the movements of individuals across a landscape. In addition, without unique identification, re-detection of individuals is limited to those animals with unique physical features, which is problematic for many abundance estimates.

While recognizing the shortcomings of cameras, there is potential to expand camera trap use in conjunction with other mountain sheep sampling methods. Population abundance utilizing mark-resight estimation is conceivable by installing cameras in concert with unique marking of individuals (McClintock and White 2007). Human presence would be reduced during the "resight" period, decreasing disturbance of sheep. Health monitoring of sheep populations is becoming paramount (The Wildlife Society and American Association of Wildlife Veterinarians 2015). Since sheep individuals often interacted with the cameras resulting in close-up facial and body images across the demographic spectrum, this could be the initial monitoring for changing body conditions or for the presence of disease. Finally, my study focused on the seasonal ranges of two sub-populations of a much larger sheep population. Expanding the study area would better capture the yearly habitat use of the population. Additionally, encompassing multiple years in a larger study site, may allow researchers to estimate site colonization and extinction parameters of sheep habitat use in relation to human activity, habitat covariates, and changing climatic patterns.

Military Land Conservation

Worldwide, wildlife populations face the threat of continual human transformation of habitat. United States Department of Defense lands provide important wildlife habitat areas that must conform to environmental statutes. Department of Defense lands, though only a small portion of federal land holdings, contain more federally endangered species than any other federal agency (Flather et al. 1994, Groves et al. 2000). The assessment of wildlife populations on U.S. military lands thus, becomes an important conservation and legal issue that must be addressed by U.S. military installations.

Monitoring wildlife on these lands can be challenging due to military training and the isolation of study areas. Depending upon the installation, access to study sites can be easy without disruption or heavily restricted due to consistent training operations. As I have demonstrated, camera traps capable of operating for multiple months without servicing and that operate in extreme climatic conditions are a viable resource for monitoring wildlife in restricted military lands. Therefore, researchers can accomplish wildlife and environmental mandates, while not having to access training areas that may typically be off limits or inaccessible. In addition, camera traps can act as both a monitor of wildlife and of illicit human behavior in remote sections of these restricted public lands, behaviors that may compromise wildlife conservation and training operations.

Military Recommendations

I have shown that Dall sheep use both Moly Ridge and BRTA, at different intensities, throughout a majority of the year. The highest sheep use of Moly Ridge appears to be between mid-October to mid-June (**Figure 1.5**), while habitat use of BRTA appears highest during the post-rut (12/15/2013 – 01/11/2014) and summer (06/22/2014 – 07/12/2014) seasons. Ewe-like groups with lambs and yearlings were detected in May and June 2014 indicating that sheep may use Moly Ridge and BRTA as lambing range. This lambing period would be the most critical time to avoid training to minimize disturbances on pregnant or nursing ewes and neonatal lambs.

Early-July to early-September on Moly Ridge appears to be the best training period to minimize sheep disturbance. Spiers and Heimer (1990) concluded that sheep were present on Moly Ridge during the winter range and migrated to Moly Ridge in early-October. My data show that winter habitat use is likely the highest, but there may be low levels of sheep presence throughout the year. Additionally, larger ewe bands were detected in mid-September 2013 and 2014, therefore migration from higher elevations may have occurred one-month earlier than previously assumed. Habitat use appears concentrated in the northwestern portions and northern arm of Moly Ridge **(Figure 1.12 & 1.13)**, thus, any training should focus on the eastern bowl and eastern portions of the main ridgeline to the east of the highest elevation point of Moly Ridge. In summary, the lambing, pre-rut, rut, post-rut, winter, and late-winter seasons should be avoided for Moly Ridge training, while both summer seasons appear to be the optimal training periods to avoid sheep habitat use.

The presence of ewes with lambs in May and June 2014 and the substantial increase of sheep images during June and July 2014 indicate that BRTA may have the highest intensity of use during this period. Additionally, ongoing road surveys of sheep centered on BRTA may show a similar pattern of higher sheep counts during lambing and early-summer (A. Brinkman pers.com.). Therefore, I advise to reduce or avoid training during the lambing and summer seasons, especially if ewe bands are observed in proposed training locations. Pre-rut through winter seasons appeared to have the lowest spatial habitat use (**Figure 1.14**). However, habitat use of BRTA appears very dynamic, as a large source population of sheep is available to move in and out of the training area.

Ultimately, I did not find support for ground-based military activities or fixed firing points affecting sheep habitat use. There was only a two-day ground training operation on Moly Ridge during the sampling period so inference of military activity effects is limited to this short period for the vast majority of the sampling points (**Table 1.3**). Ground-based training at BRTA was non-fire operations and was rather consistent for the first eight seasons, then more than doubled during the late-summer 2014 season. Sheep images during this season more than tripled compared to the same season the previous year and the probability of use for optimal sheep habitat was high (**Figure 1.15**), adding to the conclusion that minor on-ground military training had no effect on sheep habitat use during this study.

Table 1.1. Dates for the ten habitat use seasons of Dall sheep across 15 months of continuous sampling on Molybdenum Ridge and Black Rapids Training Area, Fort Wainwright, Alaska, USA. Two weeks were censored between each season and when researchers were camped on Molybdenum Ridge in July 2014.

Season Classification	**Start Date**	**End Date**
Late-Summer 2013	8/11/2013	9/07/2013
Pre-Rut 2013	9/22/2013	10/19/2013
Rut 2013	11/03/2013	11/30/2013
Post-Rut 2013	12/15/2013	1/11/2014
Winter 2014	1/26/2014	3/08/2014
Late-Winter 2014	3/23/2014	4/19/2014
Lambing 2014	5/04/2014	6/07/2014
Summer 2014	6/22/2014	7/12/2014
Late-Summer 2014	7/27/2014	8/30/2014
Pre-Rut 2014	9/14/2014	10/18/2014

Table 1.2. Hypotheses of Dall sheep habitat use and detection probability relationships with habitat and camera site covariates on Molybdenum Ridge and Black Rapids Training Area study sites of interior Alaska, USA.

Variable	Variable Abbreviation	Parameter	Variable Definition	Predicted Response
Location Factors				
Study Site	Site	Use	Difference between Molybdenum Ridge and Black Rapids Training Area	Black Rapids > Moly Ridge
Study Site	Site	Detection	Difference between Molybdenum Ridge and Black Rapids Training Area	Black Rapids > Moly Ridge
Demographic Factors				
Demographic group	Sex	Use	Difference between ram and ewe-like individuals	Ewe-like > Rams
Temporal Factors				
Seasons	Seasons	Use	Temporal variation across the ten seasons	Variable (see in text predictions)
Seasons by site	Seasons*Site	Use	Interaction between seasonal use and study site	Variable (see in text predictions)
Ewe-like Winter & Lambing	Ewe S567	Use	Habitat use by ewe-like individuals in the winter, late-winter, and lambing seasons vs other seasons	EweS567 > other season
Habitat Characteristics				
Elevation (m)	Elevation	Use	Elevation of a camera site	+
Slope (%)	Slope	Use	Average slope of a 500m radius circle around each camera	–
Distance to Escape Terrain	Escape	Use	Distance from a camera to barren/rocky terrain with a slope greater than 60%	–
Distance to Escape Terrain by Demographic group	Escape*Sex	Use	Interaction between habitat use of demographic group and distance to escape terrain	Ewe-like use closer to escape terrain
Snow Depth (cm)	Snow	Use	Estimated average snow depth at each camera site	–

Military Firing Points	Firing pt.	Use	Distance of a camera site to a weapon firing location	–
Military Training (days)	Training	Use	The number of on-ground military training days at a study site during a season	–
Graminoid Cover (%)	Gram	Use	Estimated percent cover of graminoids at a camera site	+
Forb Cover (%)	Forb	Use	Estimated percent cover of forb species at a camera site	+
Veg. Species Richness	SpRich	Use	Estimated richness of plant species at a camera site	+
Camera characteristics				
Wildlife trails	Trail	Detection	If a camera is capturing an image of a wildlife trail or not	On trail > not on trail
Camera Viewshed (ha)	Viewshed	Detection	The land surface area that a camera is capturing within each image	+

Table 1.3. The approximate number of on-ground military training days by season and study site (Date = MM/DD/YY), on Black Rapids Training Area (BRTA) and Molybdenum Ridge (Moly Ridge), Fort Wainwright, Alaska, USA.

Study Site	**08/11/13-09/07/13**	**09/22/13-10/19/13**	**11/03/13-11/30/13**	**12/15/13-01/11/14**	**01/26/14-03/08/14**	**03/23/14-04/19/14**	**05/04/14-06/07/14**	**06/22/14-07/12/14**	**07/27/14-08/30/14**	**09/14/14-10/18/14**	**Total**
BRTA	20.4	1.7	15.3	9.4	24.7	4.5	14.7	13.0	58.8	2.3	164.9
Moly Ridge	0	0	0	0	0	0	0	0	1.6	0	1.6

Table 1.4. Cumulative $\mathrm{AIC_c}$ weights ($\Sigma\ \mathrm{AIC_c}\ w_i$) for factors in the first round of model analysis of Dall sheep habitat use (ψ) and detection probability (p). Bolded numbers indicate a variable that was retained to the second round of modeling.

Habitat Use Variables [a]	$\Sigma\ \mathrm{AIC_c}\ w_i$
ψ Study Site	**1.000**
ψ Seasons, Ewe S567	**1.000**
ψ Seasons, Ewe S567*Site	**1.000**
ψ Distance to Escape Terrain	**1.000**
ψ Sex	**1.000**
ψ Escape*Sex	**1.000**
ψ Snow	**1.000**
ψ Slope	**0.994**
ψ Firingpt	**0.643**
ψ Gram	**0.527**
ψ Forb	**0.503**
ψ Elevation	0.384
ψ SpRich	0.360
ψ Training	0.335
ψ Viewshed	0.298
ψ Dshrub	0.271
Detection Variables	
p Trail	**1.000**
p Viewshed	**1.000**
p Study Site	0.256

[a] Defintions of habitat use and detection variables can be found in Table 1.2.

Table 1.5. Occupancy model results of Dall sheep habitat use analysis on military lands of interior Alaska. All models with $\Delta AIC_c <$ 10.00 are displayed. Models represent hypothesized relationships of habitat use (ψ) and probability of detection (p) to seasonal and study site differences and individual covariates.

Model[a]	AIC_c	ΔAIC_c	AIC_c w_i[b]	ML[c]	K[d]
ψ (Seasons, Ewe S567*Site[d]+Escape*Sex[e]+Slope[f]+Snow[g]+Gram[h]) p(Trail[i]+View[j])	1416.571	0.000	0.399	1.000	29
ψ (Seasons, Ewe S567*Site+Escape*Sex+Slope+Snow+Gram) p(Trail)	1417.637	1.066	0.234	0.587	28
ψ (Seasons, Ewe S567*Site+Escape*Sex+Slope+Snow) p(Trail+View)	1417.828	1.258	0.213	0.533	28
ψ (Seasons, Ewe S567*Site+Escape*Sex+Slope+Snow) p(Trail)	1418.615	2.044	0.144	0.360	27
ψ (Seasons, Ewe S567*Site+Escape*Sex+Snow) p(Trail+View)	1426.387	9.816	0.003	0.007	27

[a] Defintions of habitat use and detection variables in model results can be found in Table 1.2.

[b] 'AIC_c w_i' is the Aikaike Information Criterion with correction for small sample size model weight.

[c] 'ML' is the model likelihood.

[d] 'K' is the number of parameter in each model.

Table 1.6. Cumulative AIC$_c$ weights (Σ AIC$_c$ w_i) for factors in the final balanced model set of Dall sheep habitat use (ψ) and detection probability (p). Bolded values indicate the variables that were present in the chosen prediction model.

Habitat Use Variables [a]	**Σ AIC$_c$ w_i**
ψ Study Site	**1.000**
ψ Seasons, Ewe S567	**1.000**
ψ Seasons, Ewe S567*Site	**1.000**
ψ Escape Terrain	**1.000**
ψ Snow	**1.000**
ψ Sex	**0.998**
ψ Escape*Sex	**0.995**
ψ Slope	**0.995**
ψ Gram	**0.631**
ψ Firing pt.	0.315
ψ Forb	0.302
Detection Variables	
p Trail	**1.000**
p Viewshed	**0.619**

[a] Defintions of habitat use and detection variables can be found in Table 1.2.

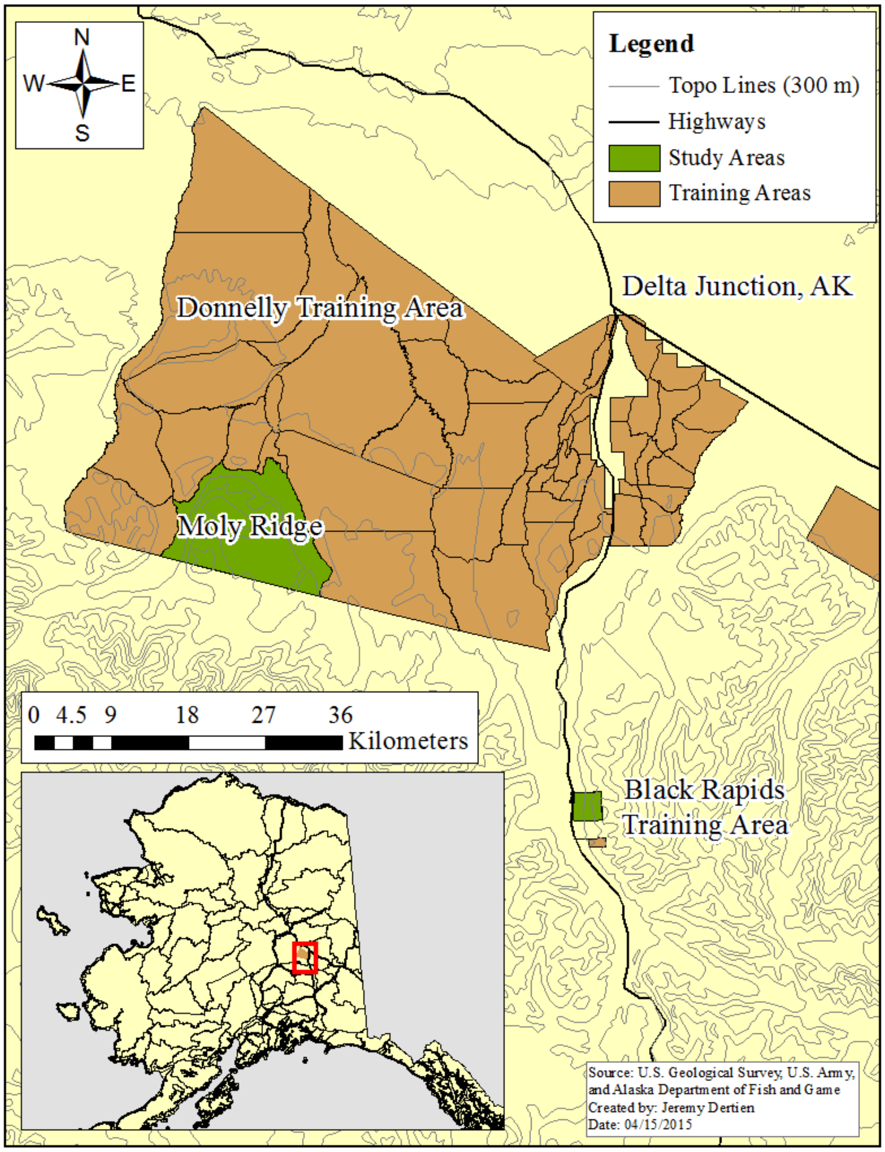


Figure 1.1. Location of the Molybdenum (Moly) Ridge and Black Rapids Training Area Dall sheep study sites in interior Alaska. Molybdenum Ridge is within the larger Donnelly Training Area. The full extent of the Black Rapids Training Area was used for the camera trap study. Note that Black Rapids Training Area is within a contiguous portion of the Alaska Range while Molybdenum Ridge is located on the northern periphery of the range.

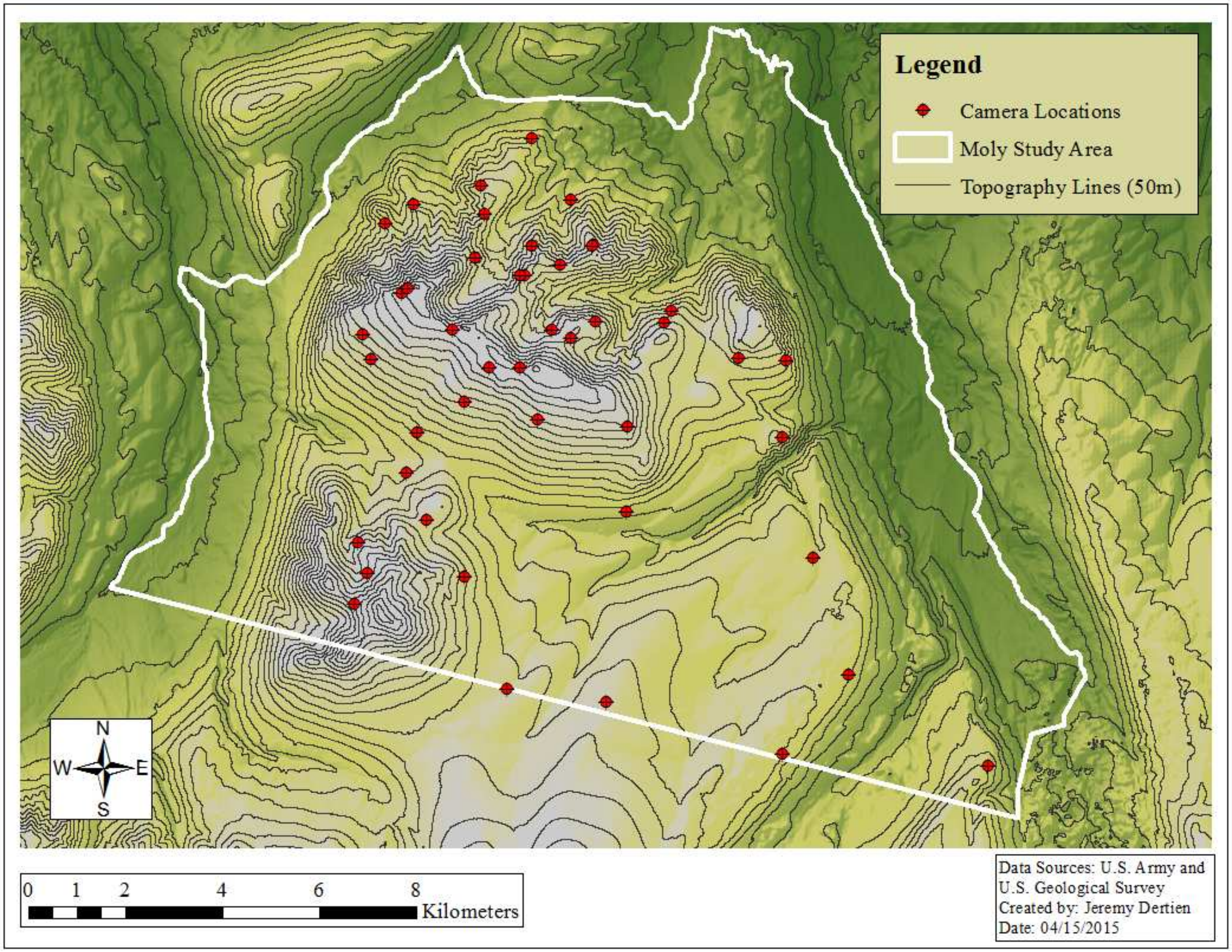


Figure 1.2. Camera trap sites on Molybdenum Ridge (Moly) within Donnelly Training Area of Fort Wainwright, Alaska. Cameras were positioned using a spatially balanced design with increased inclusion probabilities on steeper slopes.

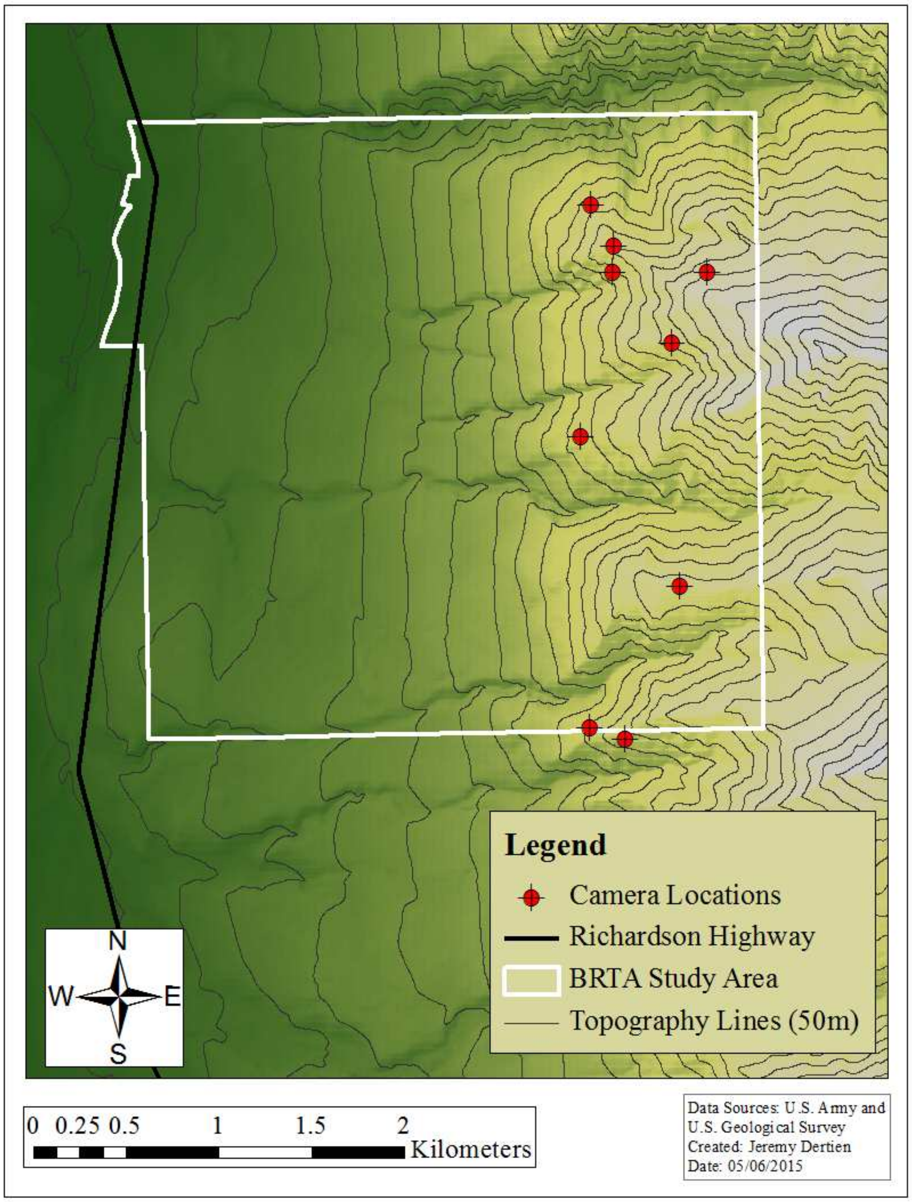


Figure 1.3. Camera trap placement in Black Rapids Training Area (BRTA) of Fort Wainwright, Alaska. Cameras sites were determined by a spatially balance design with increased inclusion probabilities for steeper slopes.

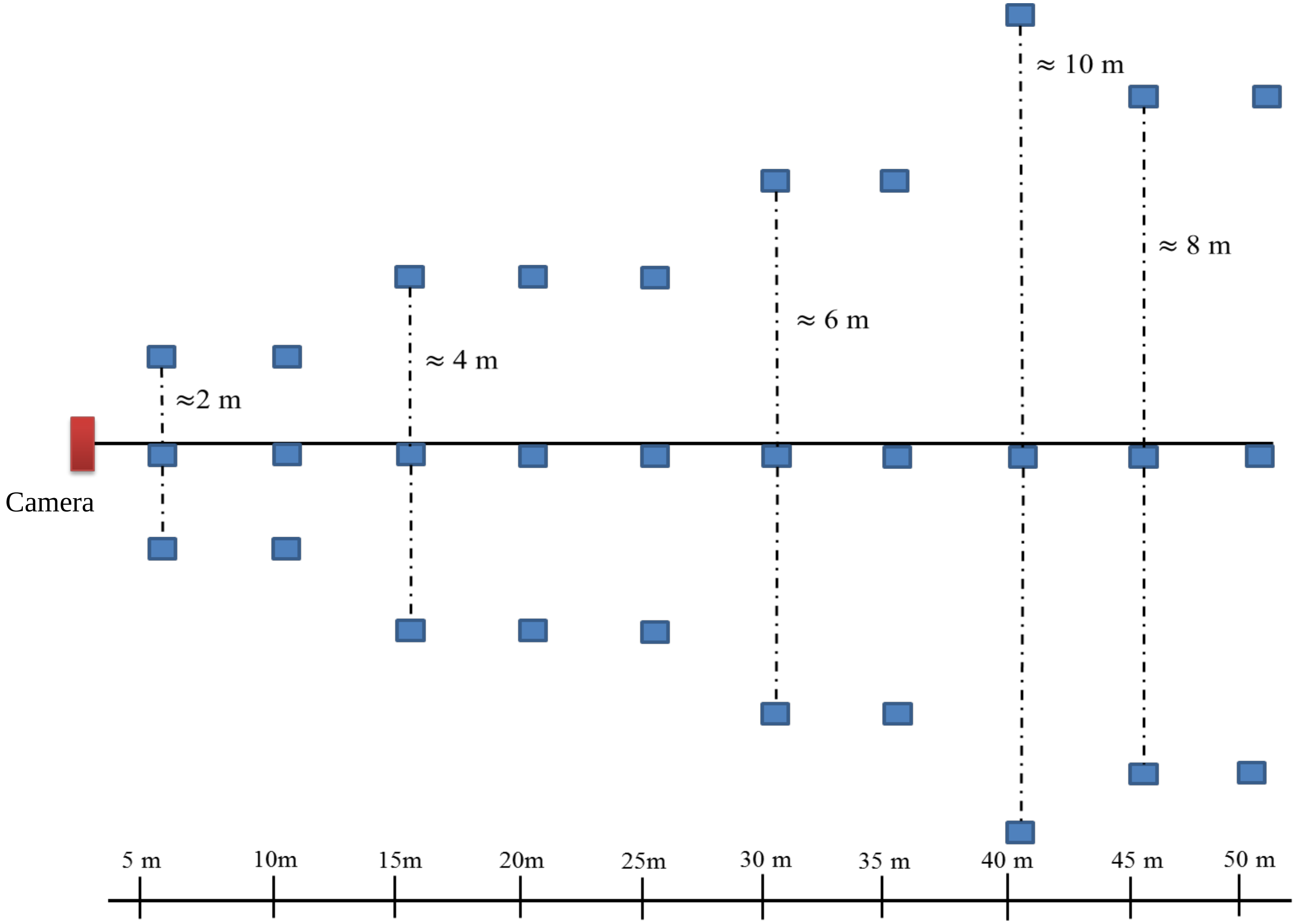


Figure 1.4. Vegetation sampling design at each camera location. Sampling quadrats offset from the main transect followed within the 40° field of view of the camera.

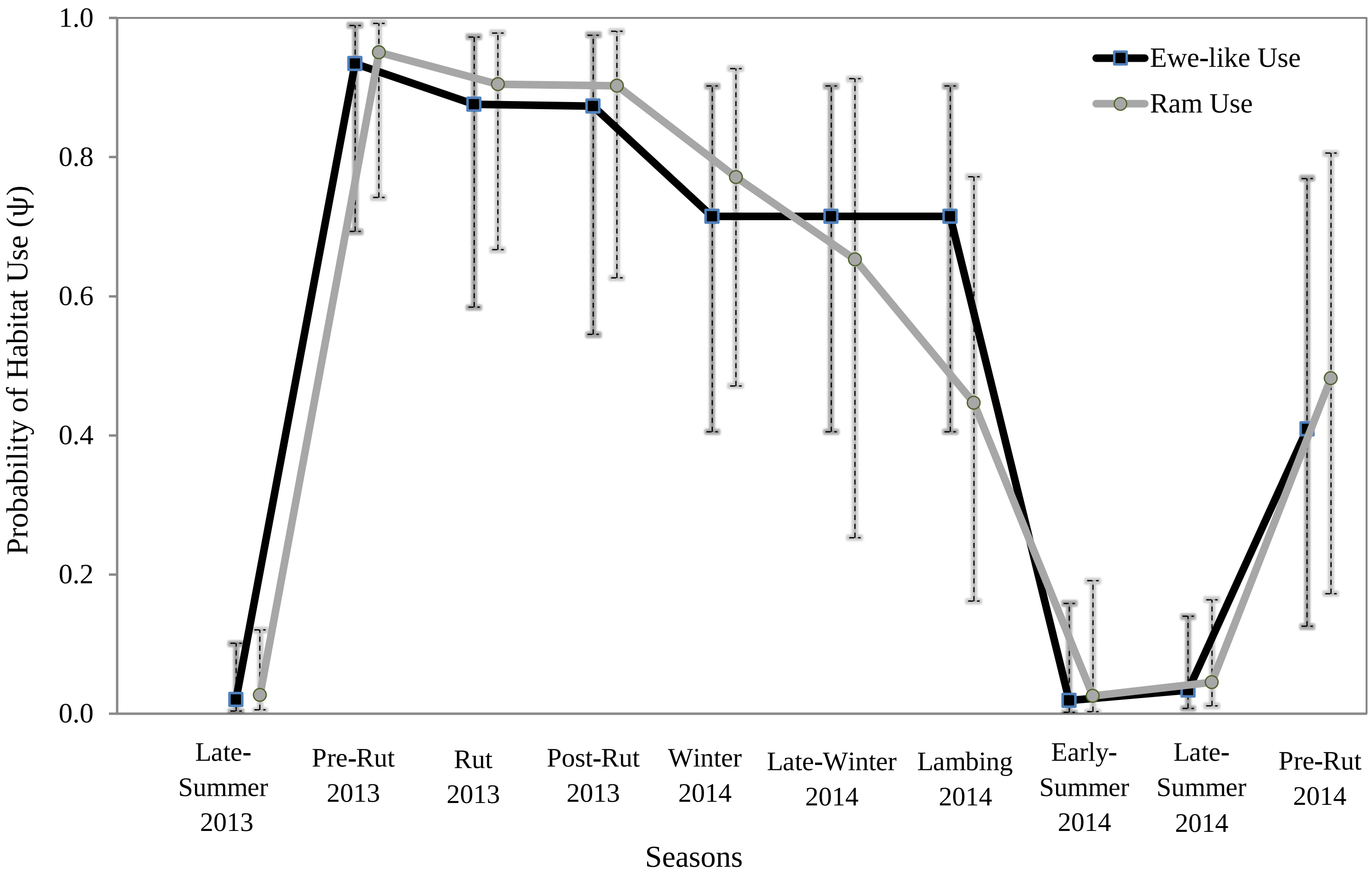


Figure 1.5. Ewe-like and ram habitat use of Molybdenum Ridge across 10 seasons of sampling. Habitat use for both demographic groups increased from the late-summer 2013 to the pre-rut 2013 season (late-September). Precision of estimates decreased through winter 2014 in part due to camera destruction and resulting lower sample size. Habitat use estimates approach zero during the summer months. To create this graph covariate values were set to the averages of: slope = 50%, distance to escape = 500 m, snow = 10 cm, graminoid = 6.5% coverage. Error bars are 95% confidence intervals.

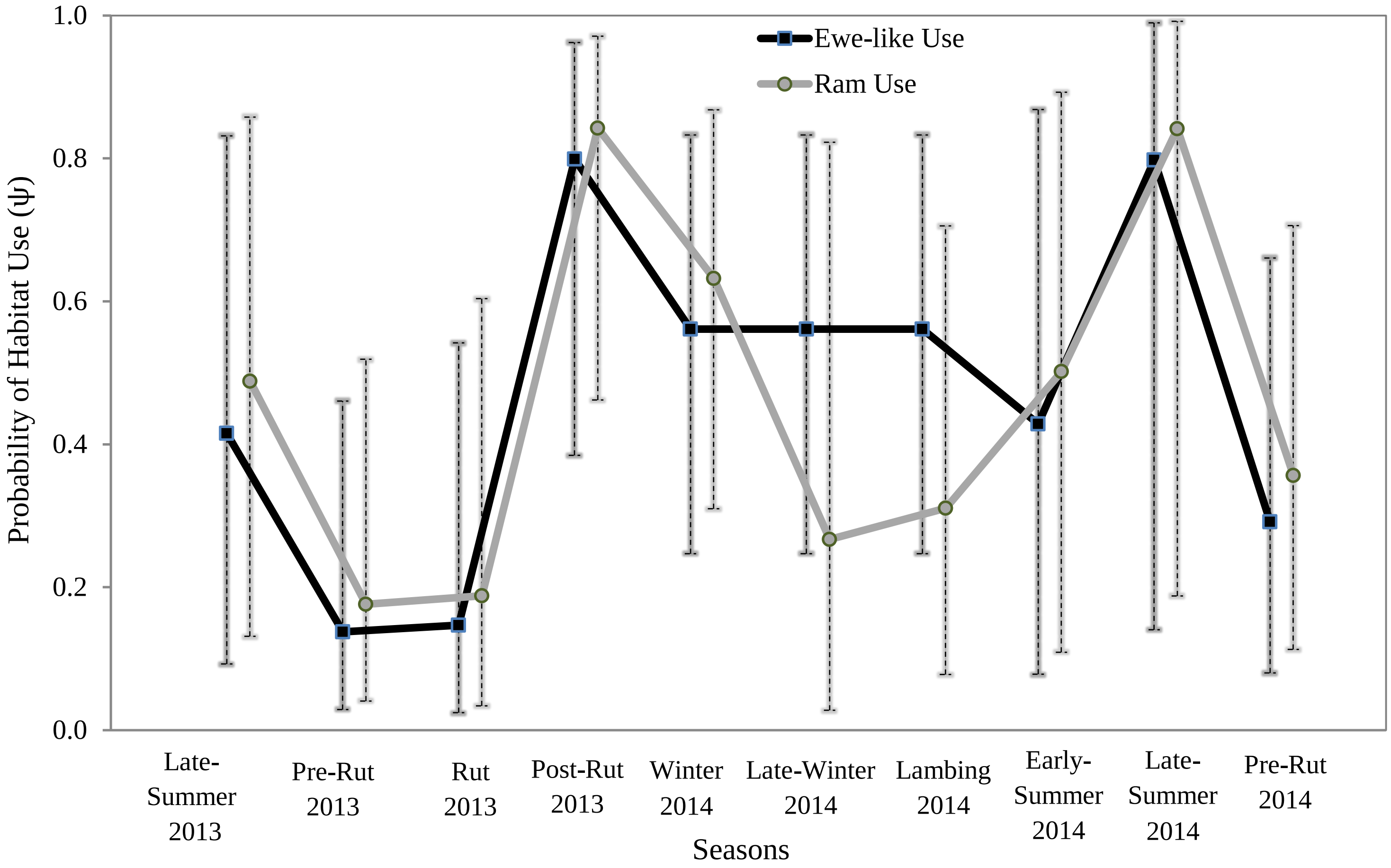
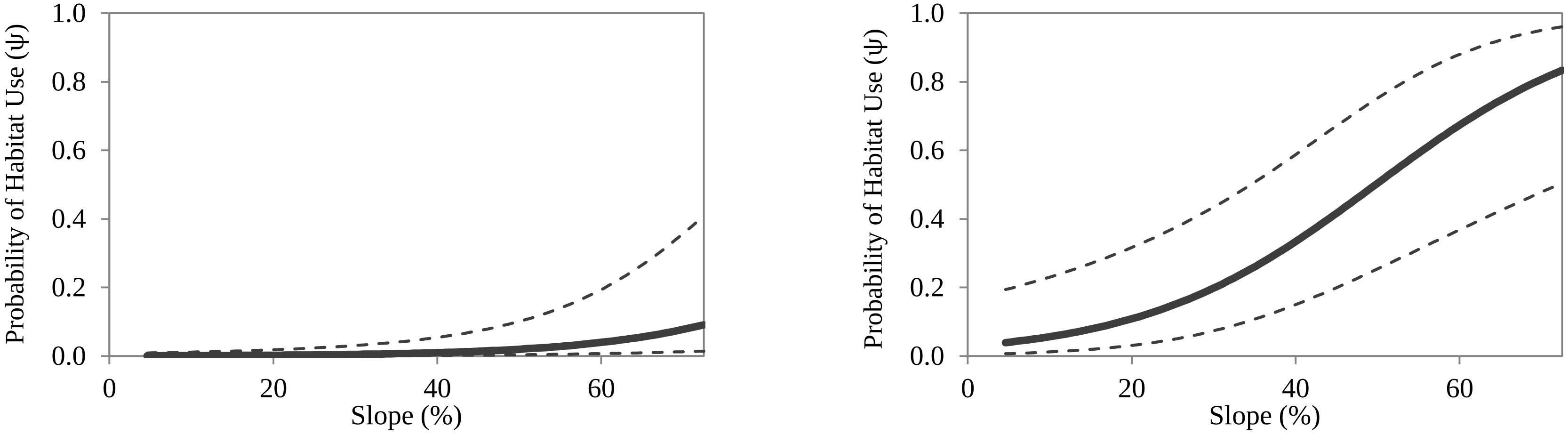


Figure 1.6. Ewe-like and ram habitat use of Black Rapids Training Area (BRTA) across 10 seasons of sampling. To create this graph covariate values were set at: slope = 50%, distance to escape terrain = 500 m, snow = 10 cm, graminoid = 6.5%. Error bars are 95% confidence intervals.

a. Molybdenum Ridge Summer 2013 **b. Molybdenum Ridge Winter 2014**



c. Black Rapids Training Area Summer 2013 **d. Black Rapids Training Area Winter 2014**

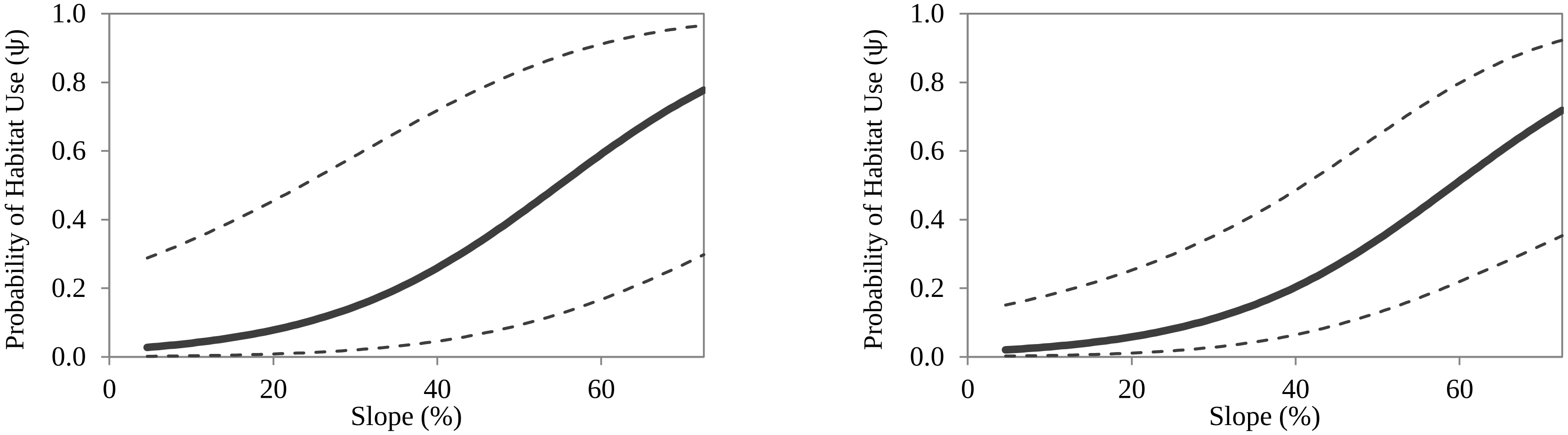


Figure 1.7. Estimated habitat use as a function of slope percentage varied between seasons (summer and winter) at Molybdenum Ridge and Black Rapids Training Area. Other covariates in the model were held at the averages of 500 m distance to escape terrain and 0 cm snow depth for summer and 10 cm snow depth for winter. Error lines indicate 95% confidence intervals.

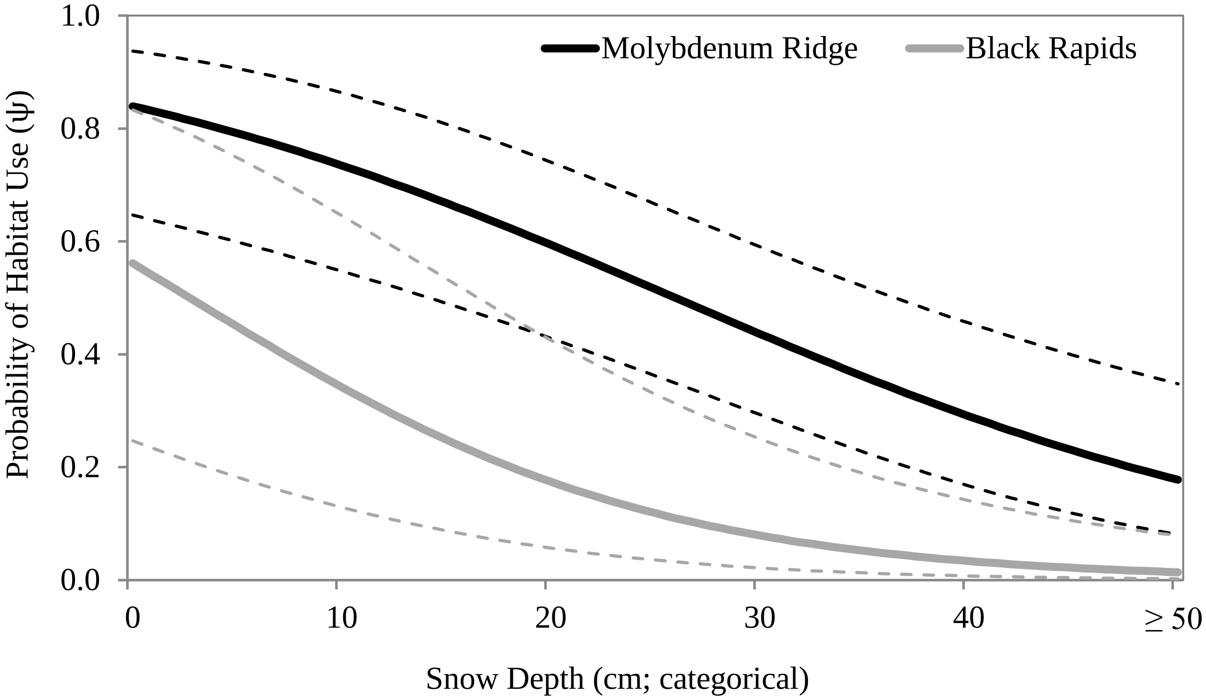


Figure 1.8. The probability of Dall sheep habitat use decreased steadily with the increasing snow depth for Molybdenum Ridge and Black Rapids Training Area. Sheep use of BRTA appears especially sensitive to snow accumulation as use approaches 0.1 at approximately 30 cm. To produce this graph the other covariates in the model, slope, distance to escape terrain and graminoid cover, were held at 50%, 500 m, and 4.6%, respectively. Dashed lines are 95% confidence intervals.

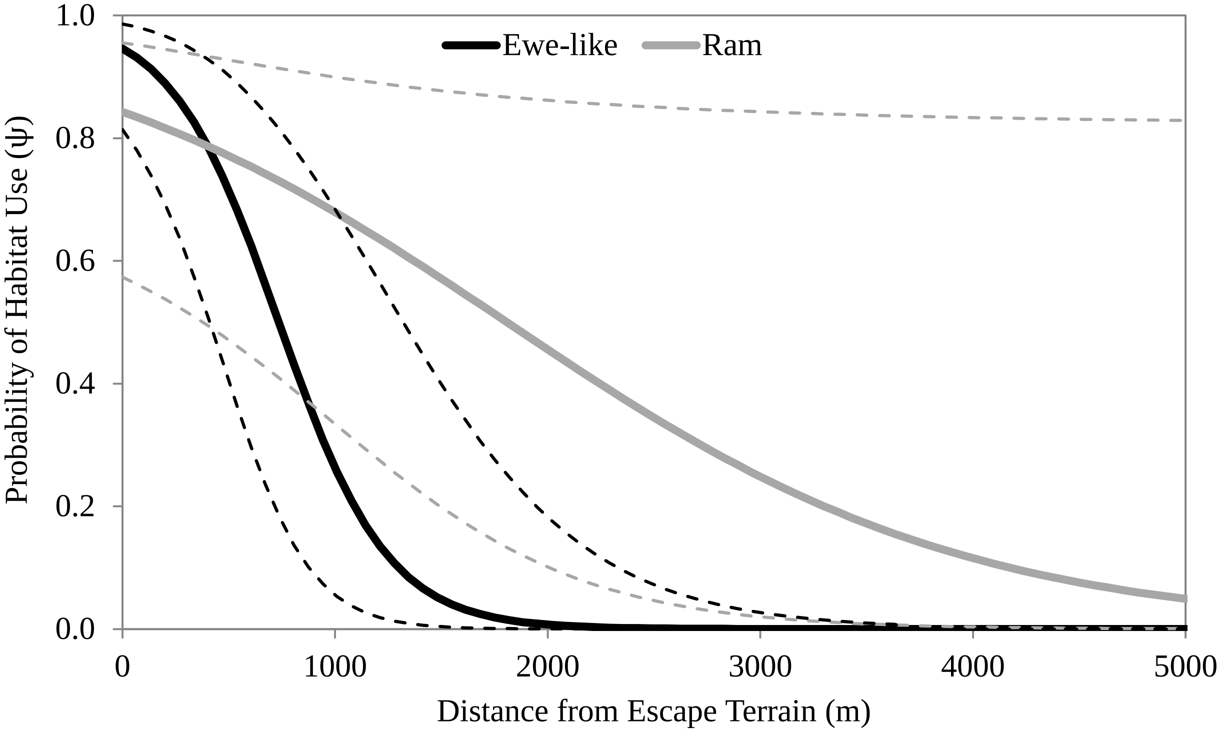


Figure 1.9. Habitat use of Dall sheep was negatively correlated with the distance from escape terrain for both ewe-like and ram groups. Ewe-like groups appeared to concentrate habitat use closer to escape terrain, while ram use included areas further from escape terrain, but with lower precision. Estimates for graphs were calculated by fixing other covariates in the model, slope, snow depth, and graminoid cover at 50%, 10 cm, and 4.6%, respectively. Dashed lines are 95% confidence intervals.

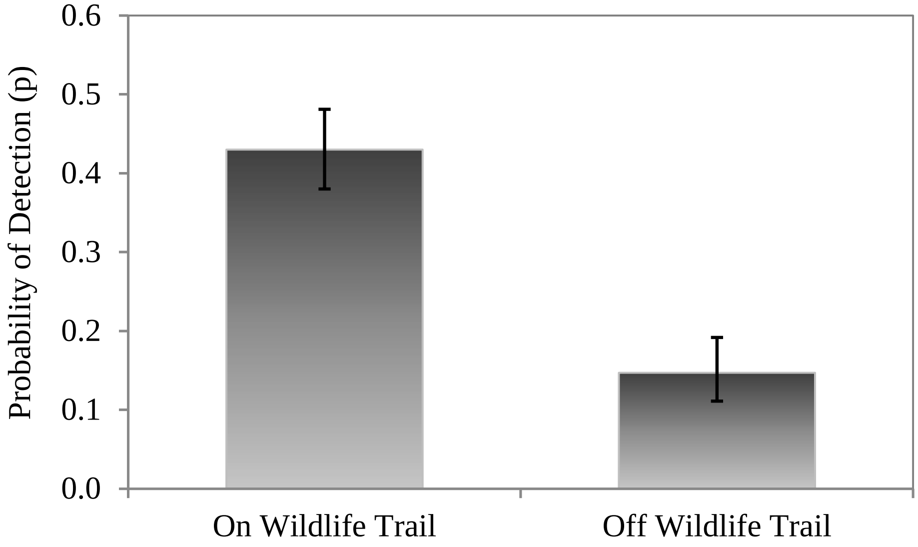


Figure 1.10. There was strong support for the probability of detecting Dall sheep varying between cameras located on or away from a wildlife trail. Error bars are 95% confidence intervals.

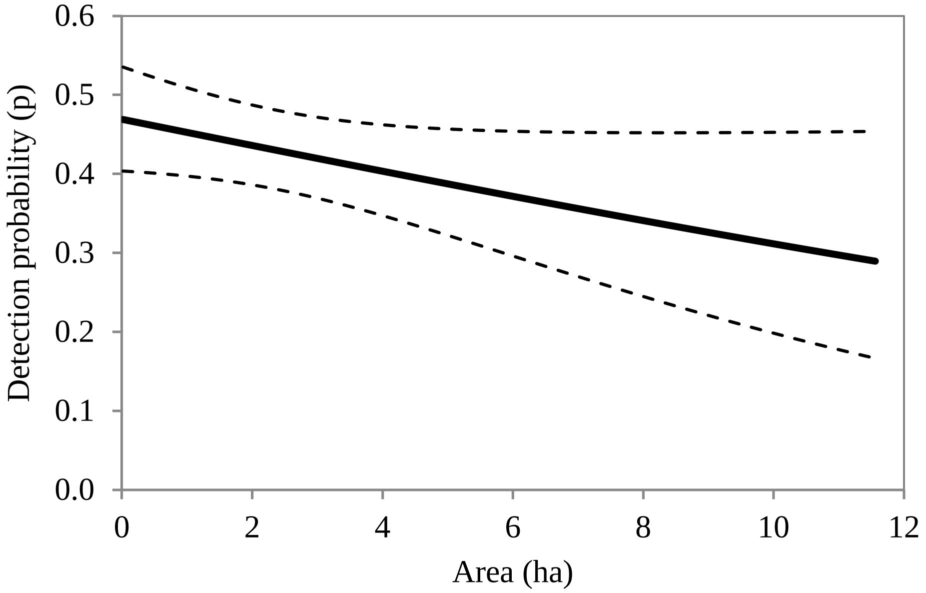
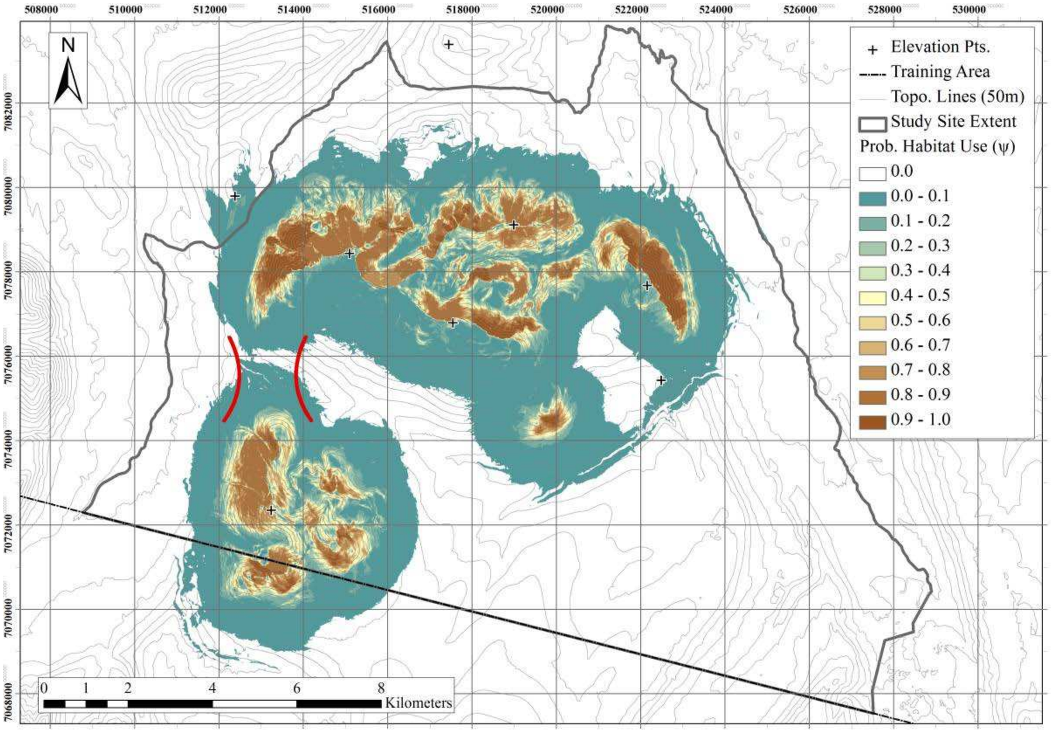


Figure 1.11. There was moderate support for detection probabilities decreasing with the increasing size of a camera's viewshed. This was opposite of the hypothesized relationship. Dashed lines are 95% confidence intervals.

a. Ewe-like pre-rut 2013



b. Rams pre-rut 2013

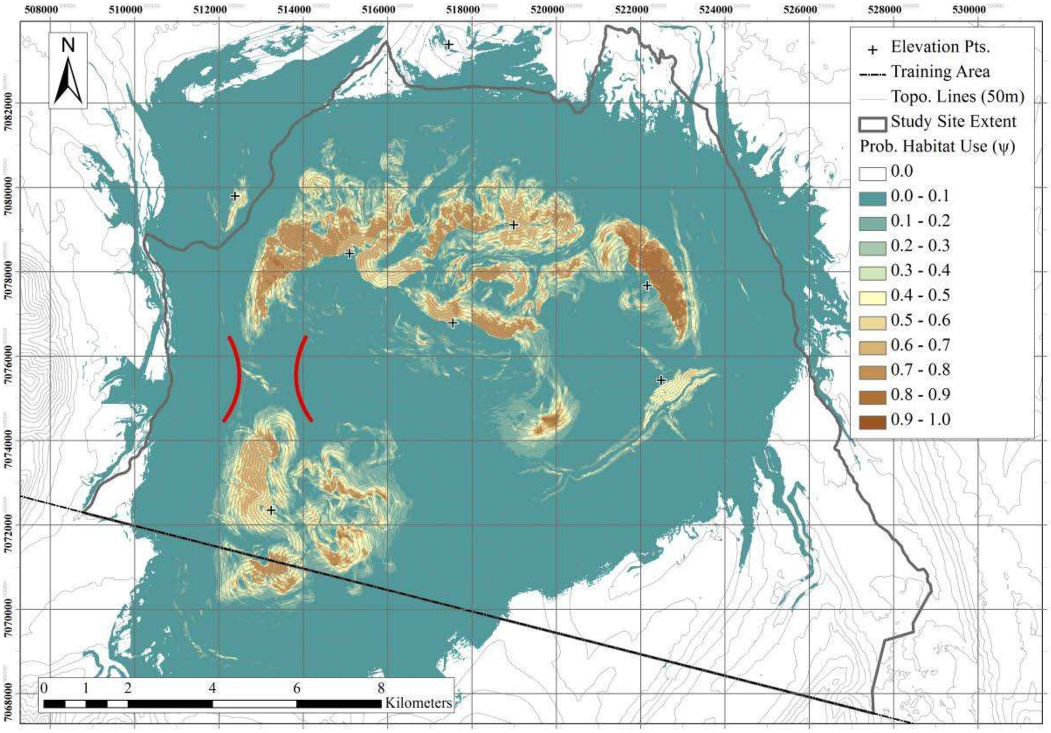
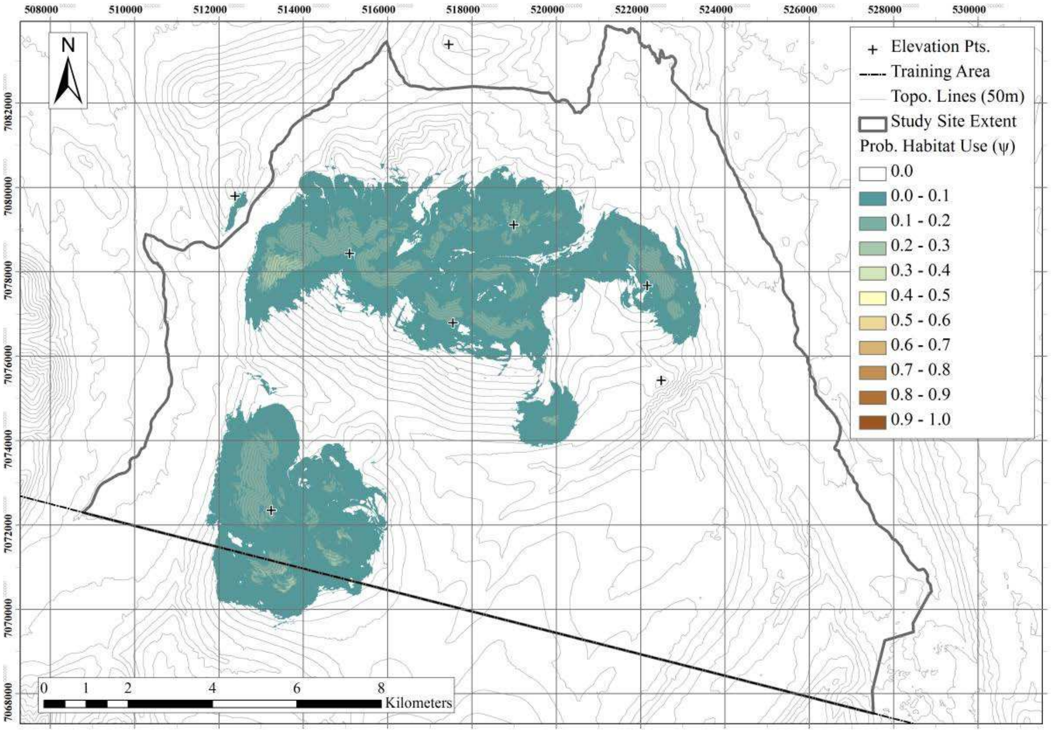


Figure 1.12. Habitat use probability maps for (a) ewe-like and (b) ram individuals on the Molybdenum Ridge study site during the pre-rut 2013 season (9/22 – 10/19/2013). Potential movement corridor of sheep onto Molybdenum Ridge via Patton Mountain (bottom-left portion of the map) is highlighted by red lines.

a. Ewe-like late-summer 2013



b. Rams late-summer 2013

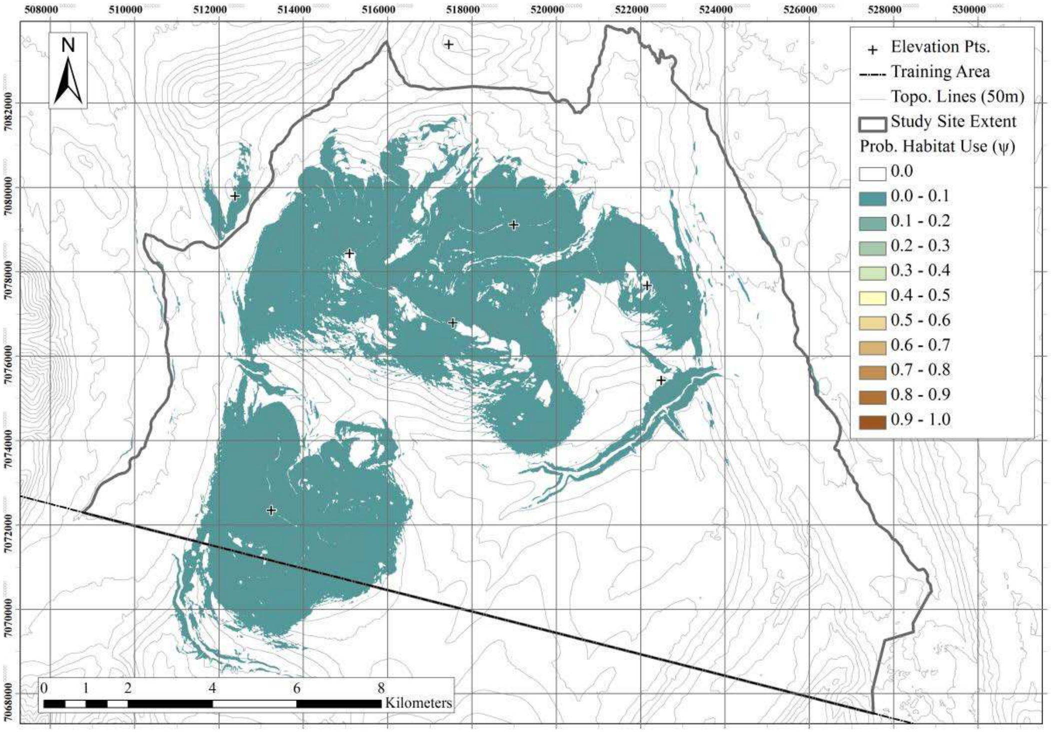
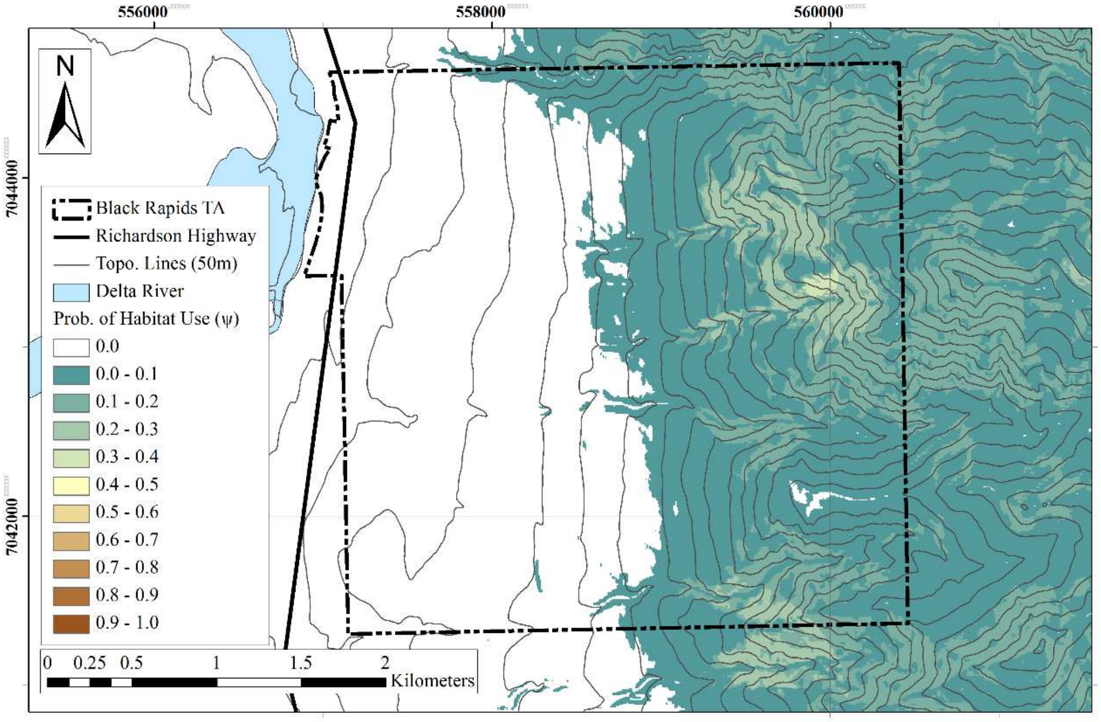


Figure 1.13. Habitat use probability maps for (a) ewe-like and (b) ram individuals on the Molybdenum Ridge study site during the late-summer 2014 season (7/27 – 8/30/2014). Habitat use is relatively low for both demographic groups. The greatest concentration of habitat use appears to be on the farthest western regions of the main ridgeline.

a. Ewe-like pre-rut 2013



b. Rams pre-rut 2013

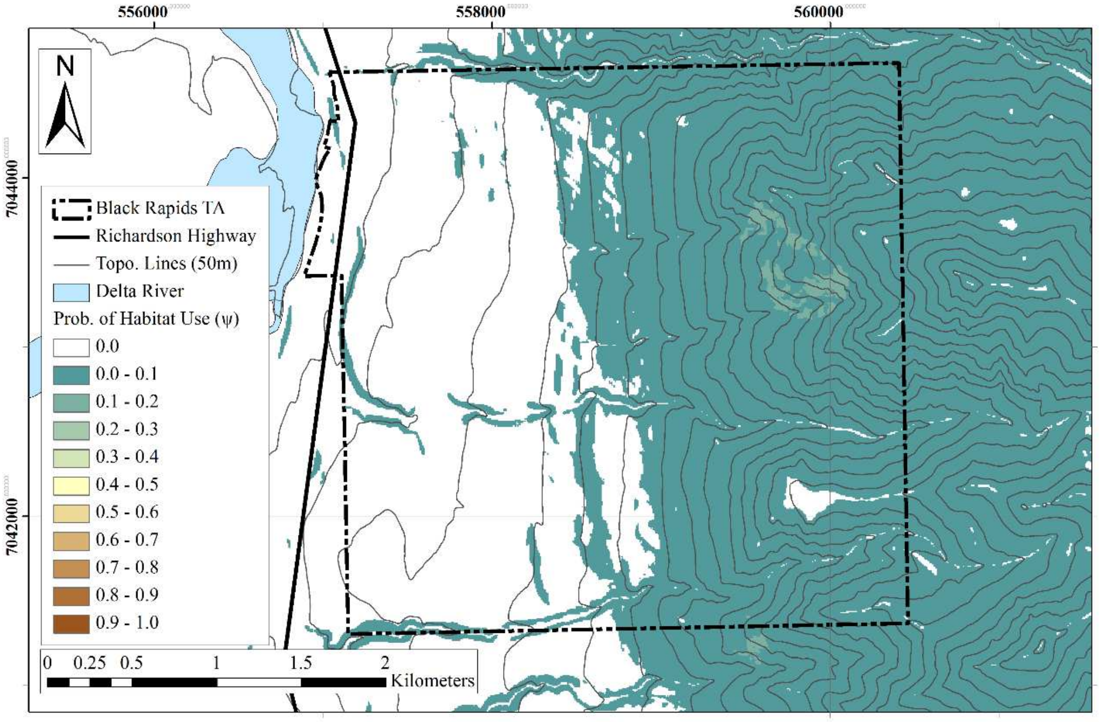
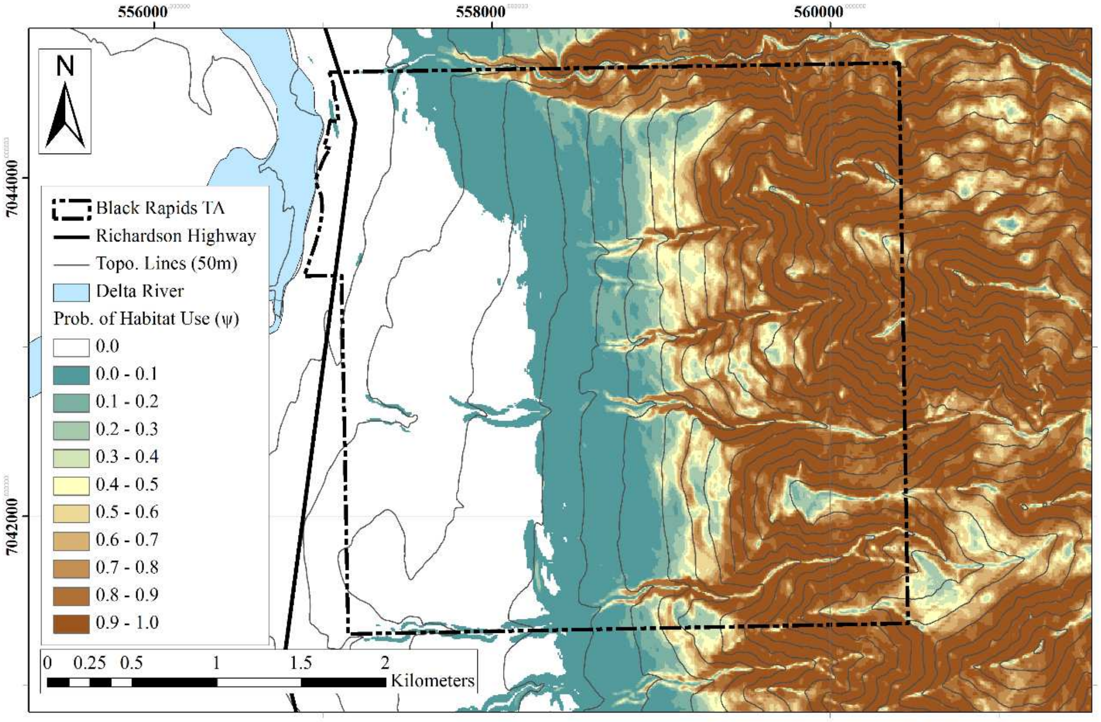


Figure 1.14. Habitat use probability maps for (a) ewe-like and (b) ram individuals on the Black Rapids Training Area study site during the pre-rut 2013 season (9/22 – 10/19/2013). Habitat use is relatively low for both demographic groups. The precision of these estimates (not shown) are very low.

a. Ewe-like late-summer 2013



b. Rams late-summer 2013

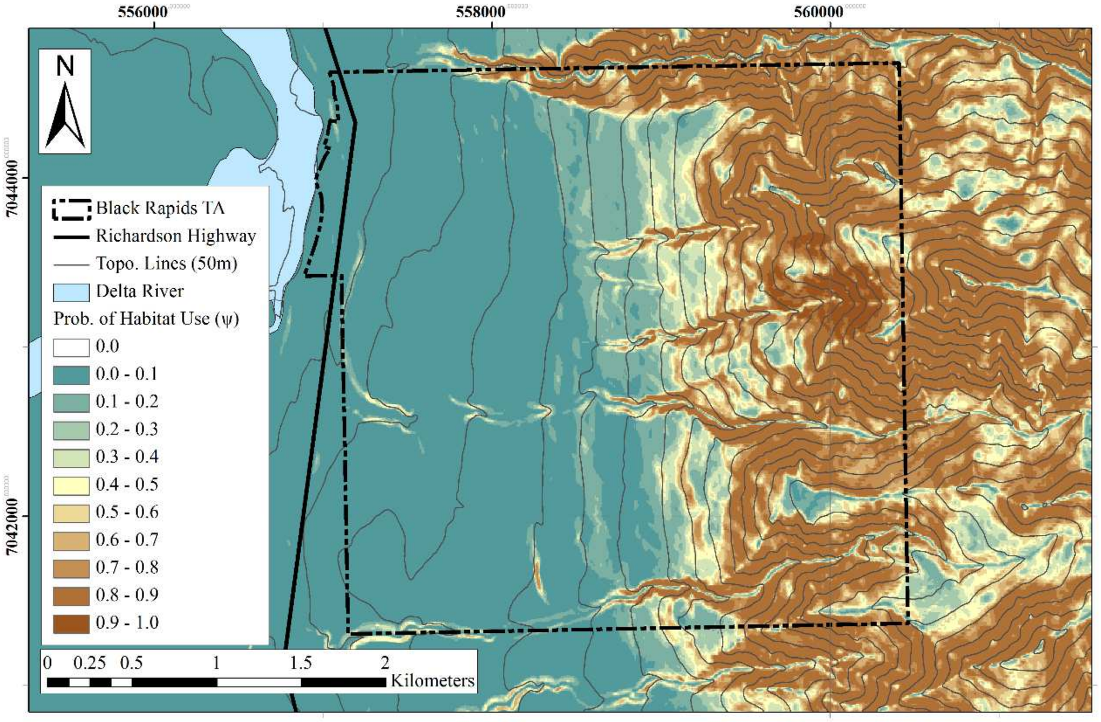


Figure 1.15. Habitat use probability maps for (a) ewe-like and (b) ram individuals on the Black Rapids Training Area during the late-summer 2014 season (7/27 – 8/30/2014). Habitat use is relatively high for both demographic groups. The precision of these estimates (not shown) are very low.

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CHAPTER 2

CAMERA TRAP SAMPLING AND HABITAT USE OF AN ALASKA MAMMAL COMMUNITY

Synopsis

Understanding how different guilds of species exploit habitat resources at different scales is important when making wildlife conservation decisions. Increasingly variable climatic patterns in Alaska are raising concerns of mismatched plant and animal patterns and altered ecosystem structures. Studying the habitat use of a mammal community can help determine intra- and inter-guild interactions and the most important habitat features correlated to habitat use, potentially improving the management of these communities in the light of a changing climate. I studied the habitat use of ten mammal species occupying alpine areas of interior Alaska, USA. I tested hypotheses about how spatial and temporal covariates varied with habitat use of these species within and between guilds. Further, I modeled two-species occupancy of grizzly bears and wolves against two different potential prey species. My results suggest that small and large herbivore habitat use was positively correlated with fine scale ground coverages (e.g., 0.5 m^2 quadrat measurements within 50 m of the sample site), while large herbivores also correlated with abiotic landscape covariates. Meso- and apex predator detections were sparse leading to imprecise estimates of habitat use and little support for most habitat covariates. Detection probabilities of most small and large herbivores were constant temporally, while detection of predators and Dall sheep was improved by cameras on wildlife trails. Two-species models suggested co-occurrence of habitat use between grizzly bear/caribou and wolf/caribou

and independence of habitat use between grizzly bear/squirrel and wolf/sheep. Further study of these systems may elucidate if temporal habitat use patterns evolve with a changing climate.

Introduction

Habitat use by a species is limited by available resources, interspecific interactions, climatic variations, and other natural and anthropogenic barriers (Berlow et al. 1999, Harley 2011, Ruell et al. 2012). Interpreting and quantifying factors determining species habitat use and a species' response to limitations of resources is a central focus of current population and community ecology research (Morris 1984, Johnson et al. 2004, Stephens and Anderson 2014). Investigating patterns of habitat use within groups of species, or guilds, is one method for community ecologists to explore differences in spatiotemporal habitat use across a diverse set of species (e.g., Cotton 1998, Hoehn et al. 2008). The guild concept is often applied to bird, insect, and small mammal communities, with less emphasis on large mammals (Root 1967, Simberloff and Dayan 1991). This decreased emphasis could be due in part to the difficulties of implementing a study design that simultaneously samples species of varying body size that use resources at different spatial scales. Understanding sympatric habitat use by guilds of mammals is an important consideration in conservation planning. This is particularly paramount in Alaska whose human population heavily relies upon wildlife resources and where an increasingly variable climate may be altering ecosystem structure and function (e.g., shrub encroachment into alpine areas; Sturm et al. 2005, Post and Pedersen 2008). Furthermore, few studies have been able to analyze the habitat use of multiple guilds of Alaskan mammals (Smith et al. 2001) and no study has focused primarily on the broader mammalian community habitat use of the Alaskan alpine tundra.

The mammalian community of interior Alaska, unlike other areas of the United States, contains relatively intact populations of apex predators (e.g., grizzly bear [*Ursus arctos*], gray wolf [*Canis lupus*]) and mesopredators (e.g., red fox [*Vulpes vulpes*], wolverine [*Gulo gulo*]). These species along with large (e.g., caribou [*Rangifer tarandus*], moose [*Alces alces*]) and small (e.g., arctic ground squirrel [*Urocitellus parryii*)]) herbivores must exist in a harsh subarctic climate, beyond the optimal environmental conditions necessary for many mammal species (Shelford 1911). These extreme environmental conditions, in part, dictate the occupancy and dispersal of these four guilds across the landscape, and regulate the spatial and temporal overlap in habitat use by the different guilds.

Occupancy and habitat use are estimates of the probability that a species occupies or uses a certain habitat area, or resource unit, over a discrete time period (MacKenzie et al. 2003, MacKenzie 2006). These metrics are growing in popularity as important parameters to quantify wildlife species distributions and interactions (Jácomo et al. 2004, Carter et al. 2012). With the inclusion of species-specific detection probabilities, researchers are able to better estimate occupancy by correcting for imperfect detection, a potentially confounding factor. This is especially important for mammals that have low detection probabilities due to cryptic behavior and low densities (O'Connell Jr. et al. 2006, Harmsen et al. 2010). The addition of environmental covariates can increase the accuracy and precision of occupancy and detection estimates and quantify the importance of different habitat variables (MacKenzie et al. 2003), potentially leading to decisions impacting species conservation. Expansion of the occupancy models has included two-species occupancy models that estimate the occupancy and detection probability of a species dependent on another species (MacKenzie et al. 2004, 2006). Two-species models are thus important for questions of predator-prey interaction or intra-guild competition.

Camera trap sampling has become an important method for the estimation of large mammal habitat use (O'Connell and Bailey 2011, Swann et al. 2011). Passive camera traps are well suited for sampling of larger mammals since larger species can consistently activate a camera and often use wildlife corridors improving detectability. However, camera traps may not detect smaller mammals or mammals that do not typically use trail systems. Using multiple camera triggering techniques (i.e., triggered and time lapse photos) could increase data for small herbivorous species.

Habitat use by herbivore species is often associated with the availability of forage, water resources, and shelter (Mysterud and Østbye 1999, Redfern et al. 2003). Both guilds of herbivores in this study, small herbivores and large herbivores, are limited by the availability of these resources, but differ in the spatial scale in which they use the resources and how they react to seasonal changes. The three small herbivore species (i.e., Hoary marmot [*Marmota caligata*], collared pika [*Ochotona collaris*], and Arctic ground squirrel) have similar diets (graminoids, forbs, and some dwarf shrubs), are territorial of their relatively small home ranges (<10 ha), and act as central place foragers (Batzli and Sobaski 1980, Barker and Derocher 2010, Barrio and Hik 2013). Hoary marmot and collared pika in particular, utilize rocky talus slopes or boulder fields for shelter, with grass cover and other vegetation in close proximity (Barash 1973). Because the majority of resource procurement is required in a relatively compact spatial area, finer-scale ground coverage covariates and plant species richness may better dictate habitat use than abiotic landscape covariates (e.g., slope; **Table 2.1**).

The large herbivore guild contains three species (i.e., moose, Dall sheep [*Ovis dalli dalli*], and caribou) that maintain home ranges > 50 km^2, form social groups, and graze and browse on a wide range of graminoids, forbs, and shrubs (Geist 1971, Ballard et al. 1991, Molvar and Bowyer 1994). While moose and caribou vary in habitat use between flatter open shrub lands, forests, and some use of steeper alpine tundra (Gasaway et al. 1992, Boertje et al. 1996, Joly et al. 2007*a*), Dall sheep are obligate users of higher slopes near steep escape terrain with shorter vegetation. Large home ranges and energy demands dictate that abiotic covariates (e.g., elevation and slope) likely correlate to habitat use of this guild. Finer-scale ground coverages may influence habitat use, but to a lesser magnitude than abiotic covariates.

The mesopredator guild is composed of generalists feeding upon small herbivores, carrion, and some plant material; wolverines in particular are recorded actively hunting marmots and ground squirrels (Hornocker and Hash 1981, Krebs et al. 2007, Lofroth et al. 2007). Both species use alpine tundra, primarily in the spring and summer seasons (Jones and Theberge 1982, Landa et al. 1998). However, they have relatively different home range sizes and dispersal patterns. Wolverines maintain large home ranges of ~ 200 - > 1,000 km^2 (varying demographically), across forest, shrub, and alpine tundra ecosystems (Whitman et al. 1986, Landa et al. 1998, Krebs et al. 2007). In contrast, Jones and Theberge (1982) found that red fox home ranges averaged 16.01 km^2 in tundra ecosystems, an order of magnitude smaller than wolverines. Thus, deciphering habitat use factors for wolverines may be more difficult given the species large dispersal capability and generalist diet.

The two apex predator species (i.e., gray wolf and grizzly bear) also maintain large home ranges. Mech et al. (1998) observed heterogeneity of home range sizes between wolf packs of interior Alaska, but a mean range size of 1,330 km^2. Estimates of grizzly bear home ranges can vary widely depending on the ecoregion and demographics of the individual, estimates from southwestern Alaska and arctic Canada vary between ~93 to ~ 900 km^2 for female grizzly bears (Collins et al. 2005, Edwards et al. 2013). Therefore, both species utilize large swaths of the landscape that have the potential to overlap with several prey species.

Wolves are social carnivores that are known to prey upon all of the herbivore species in this study, especially the large herbivore species (Murie 1944, Gasaway et al. 1983). Therefore, direct overlap of wolf habitat use in areas of prey use could be correlated with the presence of that prey species. Unlike wolves, grizzly bears are omnivorous and will consume large quantities of berries including crowberry (*Empetrum nigrum*), and *Vaccinium* spp., herbaceous roots, and arthropods (Munro et al. 2006). Co-occurrence thus of bears and prey species is potentially confounded with the abundance of vegetation and other resources at the same sampling site.

Predator habitat utilization is often associated with the habitat types in which prey species inhabit (Jones and Theberge 1982, Krebs et al. 2007, Robinson et al. 2014). Therefore, important covariates correlated to the habitat use of prey species may be correlated to the habitat use of predator species. In addition, intra-guild interactions and meso/apex predator co-occurrence can facilitate or deter habitat use by a predator species (Khalil et al. 2014, Wang et al. 2015). I hypothesized that predator habitat use would resemble the habitat use of the predator’s prey species as the predators would be selecting for areas of higher resource availability. Therefore, habitat covariates important for ground squirrels would be important for the habitat use of red fox and grizzly bear, and variables for moose and caribou would be important for grizzly bear, wolves, and wolverines. In addition, I predicted that two-species occupancy models between apex predators and prey species would demonstrate co-occurrence of habitat use between each set of species. This would further validate the hypotheses that predators had higher habitat use in areas with prey present.

Study Goals & Objectives

My primary goal of this community assessment was to determine how and if the habitat use of different mammalian guilds vary dependent on time, habitat, and available resources (e.g., prey species). Secondarily, I also investigated the tenability of using scheduled time lapse photos to collect presence-absence data for a mammalian community. This type of assessment is rare and to my knowledge no such camera trap study, to this extent, has been conducted in an alpine environment. This camera trap study was primarily focused on the habitat use of Dall sheep on Molybdenum Ridge (“Moly Ridge”) in Donnelly Training Area (DTA) and within Black Rapids Training Areas (BRTA) of U.S. Army Fort Wainwright, Alaska (Dertien 2016; **Figure 2.1**). Therefore, the study design focused on sheep as the primary species of interest. However, sampling within this habitat provided the opportunity to assess the habitat use of the mammalian community.

I modeled the habitat use of ten mammal species across four guilds using 15-months of continuous detection-non-detection camera trap data. I used single-species and two-species occupancy models coupled with fine scale ground coverages, abiotic landscape covariates, and temporal differences to estimate habitat use and detection probabilities. Single-species occupancy models elucidated important factors correlated to the habitat use of each species within a guild, while two-species models determined co-occurrence, independence, or avoidance between predator and potential prey species.

Materials & Methods

I installed cameras during July and August 2013, atop and in surrounding habitat of Moly Ridge in DTA and BRTA of Fort Wainwright, Alaska (**Figure 2. 1**). Moly Ridge is located on the northern foothills of the Alaska Range, approximately 50 km southwest of Delta Junction, Alaska. BRTA is adjacent to the Richardson Highway in the Delta River valley of the Alaska Range approximately 70 km south of Delta Junction, Alaska. Elevations at Moly Ridge and BRTA ranged from 800 – 1,900 m and from 1,050 – 1,525 m, respectively, and slope grades ranged from 0-272%. Sampling at both locations was predominately in alpine habitats with prevalent graminoids, dwarf shrubs (i.e., shrubs ≤ 20 cm tall), low growing forbs, and unconsolidated rocky slopes. Lower elevations of Moly Ridge (< 1,100 m), where limited sampling occurred, were typically flatter and dominated by *Salix* spp. (≥ 20 cm tall), green alder (*Alnus viridus*) and dwarf birch (*Betula nana*) thickets. Lower elevations of BRTA, adjacent to sampled alpine areas, had large patches of green alder on inclined slopes. Both study sites were exposed to high wind conditions, especially during the winter ($\bar{x} = 19.3$ km/h; NOAA 2015) leading to large windswept areas. Moly Ridge is on the edge of the mountain range and is within an ecotone separating the mountain range and forested flatlands. In contrast, BRTA is in the center of the Alaska Range and is more dynamic topographically with large contiguous patches of escape terrain, while being bordered by a braided river valley.

Camera Trap Sampling Design

The sampling design was influenced by the companion Dall sheep study (see Chapter 1). I stratified the study area by three classes of slope percentage, flat (≤ 15%), inclined (15% < slope ≤ 45%) and steep (slopes > 45%) and I used 45 cameras on Moly Ridge and nine on the BRTA (**Figure 2.2 & 2.3**). Camera locations were determined through a spatially balanced design. A spatially balanced survey is a probability-based survey generated via the Reversed Randomized Quadrant-Recursive Raster (RRQRR) algorithm (Stevens and Olsen 2004, Theobald et al. 2007), which I calculated using ArcGIS (ArcGIS v10.0; Environmental Systems Research Institute, Redland, California, USA). The RRQRR algorithm allows for varying numbers of sample site locations per strata by assigning differing inclusion probabilities to each stratum. Inclusion probabilities were chosen by following recommendations of Theobald and Norman (2006); flat, inclined and steep strata had 0.1, 0.7, and 0.8 inclusion probabilities, respectively. This resulted in 5, 23, and 17 cameras being installed in the flat, inclined, and steep strata, respectively.

Logistic issues such as timing of installation, scouting of camera locations, and safety of personnel were factors determining the exact placement of some of the cameras. Once arriving at the coordinates for a camera location, I chose a site within 100 m that would provide the best opportunity to capture an image of sheep and other mammals. If I could not safely access the exact chosen camera location, then I chose a location within ~100 m, which would capture an image of the predetermined camera location and coordinates. RECONYX PC800 or PC900 Professional Hyperfire Infrared cameras (RECONYX, Inc. Holmen, Wisconsin, USA 54636) were installed upon RECONYX t-post mounts, thunderbolt mounts, or security boxes affixed to rock faces using a combination of construction adhesive and ratchet straps.

Moly Ridge and BRTA are within an active U.S. Army training area, thus researcher access revolved around periods of limited military training. The timing of camera installation and vegetation sampling at the Moly Ridge site was when the training range of DTA was conducting a three-week “range cleanup” during late July and early August. This period provided the only opportunity to install and perform camera maintenance.

I programmed camera traps to trigger by a combination of movement and infrared signature, as well as to record a time lapse image every hour. Once a trigger occurred, the camera would capture three images in succession, separated by one second between images. To conserve memory, the camera would then have a “quiet period” of 15 seconds in which a trigger could not occur. Following the first camera maintenance, and noting the amount of space still available on the memory cards, I did not program a quiet period for the last three months of the study. Time lapse photos were initially taken at the beginning of each hour (i.e., each camera captured 24 of these images per day), but I increased frequency of time lapse photos to every 30 minutes for the last three months of the study. Camera maintenance occurred again in mid-October 2014 to exchange SD cards and to repair some cameras.

Covariate Descriptions

I considered fine scale covariates to be variables including ground coverage classes and plant species richness that were measured in quadrats within 50 m of the camera location and which, in an alpine environment, are likely to have higher variability on smaller spatial scales (Körner 2003). I considered landscape covariates to be abiotic covariates extracted from remotely-sensed data, including elevation and mean slope.

Vegetation coverage classes and species richness sampling occurred at each of the 54 camera sites. I placed a 50-m transect perpendicular to the face of the camera and sampled 0.5 m^2 quadrats every 5 m along the transect and at varying distances perpendicular from the transect totaling 30 quadrats at each camera (**Appendix I**). Vegetation coverage sampling focused on estimating aerial coverage, the coverage of vegetation as seen from above, and ground coverage, the coverage of material actually touching bare ground or rock. Each coverage percentage was either rounded up to the nearest 5% or recorded as “trace if < 1% coverage was in the quadrat. I also counted all vascular plant species within the quadrat. Due to time constraints, I only identified vascular plants at quadrats on the 10's of meters, resulting in 15 quadrats at each camera.

I estimated weekly snow depths for each camera location classifying the snow depth in sequential images into one of six categories (No snow/Trace, < 10 cm, 10 - < 20 cm, 20 - < 30 cm, 30 - < 40 cm, ≥ 40 cm). Snow posts with 20-cm sections of contrasting black and white paint were installed in front of four cameras, which aided in training observers at estimating the snow depth at all camera locations.

I estimated landscape scale covariates from remote sensing data (U.S. Geological Survey, National Elevation Dataset [USGS NED]) using ArcGIS and measured camera site elevation (m), mean slope (%), and surface distance of camera site to escape terrain (m). Mean slope was calculated by clipping a slope raster with a 500 m buffer radius around each camera site and averaging slope values for all the cells within that buffer. Distance from escape terrain was the surface distance from the camera site to a contiguous area > 1 ha of barren/rocky slopes greater than 60% grade (Wakelyn 1987, McKinney et al. 2003). Escape terrain distance was determined by overlaying a slope raster on the U.S. Geological Survey National Land Cover Database: Alaska 2011 (U.S. Geological Survey 2015), and creating a raster of the areas that met the escape terrain criteria. I tested for correlation between all covariates and I censored one covariate from any covariate pair with ≥ |0.70| correlation coefficient.

I quantified the viewshed for each camera because topography limited the viewshed differently for each camera and defined viewshed as the land area (ha) a camera was capturing an image of within 500 m of the camera. I determined viewshed by utilizing the ArcGIS Viewshed tool, which creates a rendering of the land area seen from a certain point with the input of a digital elevation model (USGS NED) and the azimuths on either edge of the cameras horizontal field of view and the degrees of vertical field of view.

Data Analysis

I modeled the habitat use of ten different mammal species. The ten species fell into four different guilds, small herbivores: hoary marmot, collared pika, and arctic ground squirrel; large herbivores: moose, Dall sheep, and caribou; mesopredators: wolverine and red fox and apex predators: gray wolf and grizzly bear. Each species is different in resource requirements and dispersal ability; however, members of each guild generally utilized the same spatial scale and depredated upon the same trophic level.

I used Program MARK (White and Burnham 1999) to construct and analyze habitat occupancy models. Given the large-scale movements of mammals throughout a season, the assumption of intra-seasonal closure was violated, thus I interpreted all occupancy estimates as habitat use rather than habitat occupancy (MacKenzie 2006). I treated each season as a separate group in a single season occupancy analysis rather than using a multi-season robust design model due to the low sample size, the increased number of parameters needed for the multi-season model, and difficulty interpreting immigration and emigration parameters in an open system. I constructed encounter occasions by separating the detection-non-detected data into two-week occasions across the 64 weeks (15 months) of continuous sampling. I then defined five biological seasons, with one two-week occasion censored between each season. These seasons constituted four seasons/year: late-summer/fall 2013 and 2014 (August to early-October), early-winter (mid-October to early-January), winter (late-January to mid-April), and spring/early-summer (early-May to early-July). I censored occasions when researchers were camped near cameras during July and early August. I also defined study site (Moly Ridge vs BRTA) as groups resulting in 10 groups (i.e., 5 seasons for each study site).

For each species, I hypothesized individual covariate relationships, temporal structures, and group effects that would best model habitat use (ψ) and detection (p; **Table 2.1**). I calculated the Akaike information criterion for small sample size (AIC_c) cumulative variable weight (w_i) for each variable across all models that contained that variable. I use a two-step modeling approach to reduce the number of unsupported covariates and determine the best model structures that explained ψ and p (Lebreton et al. 1992, Doherty et al. 2012, Bromaghin et al. 2013). First, holding p constant, I constructed a balanced set of all additive habitat use models, all variables with a cumulative w_i greater than 0.50 were retained for a second round of analysis. This procedure was repeated by holding ψ constant and varying p across variables of interest. All variables for ψ and p retained to the second round of analysis were combined into a global model. Final cumulative w_i's were calculated from a balanced model set of all additive combinations of these variables. Following Barbieri and Berger (2004), I defined a predicting model as the model containing all variables with a cumulative w_i greater than 0.50 from this model set. This procedure allowed me to handle a large number of variables efficiently, but also avoided possible spurious results.

Species that were detected two or fewer times at a study site were censored from that study site. If a species was detected less than six times during the study, that species was censored from the total analysis due to the sparsity of data. Finally, hibernating species (arctic ground squirrel, hoary marmot, and grizzly bear) were censored from the two winter seasons given the species unavailability for detection.

Two-Species Occupancy Models

After completion of single-species occupancy models, I conducted conditional two-species occupancy models testing for co-occurrence between apex predators and prey species (Richmond et al. 2010). This model allows for the estimation of one species occupancy (or use) and detection (i.e., species B, typically the subordinate species) conditional on the presence or absence of another species (i.e., species A, typically the dominate species). Estimates from this model include, the probability of occupancy/use given both species are present (ψ_{AB}), the occupancy/use of species B conditional on A being present (ψ_{BA}), or not present (ψ_{Ba}). In addition, detection of species B can be estimated when species A is not present (p_B) or when species A is present and is detected (r_{BA}) or when A is not detected (r_{Ba}). A species interaction factor (SIF) is then derived:

$$\mathrm{SIF} = \frac{\psi_A \psi_{BA}}{\psi_A\left(\psi_A \psi_{BA} + \left(1-\psi_A\right)\psi_{Ba}\right)} \tag{1.1}$$

where:

$$\psi_{AB} = \psi_A \times \psi_{BA} \tag{1.2}$$

SIF values less than one are considered avoidance between the two species, values greater than one are considered co-occurrence, and values at one demonstrate independence between the two species.

I tested four different occupancy interactions: wolf/caribou, wolf/sheep, grizzly bear/arctic ground squirrel, and grizzly bear/caribou. I hypothesized that predator habitat use would exhibit co-occurrence with prey habitat use. I constructed the four different two-species interactions with the predator as species A and herbivore/prey as species B. Due to issues with model convergence with the two-species models, I did not construct a balanced model set to calculate cumulative w_i. Rather, I constructed a set of *a priori* additive models, utilizing only the covariates supported for each species in the results of single-species occupancy models. I ran each model as conditional (i.e., $\psi_{BA} = \psi_{Ba}$) and unconditional (i.e., $\psi_{BA} \neq \psi_{Ba}$) occupancy to test for the support of co-occurrence between the species. I presented model averaged estimates of habitat use, SIF, and detection.

Mesopredators were not included as a dominate species in any of the two-species models. Wolverine data were too sparse to attempt two-species occupancy model. Given the varied diet of red foxes, and that I did not have detection-non-detected data for several of the fox staple food items including voles and other small ground dwelling mammals, I did not consider it appropriate to attempt modeling the relationship between red fox and any of the herbivore species in the study.

Results

Camera Data

During the first year of sampling, the 54 camera traps captured 629,392 photos, over approximately 15,390 camera-trap days. At different points of the first sampling year, 19 of the cameras were either severely altered in their orientation or were destroyed by grizzly bear, caribou, or moose. Additionally, two cameras stopped operating for unknown reasons. In total, this constituted a loss of ~25% more camera-trap days than if the cameras had continued operating. Camera maintenance occurred again in October 2014 to perform any necessary repairs and to exchange SD memory cards. During this three-month period, the cameras captured 196,331 photos over approximately 3,809 camera trap days. Four of the cameras had severe animal damage with one lost SD card, 18 had disabling card read errors at different points during the three-month period, and three cameras were inaccessible due to safety reasons. In total, over 825,000 photos were taken over the 15-month sampling period. These photos captured images of 15 mammal species (**Table 2.2**), ten of which were detected with enough frequency to estimate habitat use.

Small Herbivores

Triggered and time lapse photos of arctic ground squirrel and collared pika were captured on both study sites (**Table 2.2**). Marmot was detected on BRTA by both methods, but only on Moly Ridge via time lapse image. Enough data were available to quantify habitat use for the three species on both study sites.

Model Results: Small Herbivores

My first step of modeling culled several detection and occupancy covariates from the analysis (**Table A4.2, A4.3, & A4.4**). The vast majority of hypothesized detection covariates for the three small herbivore species found little support (**Table 2.3**). Temporal and study site differences in detection were retained for marmot and squirrel, while snow depth and viewshed size were maintained for pika detection (**Table A4.5, A4.6, & A4.7**). I found support for several habitat use variables including vegetation coverages, elevation for marmots and pika, and temporal difference in marmot habitat use (**Table 2.3**). Study site differences were supported for marmot habitat use, but not for pika or squirrel habitat use.

The second round of modeling found support for different variables affecting habitat use and detection (**Table 2.4, A5.1, A5.2, & A5.3**); following Barbieri and Berger (2004), I used a prediction model for each species consisting of variables with > 0.5 AIC_c cumulative weight. Habitat use of marmot varied strongly with elevation ($\hat{\beta}$ = -0.011 SE 0.006; **Table 2.4**), and rock coverage ($\hat{\beta}$ = 0.093 SE 0.064). Difference of marmot habitat use between study sites was well supported (ψ = 0.148 SE 0.107 [Moly]; ψ = 0.874 SE 0.111 [BRTA]; $\hat{\beta}$ = 3.801 SE 1.321, **Figure 2.4**), while temporal differences were slightly below the cumulative weight threshold (**Table 2.4**). Probability of detection was higher during the late spring/early-summer (p = 0.258 SE 0.110) versus late-summer/fall seasons (p = 0.701 SE 0.010; **Figure 2.5**) and negatively correlated with viewshed area ($\hat{\beta}$ = -0.529 SE 0.174; **Table 2.4**).

Habitat use of pika did not vary temporally and was low (ψ = 0.085 SE 0.067), especially when compared to the other small herbivores (**Figure 2.4)**. Pika use was negatively correlated with the landscape covariates elevation ($\hat{\beta}$ = -0.007 SE 0.003) and mean slope percentage ($\hat{\beta}$ = -0.081 SE 0.031), while positively correlated with rock coverage ($\hat{\beta}$ = 0.172 SE 0.048) and dwarf shrub coverage ($\hat{\beta}$ = 0.104 SE 0.039; **Table 2.4**). Pika detection was negatively correlated with snow depth ($\hat{\beta}$ = -0.472 SE 0.269) and marginally correlated with viewshed size ($\hat{\beta}$ = -0.137 SE 0.091; **Table 2.4**). Estimates of pika detection were relatively high (p = 0.577 SE 0.091; **Figure 2.5**).

Forb coverage ($\hat{\beta}$ = 1.265 SE 0.593) was the only covariate or group effect that was retained to the final round of squirrel habitat use modeling (**Table 2.4**). Habitat use did not vary temporally or across study sites (ψ = 0.605 SE 0.115; **Figure 2.4**). Estimates of squirrel detection were higher on BRTA (p = 0.362 SE 0.063) than Moly Ridge (p = 0.245 SE 0.033). In addition, there was some model support for lower detection during the late-summer/fall seasons (**Table A5.3**), however, this temporal effect fell below my variable weight threshold and was not in the final squirrel prediction model (**Table 2.4**).

Large Herbivores

Dall sheep and caribou were the most photographed species (**Table 2.2**). Images of moose, sheep, and caribou were captured on both study sites; however, caribou were only detected two unique times on BRTA. Therefore, only Moly Ridge data were analyzed for the caribou analysis. Images of moose were captured primarily in lowland areas of high shrub cover, but several photos were in high elevation alpine habitat at both Moly Ridge and BRTA.

Model Results: Large Herbivores

The first round of large herbivore habitat use modeling culled habitat use and detection parameters from the three species. Cumulative AIC_c weights of parameters in moose occupancy models found support for detection probability varying by shrub coverage, camera viewshed, and study site, but minimal support for being on a wildlife trail (**Table 2.3**). Moose habitat use was strongly supported by differences in elevation, study site, and winter versus summer seasons. Moose models found minimal support for vegetation coverages, snow depth, or mean slope percentage as important covariates predicting habitat use (**Table A4.8 & A4.9**). Sheep detection varied strongly by being on a wildlife trail and camera viewshed size, while habitat use was strongly correlated to distance from escape terrain and slope percentage. Sheep habitat use also varied between study sites, demographic groups, and by snow depth (**Table 2.3, A4.10, & A4.11**). As with moose, caribou maintained support for higher use during the summer season and no covariates were supported for modeling detection (**Table 2.3, A4.12, & A4.13**).

Prediction models from the second round of large herbivore modeling determined the best supported habitat use and detection probability factors for the three species (**Table A5.4, A5.5, & A5.6**). Habitat use varied temporally by each species and was supported primarily by landscape covariates, with some support for ground coverage covariates (**Table 2.4**). Moose habitat use varied temporally, with higher use estimates during the late-summer/fall season (ψ = 0.590 SE 0.136) rather than the early-winter through early-summer seasons (ψ = 0.140 SE 0.062; **Figure 2.6**) and was negatively correlated with elevation ($\hat{\beta}$ = 0.007 SE 0.002). Habitat use at elevations > 1,700 m was low for both summer (ψ = 0.090 SE 0.022) and winter seasons (ψ = 0.011 SE 0.119). Detection of moose was positively correlated with shrub coverage ($\hat{\beta}$ = 0.398 SE 0.125) and differed between Moly Ridge (*p* = 0.132 SE 0.30) and BRTA (*p* = 0.031 SE 0.022; **Table A5.4**).

Sheep habitat use varied between seasons, study sites, and demographic groups. Moly Ridge habitat use was highest during early-winter 2013 and winter 2014 seasons (ψ = 0.799 SE 0.108) and lowest in the late-summer/fall 2013 (ψ = 0.385 SE 0.111) and 2014 seasons (ψ = 0.123 SE 0.062; **Figure 2.6)**. Estimates of use on BRTA were less precise but showed higher use by sheep during the summer seasons (see chapter 1 for more details). Habitat use of sheep was strongly correlated with slope percentage ($\hat{\beta}$ = 0.135 SE 0.025), snow depth ($\hat{\beta}$ = -0.851 SE 0.277), distance to escape terrain ($\hat{\beta}$ = -0.002 SE 0.0005), and graminoid cover ($\hat{\beta}$ = 0.203 SE 0.064). Demographic differences were supported ($\hat{\beta}$ = 1.075 SE 0.364) indicating higher probability of use by ewe-like individuals. Sheep detection probability was similar in both study sites and varied with the presence of a trail (*p* = 0.437 SE 0.026 [on trail]; *p* = 0.235 SE 0.030 [off trail]; **Table 2.4 & Table A5.5**).

Caribou habitat use varied temporally in a similar fashion as moose with higher use during the late-summer season (ψ = 0.857 SE 0.054) than the winter and early-summer seasons (ψ = 0.478 SE 0.073; **Table 2.4 & Figure 2.6**). In addition, habitat use was negatively correlated with elevation ($\hat{\beta}$ = -0.005 SE 0.002) and slope percentage ($\hat{\beta}$ = -0.093 SE 0.023). Forb ($\hat{\beta}$ = 1.066 SE 0.307) and dwarf shrub coverage ($\hat{\beta}$ = 0.065 SE 0.032) was positively correlated with caribou habitat use while lichen coverage was weakly correlated with habitat use ($\hat{\beta}$ = -0.029 SE 0.025). Caribou detection estimates were temporally constant (*p* = 0.425 SE 0.026; **Table A5.6**).

Mesopredators

Five different mesopredator species were detected on one or both study sites including coyote (*Canis latrans*), wolverine, American marten (*Martes americana*), weasel (*Mustela* spp.), and red fox. Of these five species, only wolverine and red fox were detected with enough frequency to model habitat use.

Model Results: Mesopredators

The first round of wolverine model analysis found support for habitat use differences between the late-summer seasons and the winter through early-summer seasons (**Table A4.14**). Forb coverage, snow depth, and study site difference maintained support through the first phase of analysis. Slope percentage and elevation were not maintained for the second round. Detection estimates were highly dependent on if the camera trap was on wildlife trails and was moderately supported for viewshed area (**Table 2.3 & Table A4.15**). Red fox habitat use maintained support for temporal differences between the two winter seasons versus early-summer and late-summer seasons (**Table A4.16**). Fox habitat use also maintained support for snow depth and study site, but lost support for slope percentage, forb, and dwarf shrub coverage. Detection probability of red fox maintained support for study site, viewshed area, and if the camera was on a trail (**Table 2.3 & A4.17**).

The second round of analysis found that detection probability of wolverines on trails (p = 0.070 SE 0.045; $\hat{\beta}$ = 2.362 SE 0.660) was higher than not on trails (p = 0.007 SE 0.006; **Table 2.4**). Temporal differences found moderate support, but did not reach the cut-off for inclusion in the prediction mode, while snow depth and forb coverage found less support (**Table 2.4 & Table A5.7**). Wolverine habitat use estimates were very imprecise (**Figure 2.7**). Fox habitat use varied by site ($\hat{\beta}$ = -1.352 SE 0.714), temporally between winter and summer seasons ($\hat{\beta}$ = -

1.942 SE 0.937; **Figure 2.7**), and snow depth ($\hat{\beta}$ = 0.696 SE 0.352). Detection probability varied by study site, trail (p = 0.243 SE 0.072 [Moly Ridge, on trail]; p = 0.118 SE 0.034 [Moly Ridge, off trail]; $\hat{\beta}$ = 0.875 SE 0.440) and viewshed area ($\hat{\beta}$ = -0.119 SE 0.070; **Table 2.4 & Table A5.8**).

Apex Predators

Cameras captured images of four apex predator species gray wolf, Canada lynx (*Lynx canadensis*), black bear (*Ursus americanus*), and grizzly bear. Images of Canada lynx were captured twice on Moly Ridge and images of black bear once within BRTA; these species were subsequently censored from the analysis due to sparse data. Grizzly bear images were captured only once within BRTA, therefore I only included Moly Ridge data in the grizzly bear analysis. The majority of grizzly bear detections were of sows with cubs or of a single adult bear. Bear detections occurred throughout the summer months until late-October; the first post-hibernation detections occurred in mid-April. Finally, gray wolf images were captured with enough frequency to include data from both study sites (**Table 2.2**).

The majority of wolf detections were recorded on Moly Ridge and were of a wolf pack of three or more uniquely identifiable wolves or solitary individuals. All wolf detections within BRTA were of solitary adult wolves, presumably different individuals than from Moly Ridge, roaming different portions of the training area during the late-winter/early-spring. Detections of solitary wolves on Moly Ridge were predominately in August and September 2013 and 2014, with a few instances in the winter 2014 season.

Single-Species Model Results: Apex Predators

First round of apex predator modeling culled the majority of the hypothesized habitat use and detection covariates from wolf and grizzly bear. Wolf habitat use maintained support for shrub coverage and temporal differences (**Table A4.18**); detection only maintained support for trail (**Table 2.3 & Table A4.19**). Grizzly bear models maintained support for slope and forb coverage as important habitat use covariates (**Table A4.20**). Trail presence in relation to detection probability was retained to the second round of modeling (**Table 2.3 & A4.21**).

In the final round of analysis, wolf habitat use varied temporally between the two winter seasons (ψ = 0.576 SE 0.231) and the early and late-summer seasons (ψ = 0.165 SE 0.092) and shrub coverage ($\hat{\beta}$ = 0.780 SE 0.417; **Table 2.4; Figure 2.7**). Detection of wolves was best modeled by the presence of a wildlife trail (p = 0.142 SE 0.057 [on trail]; p = 0.049 SE 0.024 [off trail]; $\hat{\beta}$ = 1.172 SE 0.509; **Figure 2.5**). Grizzly bear habitat use was constant (ψ = 0.774 SE 0.198) temporally, negatively correlated with slope percentage ($\hat{\beta}$ = -0.121 SE 0.064), and moderately correlated with forb coverage ($\hat{\beta}$ = 1.498 SE 1.008; **Table 2.4**). Grizzly bear detection probability was best modeled by the camera being on a wildlife trail (p = 0.168 SE 0.065 [on trail]; p = 0.062 SE 0.020 [off trail]; $\hat{\beta}$ = 1.116 SE 0.567; **Figure 2.5**).

Two-Species Occupancy Model Results: Apex Predators

I built four sets of models comparing habitat use of apex predators as they relate to prey species. Only simple models, with minimal covariates or temporal structures, would converge for any of the species interactions. Models that held caribou occupancy conditional on wolf occupancy found more support compared to unconditional models (**Table A6.1).** Species interaction factors (SIF) indicated some evidence of co-occurrence between wolf and caribou

(**Figure 2.8).** Estimates for conditional occupancy given that wolves were present (ψ_{BA}= 0.917 SE 0.113) and that wolves were not present (ψ_{Ba} = 0.748 SE 0.195) lacked precision and overlapped substantially making any inference difficult.

Wolf and sheep habitat use did not appear correlated. The two top models carried the majority of the AIC$_c$ weight (w_i = 0.727) and held sheep use as unconditional on wolf presence (**Table A6.2**). Interaction between the species appeared independent (SIF = 1.001 SE 0.191). Model averaged estimates of sheep habitat use given wolf presence (ψ_{BA}= 0.327 SE 0.136 [late-summer/fall]; ψ_{BA}= 0.317 SE 0.093 [winter]) versus absence (ψ_{Ba}= 0.363 SE 0.127 [late-summer/fall]; ψ_{Ba}= 0.319 SE 0.101 [winter]) varied slightly and confidence intervals overlapped. Detection of sheep was lower in areas where wolves were absent (p_B = 0.419 SE 0.073) compared to locations where wolves were present and detected (r_{BA}= 0.670 SE 0.054) or present and not detected (r_{Ba}= 0.740 SE 0.061).

Hibernation of bears reduced the available data to three seasons for both grizzly bear two-species occupancy model sets. Grizzly bear-squirrel top models did not find evidence for habitat use of squirrels conditional on the presence of grizzly bears (**Table A6.3**). The SIF between grizzly and squirrel was centered on one (SIF = 1.023 SE 0.158), indicating independence between the two species (**Figure 2.8**). Model averaged estimates of conditional habitat use given that a bear is present (ψ_{BA}= 0.571 SE 0.307) and not present (ψ_{Ba} = 0.537 SE 0.281) were both very imprecise and substantially overlapped.

Habitat use of grizzly bears and caribou showed evidence of co-occurrence (SIF = 1.265 SE 0.194; **Figure 2.8**), but precision was low and the confidence interval crossed one. Model averaged estimates of caribou habitat use conditional on bear presence (ψ_{BA} = 0.927 SE 0.114) was estimated higher than models where caribou habitat use was not conditional on bear habitat use (ψ_{Ba} = 0.435 SE 0.229). Detection of caribou and grizzlies did not appear to be affected by the presence of the other species because the top models all held the conditional detection parameters constant (**Table A6.4**).

Discussion

Guild and Habitat Use

This is the first study to use camera trap data to model the habitat use of an Alaskan alpine mammal community. The habitat use of all of the species within this study has been observed, to varying degrees, by other projects (e.g., Stelmock and Dean 1986, Krebs et al. 2007, Barrio and Hik 2013). However, to my knowledge no other study has been able to investigate the sympatric habitat use of multiple guilds of Alaskan mammals continuously across multiple seasons. Application of the guild concept to this diverse set of mammals elucidated patterns of habitat use within guild and potential overlap in resource use and interactions across guilds.

Smaller home range size and dispersal distances of small herbivores correlated with the support of fine scale coverage variables. The importance of rock cover for hoary marmot and collared pika, mainly in the form of talus slopes/boulder fields, is well documented in previous literature. Marmots and pika use rock cover as shelter and maintain close proximity when grazing (Barash 1973). Surprisingly, graminoid cover, which is a well-established component of pika natural history (Barash 1973, Ballová and Šibík 2015), was not supported for pika habitat use, while dwarf shrub coverage was supported. Morrison et al. (2004) found that collared pika concentrated foraging/home ranges within patches of *Cassiope tetragona*, a prevalent dwarf shrub on both of my study sites, even though pika heavily favored graminoids and other dwarf shrubs when foraging. Collared pika survival increased in areas dominated by *C. tetragona*, possibly, because hoary marmots and arctic ground squirrels also found the dwarf shrub species unpalatable, and thus pika were competitively excluded from better foraging locations (Franken 2002). Barrio and Hik (2013) also found that collared pika use is restricted to much smaller habitat components than either arctic ground squirrel or hoary marmot. Pika habitat use estimates were low (**Figure 2.4**), especially compared to the estimates of the other two small herbivore species, also providing support for competitive exclusion. Two-species occupancy models between marmot and pika could further elucidate the relationship between the two species; however, data in this current study was too sparse for meaningful results.

Contrary to my predictions, elevation was negatively correlated to marmot and pika use and slope was negatively correlated with pika use. I predicted that the higher elevations of the study site would contain the best rock and alpine habitat; however, the higher elevations typically retained the deepest snow cover and therefore may have had less available resources for these species. Vegetation microhabitats in mountainous terrain can be highly variable as a result of elevation, slope, and aspect; this affects differential timing of snowmelt, available burrowing substrate and ultimately the availability of vegetation resources (Korner 2003). Therefore, there is collinearity between the macro-geologic structure, underlying substrate, and the ultimate ground cover with which wildlife species utilize. These correlations are present in most ecological studies (Dormann et al. 2013), however, they are especially pronounced in studies of highly heterogeneous landscapes. My results point to the importance of incorporating fine-scale ground coverage and coarser landscape covariates to predict the habitat use of small mammals, while also remaining cognizant of the potential correlations between predicting variables.

Similar to the small herbivore guild, habitat use by the large herbivore guild was correlated to ground coverages and abiotic landscape covariates. Moose and caribou habitat use is generally defined by vegetation cover (Gasaway et al. 1992, Molvar and Bowyer 1994, Poley et al. 2014), compared to Dall sheep which are generally characterized by geologic or abiotic features (Nichols and Bunnell 1999). However, abiotic covariates and ground coverages were important for all three of the large herbivores. Moose and caribou appeared to have lower habitat use of higher elevations (i.e., >1,700 m) and caribou had decreased habitat use of steeper slopes, especially in the winter. Boertje et al. (1996) noted that moose and caribou rarely ventured above 2,000 m in the foothills of the Alaska Range, and caribou of Denali National Park used mid-elevation areas between 760 – 1,220 m (Boertje 1984). Parturient caribou and individuals escaping from insects during warmer seasons have been found to select for steeper slopes (Boertje 1984, Pinard et al. 2012). In addition, Barten et al. (2001) concluded that preparturient caribou selected for lower sloped areas more than parturient females. My results appear to show a similar pattern of highest use of steeper slopes during the summer seasons.

Vegetation ground coverages were important for the habitat use of Dall sheep and caribou and detection of moose (**Table 2.4**). Dall sheep heavily rely upon sedges and grasses during the winter (Rachlow and Bowyer 1998, Walker et al. 2007). Forbs and dwarf shrubs are also important components of the Dall sheep diet (Murie 1944, Hoefs 1976), however, I did not find support for these coverages. I found a weak negative correlation between caribou habitat use and lichen coverage, even though it is a staple of caribou winter diet (Russell et al. 1993, Joly et al. 2007*b*). My sampling design did not distinguish between different orders of lichen including lichen directly on rocks; therefore, this binning of lichen classifications may have led to this negative result.

Unlike the small herbivores, there was strong support for temporal differences in habitat use between the three large herbivores. Caribou and moose appeared to decrease use of Moly Ridge during the winter coinciding with the influx of sheep and higher snow depths (**Figure 2.6**).

Limited accounts of caribou and sheep interactions in the Alaska Range describe an oddly aggressive instance of behavior by rams towards caribou (Henshaw 1970). While it is likely that the decreased use of Moly Ridge by caribou and moose is due to increased snow cover and less available vegetation, further investigation of species interactions could determine if avoidance of sheep by caribou is a factor.

Mesopredator data were relatively sparse which likely contributed to the high model uncertainty and the low number of covariates finding support (**Table 2.4**). Wolverine densities are low, therefore, I anticipated that detections would be minimal and basic habitat use models would have difficulty converging. My results indicate the importance of camera placement along trails if wolverines are the focal species of study. These may be the first estimates of habitat use by wolverines via non-baited camera trap sites; however, it should be cautioned that little inference is possible from the wolverine estimates due to the extremely low precision of the habitat use estimates.

Mesopredators appeared to have higher use of the study sites during the spring and summer seasons (**Table 2.4**; **Figure 2.7**). Radio-collared wolverines in central Norway utilized alpine areas with higher frequency in the summer, and concentrated winter use in the lower elevation woodlands (Landa et al. 1998). Wolverine use of alpine areas of British Columbia, Canada was highest in the summer, presumably correlated with marmot activity (Krebs et al. 2007). Previous research of red fox habitat use showed a similar relationship of summer and higher red fox habitat selection of alpine areas (Jones and Theberge 1982).

Red fox individuals preferred sampling sites with higher average snow depths, counter to my hypothesized relationship and the findings of previous studies (Halpin and Bissonette 1988). Fox have more difficulty hunting for prey items in deeper snow therefore this finding was especially unexpected (Halpin and Bissonette 1988, Jedrzejewski and Jedrzejewska 1992). A possible explanation is that fox individuals transitioned through ridgeline sample sites, areas which were prone to collect deeper snow, but which foxes were not actively hunting.

Contrary to my predictions, I did not find specific habitat covariates correlated between mesopredator and herbivore species habitat use (**Table 2.4**). Wolverine and red fox are broad and opportunistic (e.g., carrion) in diet (Lofroth et al. 2007), therefore, deciphering habitat covariate correlations could be difficult, especially given limited detection data. However, given the temporal pattern of habitat use, there is some evidence that these mesopredators, in particular red fox, were selecting for habitat areas when potential prey species were active in the same habitat.

Apex predators showed some evidence of spatiotemporal overlap with prey species. Wolf habitat use of Moly Ridge and BRTA was higher during the early-winter and winter seasons and much lower during the spring to late-summer seasons (**Figure 2.7**). This corresponded with the highest sheep use of Moly Ridge. Shrub coverage was the only habitat covariate supported for wolf habitat use, which correlates with higher detection probabilities of moose, an important wolf prey species. However, further analysis of wolf and moose co-occurrence using two-species occupancy models was not possible due to sparse moose and wolf data. Two-species models of wolf/caribou did exhibit some evidence of co-occurrence between the species (**Figure 2.8**), further indicating that wolf habitat use may be affected by the presence of these prey resources in alpine habitats.

Grizzly bear detections were almost entirely on Moly Ridge, but were more frequent than wolf detections (**Table 2.2**). Grizzly bears appeared to avoid steeper slopes and concentrated use in areas of increased forb cover, a highly supported covariate correlated with ground squirrel habitat use. Stelmock and Dean (1986) observed a similar relationship that grizzly bear use of herbaceous areas during the fall corresponded to the hunting of ground squirrels. However, further examination of grizzly/squirrel two-species occupancy found no evidence of co-occurrence and possible avoidance (**Figure 2.8**). Correlation between higher forb cover and grizzly use could also correspond to bears concentrating on vegetative food sources. Munro et al. (2006) found that alpine and subalpine grizzlies relied largely upon consuming forbs and roots, and that prey consumption was greatly reduced compared to bears in wooded areas. Thus, it is ambiguous if the correlation between forb coverage and bear habitat use is a due to the presence of squirrels, the availability of plant matter, or a combination these and other factors.

Two-species occupancy models showed co-occurrence of grizzly and caribou throughout the spring and summer seasons; therefore, grizzlies appeared to use areas dependent, in part, on the use of caribou. Predation on caribou by grizzlies is well documented in habitats adjacent to my study sites (Murie 1944, Stelmock and Dean 1986, Boertje et al. 1988), therefore my conclusions only add some evidence to the direct observations of grizzly bear depredation of caribou. However, my findings indicate that bears likely use areas high in resources and with the need for reduced energy expenditure.

Detection of the Guilds

I found differences in the factors that affected the detection probabilities of different guilds. Mesopredator and apex predator detection was highly correlated with the presence of a wildlife trail (**Table 2.4**). Most camera trap studies, especially studies focused on carnivores, concentrate cameras along trails to maximize detections (e.g., Crooks et al. 2008, Massara et al. 2015). My results show that placing cameras along trails or corridors of wildlife movement improve detections, especially for low density predators.

Dall sheep detection was also correlated with trail presence, which is likely associated with the natural history of the species. Mountain sheep species follow ridgelines adjacent to escape terrain and webs of historical wildlife trails are visible leading from mineral licks and other alpine areas heavily used by sheep (Geist 1971, Nichols and Bunnell 1999). Unlike sheep, shrub coverage, not wildlife trails, was positively correlated with the probability of moose detection. Moose predominately browse on woody vegetation (Pastor et al. 1993), therefore, I anticipated that habitat use would be positively correlated with the cover of shrubs. Rather, increased shrub cover increased the probability of detecting moose, which may be caused by moose browsing preference for large shrubs for multiple hours singularly or in small groups (Molvar and Bowyer 1994). The increased detections due to moose browsing behavior appeared to contribute the most to increasing time lapse detections and ultimately increasing the probability of detection.

Small herbivore detection appeared more affected by temporal differences in behavior than other guilds. Hoary marmot detection was lower during the late-summer/fall 2013 and 2014 seasons and arctic ground squirrel showed some evidence of following the same pattern (**Table 2.4**). This corresponded to decreased activity by these species prior to the onset of hibernation (Taulman 1990). Hoary marmot daily foraging time in Mount Rainer National Park, Washington, USA, gradually decreased from the beginning of August to immediately prior to hibernation in late-October (Barash 1976). Reduced foraging pre-hibernation could reduce the opportunities for detection, and the onset of hibernation in some individuals could have decreased the probability of availability to be detected.

Time Lapse Images and Sampling Application

Developing a study design that incorporates sampling across multiple taxa and trophic levels is typically only possible through the integration of multiple sampling methodologies. Through the incorporation of time lapse with triggered images, I was able to sample a large portion of the interior Alaskan mammalian community, while relying upon one remote sampling platform. However, time lapse imagery did not substantially increase detections of meso- or apex predators compared to triggered only detections (**Table 2.2**). Prey species such as squirrels or caribou occur at higher densities than predators such as red fox or wolf (Jones and Theberge 1982, Adams et al. 2008, Donker and Krebs 2011, Parrott et al. 2012), which should inherently increase the opportunities for detection. Sheep and caribou, especially, were often detected in clusters of six or more individuals, which increased photo observer's ability to record a species in an image. Because of behavioral differences, such as grazing and browsing, herbivores likely spent longer durations within the viewshed of a camera increasing opportunities to be detected via time lapse imagery. Of the predator species, grizzly bear was detected the most via time lapse photos; ten of the twelve images were due to the bear individuals either grazing on fruit or digging for ground squirrels. Though an anecdotal insight, it is potentially because of these omnivorous behaviors that they were detected more frequently than other predators. Therefore, there appears to be a correlation between a species' behavior, density, and the probability that time lapse images will assist in increasing detections.

Time lapse photos and the spacing of camera traps away from trail networks decreased biases from human habitat selection and created a record of climatic and environmental conditions. As I demonstrated with my snow depth covariate, this record can prove to be an important factor to predict wildlife habitat use. However, reliance on time lapse photos has caveats and limitations. The feature was maximized because my study occurred in an alpine tundra environment, which allowed for the sampling of large viewshed areas. Future utilization of this technique will be feasible in areas of low tree and brush density; it will assist less in dense forests where the camera's viewshed is highly obstructed. In addition, my camera traps captured over half-a-million time lapse images that did not contain wildlife detections. This large number of photos increased processing time, a factor that must be considered when calculating the costs and benefits of employing both detection techniques. Ultimately, the decision to add time lapse photos to studies sampling wildlife populations is dependent on habitat and study goals.

Conservation Implications and Conclusions

This study provided a rare opportunity to capture a continuous sample of the habitat use of an alpine mammal community. By coupling detection-non-detection data of multiple species across several guilds, I was able to compare how different species interact with the same environment and to a lesser extent interspecifically. Provided with an extensive time-series of data, I modeled temporal differences and utilized repeated images to quantify an important climatic variable.

Differential temporal use by caribou and moose versus Dall sheep showed some spatial and temporal overlap in habitat use between the three species. Moose, sheep, and caribou may interact, for short periods, at ecotone boundaries between higher mountains and lower drainages. Therefore, it is important when making habitat management decisions to incorporate the full suite of possible affected species. In addition, the importance of graminoid, dwarf shrub, and forb for different species of both herbivore guilds exemplifies why shrub encroachment into Alaskan alpine areas is a concern for mammal conservation (Hughes 2003). Alpine areas may increasingly be transformed as warmer weather persists into the future (Sturm et al. 2005, Post and Pedersen 2008).

Direct measurement of species interactions through two-species occupancy models could be important for future assessments of predator harvest limits, across different ecosystems. These methods could also address basic biological questions about interspecific competition or exploitation. The correlation between habitat use of both apex predators and caribou show the importance of a robust ungulate population for the sake of the predator and entire mammal community.

With the advent of new technologies, wildlife researchers can repeat and improve upon my procedures to investigate the habitat use and species interactions in a wide swath of environments. Having the ability to ask questions about entire wildlife communities from one platform, rather than piecing together different single-species studies could be a more efficient tool for assessing anthropogenic impacts on a community, asking basic ecological questions, or simultaneous monitoring of a diverse set of species.

Table 2.1. Hypothesized temporal, study site, group, and covariate effects on the habitat use (ψ) and detection probability (p) of each mammal species for the Molybdenum Ridge (Moly) and Black Rapids Training Area (BRTA) study sites of interior Alaska, USA.

		Small Herbivores			Large Herbivores			Mesopredators		Apex Predators	
Parameter	Variables	Hoary marmot*	Collared pika	Arctic ground squirrel*	Moose	Sheep	Caribou	Wolverine	Red fox	Gray wolf	Grizzly bear*
Habitat Use (ψ)	Season	S1[a]	S12[b]	S1	S234[c]	S1,S23,S4[d]	S234	S234	S23	S23	S1
	Site	BRTA[e]	BRTA	BRTA	Moly[f]	BRTA	N/A	BRTA	BRTA	Moly	N/A
	Season*Site					Variable					
	Sex					Ewe-like[g]					
	Elevation (m)	+	+	+	−	+	−	+	−	−	−
	Slope (%)		+	+	−	+	−	−	−		−
	Plant Species Richness	+	+	+	+	+	+				
	Rock (%)	+	+								
	Lichen (%)						+				
	Graminoid (%)	+	+	+		+				+	
	Forb (%)	+		+		+	+	+	+		+
	Dwarf Shrub (%)	+	+	+	+		+		+	+	+
	Shrub (%)				+		+		+	+	
	Distance to Escape Terrain (m)					+					
	Snow (cm)	−	−	−	−	−	−	−	−	−	−
Detection (p)	Season	S1&S5[h]	S23	S1&S5							
	Site	BRTA	BRTA	BRTA	Moly						
	Viewshed (m^2)	+	+	+	+	+	+	+	+	+	+
	Trail	+		+	+	+	+	+	+	+	+
	Snow (cm)		−								
	Shrub				+						

[a] ‘S1’ denotes different habitat use in the late-summer/fall 2013 season.

[b] ‘S12’ denotes the different habitat use in 2013 seasons versus the 2014 seasons.

[c] ‘S234’ denotes habitat use is the same from the early-winter 2013 through spring/early-summer 2014 seasons.

[d] ‘S1, S23, S4’ denotes habitat use between the five seasons except the early-winter 2013 and winter 2014 seasons (S23).

[e] ‘BRTA’ Black Rapids Training Area will have a higher value.

[f] ‘Moly’ Molybdenum Ridge will have a higher value.

[g] ‘Ewe-like’ Ewe-like sheep individuals will have higher habitat use than ram individuals.

[h] ‘S1&S5’ different probability of detection in the late-summer/fall seasons.

* Hibernating species, data was censored during the early-winter 2013 (S2) and winter 2014 (S3) seasons.

Table 2.2. All mammal species detected and the total number of images captured of each species on Molybdenum Ridge and Black Rapids Training Area, Fort Wainwright, Alaska, USA. Species are presented in order of most to least number of photos captured. Photos are separated by study site and detection type.

	Molybdenum Ridge		Black Rapids Training Area	
Species	Triggered photos	Timelapse photos	Triggered photos	Timelapse photos
Dall sheep	2876	879	4079	302
Caribou	6404	388	45	1
Arctic ground squirrel	773	81	578	77
Moose	1055	36	17	0
Grizzly bear	608	12	3	0
Hoary marmot	0	10	295	19
Red fox	183	6	12	0
Collared pika	7	36	121	10
Gray wolf	141	3	8	0
Wolverine	39	1	28	0
Coyote*	32	0	0	0
Mustela spp.*	2	3	6	1
Canada lynx*	6	0	0	0
Black bear*	0	0	5	0
American marten*	3	0	0	0

* Species not included in habitat use analysis

Table 2.3. AIC_c cumulative variable weights from the first round of p constant and ψ constant occupancy model sets for all mammal species. Bolded weights indicate variables that were retained to the second round of modeling.

		Small Herbivores			Large Herbivores			Mesopredators		Apex Predators	
Parameter	Variables	Hoary marmot	Collared pika	Arctic ground squirrel	Moose	Sheep	Caribou	Wolverine	Red fox	Gray wolf	Grizzly bear
Habitat Use (ψ)	Season	0.269	0.279	0.266	**0.993**	**0.968**	**0.972**	**0.786**	**0.649**	**0.650**	0.310
	Site	**0.882**	0.270	0.448	**0.770**	**1.000**		**0.551**	**0.522**	0.268	
	Season*Site					**0.936**					
	Sex					**0.970**					
	Elevation (m)	**0.911**	**0.908**	0.306	**0.999**	0.374	**0.909**	0.329	0.281	0.330	0.444
	Slope (%)	0.094	**0.767**	0.265	0.389	**1.000**	**1.000**	0.471	0.394		**0.729**
	Plant Species Richness	0.258	0.194	0.267	0.293	0.408	0.453				
	Rock (%)	**0.891**	**1.000**								
	Lichen (%)						**0.553**				
	Graminoid (%)	0.317	0.267	0.328		**0.950**	0.264			0.344	
	Forb (%)	0.266		**0.983**		0.303	**0.996**	**0.592**	0.433		**0.665**
	Dwarf Shrub (%)	**0.701**	**0.902**	0.285	0.313		**0.674**		0.366	0.319	0.314
	Shrub (%)				0.302		0.391		0.271	**0.711**	
	Distance to Escape Terrain (m)					**0.955**					
	Snow (cm)	**0.807**	0.215	0.259	0.451	**0.934**	0.449	**0.603**	**0.635**	0.429	0.264
Detection probability (p)	Season	**0.999**	0.350	**0.934**							
	Site	**1.000**	0.281	**0.934**	**0.572**	**0.597**		0.295	**0.974**	0.415	
	Viewshed (m^2)	**0.948**	0.435	**0.553**	**0.746**	**0.985**	0.265	**0.523**	**0.639**	0.480	0.314
	Trail	0.336		0.318	0.271	**1.000**	0.359	**0.996**	**0.855**	**0.748**	**0.737**
	Snow (cm)		**0.874**								
	Shrub				**1.000**						

Table 2.4. AIC$_c$ cumulative variable weights from the final round of model results for all species. Bolded weights indicate variables that were maintained into the final prediction model, dashed lines indicate variables that were dropped in the first round of analysis.

		Small Herbivores			Large Herbivores			Mesopredators		Apex Predators	
Parameter	Variables	Hoary marmot	Collared pika	Arctic ground squirrel	Moose	Sheep	Caribou	Wolverine	Red fox	Gray wolf	Grizzly bear
Habitat Use (ψ)	Season	- -	- -	- -	**0.993**	**0.974**	**0.999**	0.447	**0.678**	**0.886**	- -
	Site	**0.596**	- -	- -	0.456	**1.000**		0146	0.251	- -	
	Season*Site					**0.911**					
	Sex					**0.970**					
	Elevation (m)	**0.810**	**0.938**	- -	**0.996**	- -	**0.874**	- -	- -	- -	- -
	Slope (%)		**0.905**	- -	- -	**1.000**	**1.000**	- -	- -		**0.907**
	Plant Species Richness	- -	- -	- -	- -	- -	- -				
	Rock (%)	**0.755**	**1.000**								
	Lichen (%)						**0.518**				
	Graminoid (%)	- -	- -	- -		**0.982**	- -			- -	
	Forb (%)	- -		**0.999**		- -	**0.994**	0.346	- -		**0.631**
	Dwarf Shrub (%)	0.400	**0.959**	- -	- -		**0.811**		- -	- -	- -
	Shrub (%)				- -		- -		- -	**0.798**	
	Distance to Escape Terrain (m)					**1.000**					
	Snow (cm)	**0.573**	- -	- -	- -	**0.969**	- -	0.357	**0.642**	- -	- -
Detection (p)	Season	**0.987**	- -	0.419			- -				
	Site	**0.630**	- -	**0.764**	**0.610**	0.269		- -	**0.805**	- -	
	Viewshed (m^2)	**0.941**	- -	**0.701**	0.472	0.288	- -	0.314	**0.639**	0.480	- -
	Trail	- -		- -	- -	**1.000**	- -	**0.981**	**0.855**	**0.748**	**0.799**
	Snow (cm)		**0.641**								
	Shrub				**0.981**						

Table 2.5. Definitions of parameters in conditional two-species occupancy models.

Parameter	Definition
ψ_A	Probability of occupancy for species A regardless of species B
ψ_{BA}	Probability of occupancy for species B, given species A is present
ψ_{Ba}	Probability of occupancy for species B, given species A is absent
p_A	Probability of detection for species A, given species B is absent
p_B	Probability of detection for species B, given species A is absent
r_A	Probability of detection for species A, given both species are present
r_{BA}	Probability of detection for species B, given both species are present and species A is detected
r_{Ba}	Probability of detection for species B, given both species are present and species A is not detected

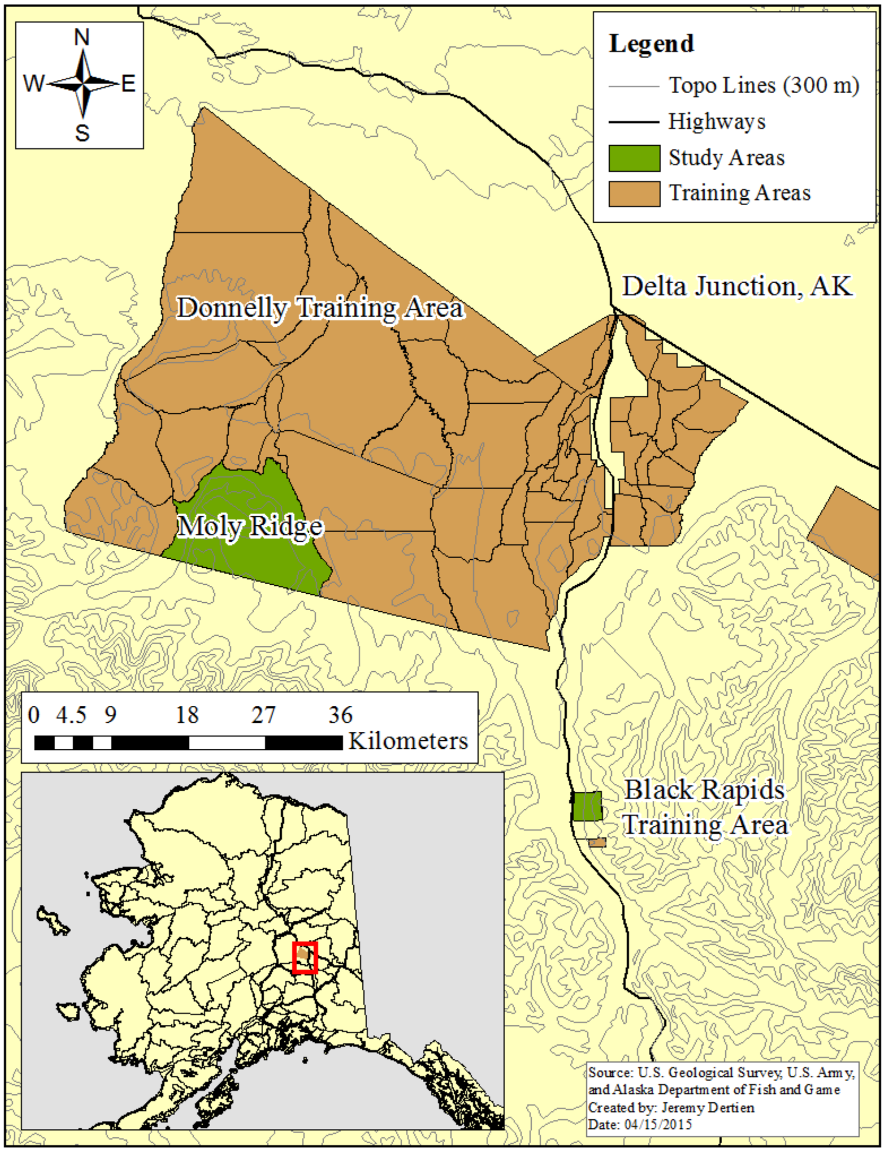

Figure 2.1. Location of the Molybdenum (Moly) Ridge and Black Rapids Training Area Dall sheep study sites in interior Alaska. Molybdenum Ridge is within the larger Donnelly Training Area. Note that Black Rapids Training Area is within a contiguous portion of the Alaska Range while Molybdenum Ridge is located on the northern periphery of the range.

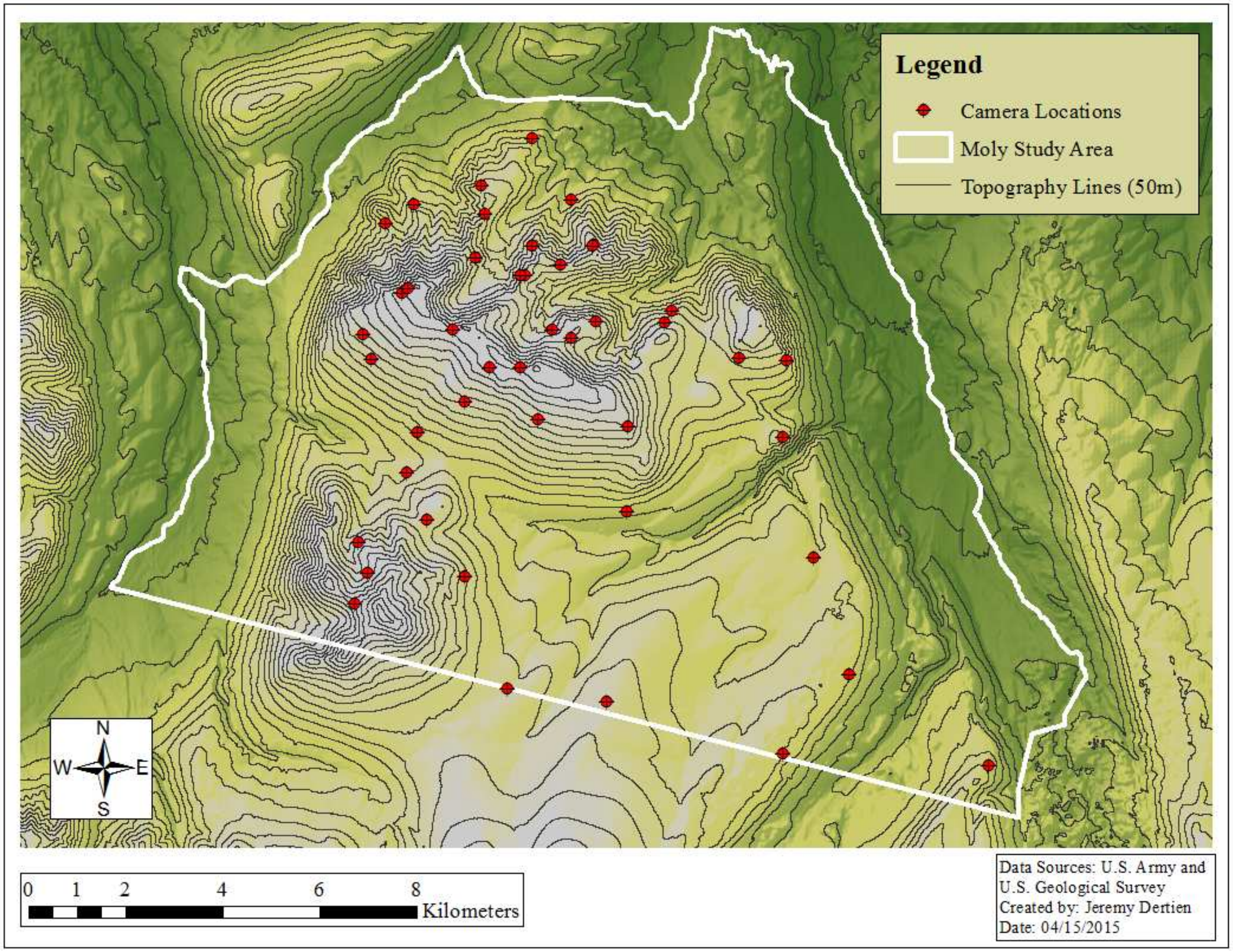

Figure 2.2. Camera trap sites on Molybdenum Ridge (Moly) within Donnelly Training Area of Fort Wainwright, Alaska. Cameras were positioned using a spatially balanced design with increased inclusion probabilities on steeper slopes**.**

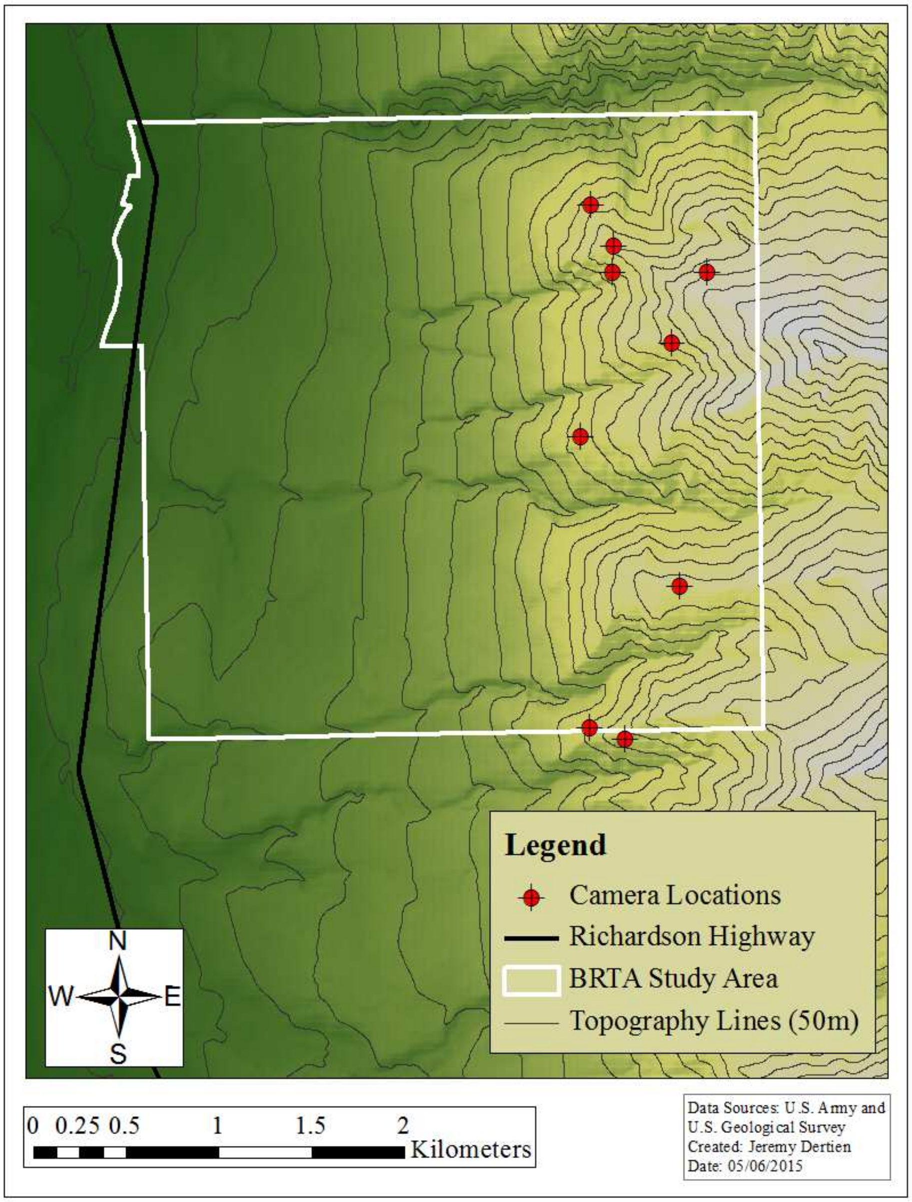

Figure 2.3. Camera trap placement in Black Rapids Training Area (BRTA). Cameras sites were determined by a spatially balance design with increased inclusion probabilities for steeper slopes.

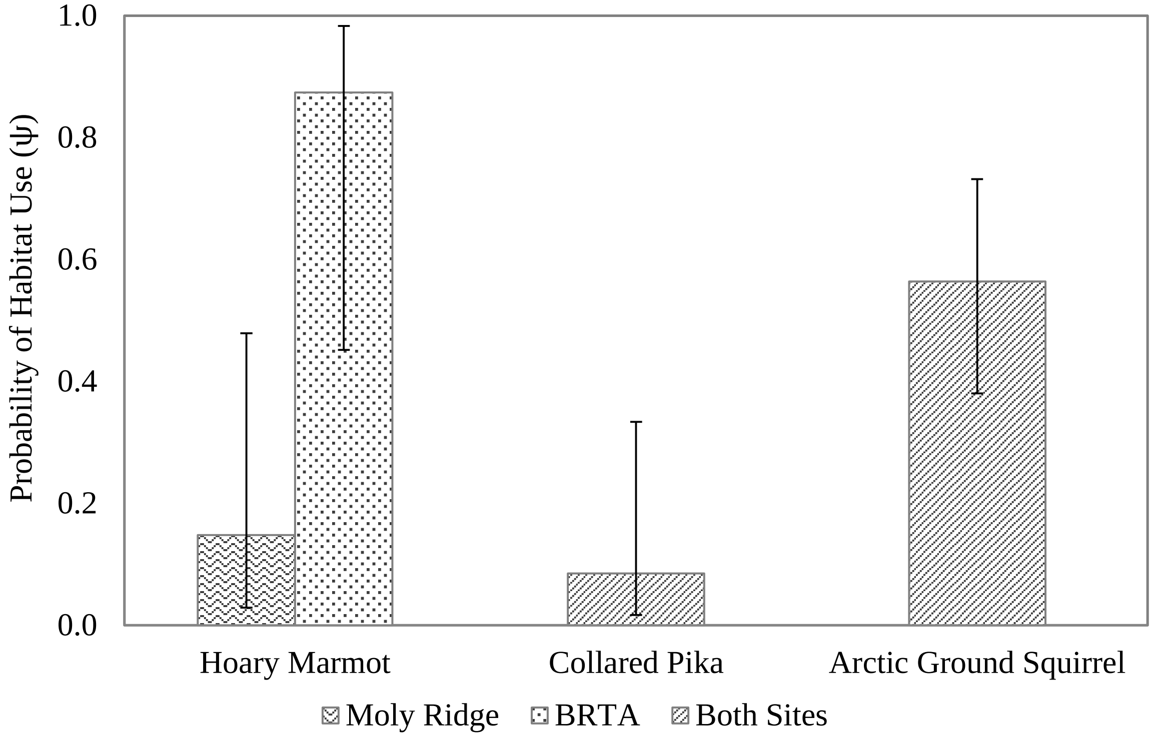

Figure 2.4. Habitat use estimates for small herbivores hoary marmot, collared pika, and arctic ground squirrel. Hoary marmot habitat use was lower on Molybdenum Ridge (Moly Ridge) compared to Black Rapids Training Area (BRTA). Collared pika and arctic ground squirrel habitat use was constant across sites. Presented with 95% confidence intervals.

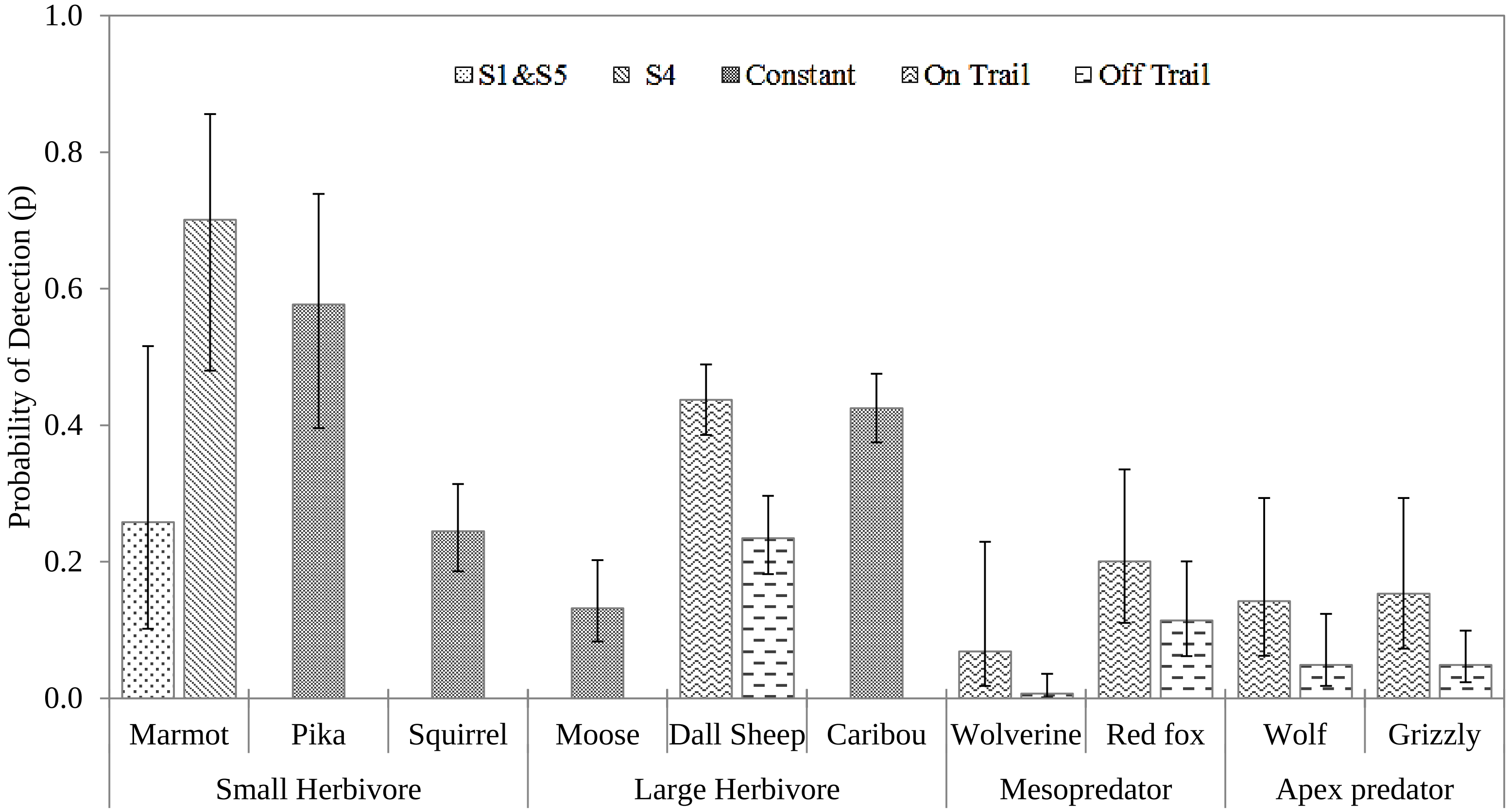

Figure 2.5. Detection probabilities of all ten mammal species for Molybdenum Ridge only. Small and large herbivore guilds had the highest detections while mesopredators and apex predators had lower detection probabilities. Hoary marmot varied temporally between the late-summer/fall seasons (S1&S5) and the spring/early-summer season (S4). Detection of Dall sheep and both predator guilds improved if a camera was placed on a trail. Presented with 95% confidence intervals.

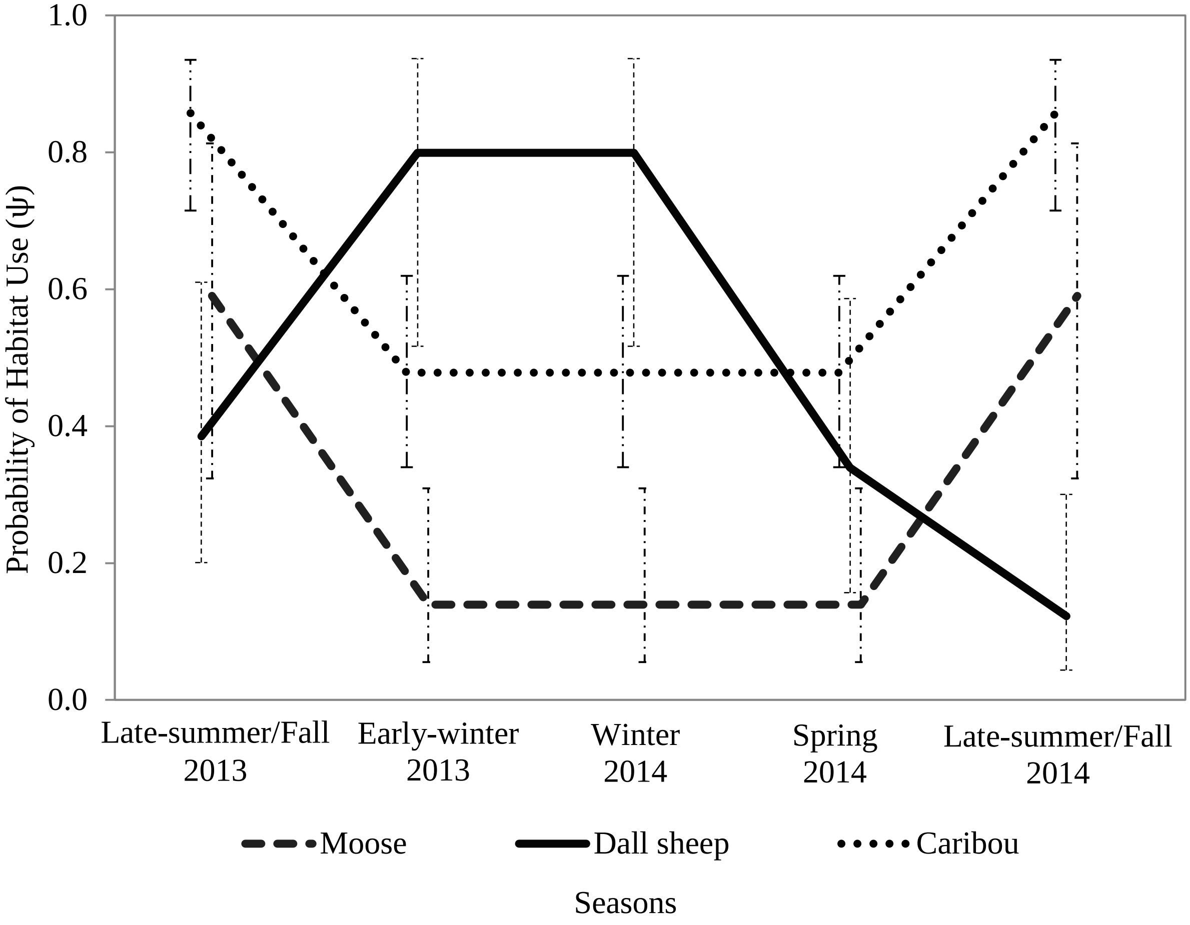

Figure 2.6. Habitat use (ψ) estimates of the large herbivore guild on the Molybdenum Ridge study site. Dall sheep habitat use was highest during the winter seasons, while caribou and moose habitat use was highest during the late-summer/fall seasons. Presented with 95% confidence intervals.

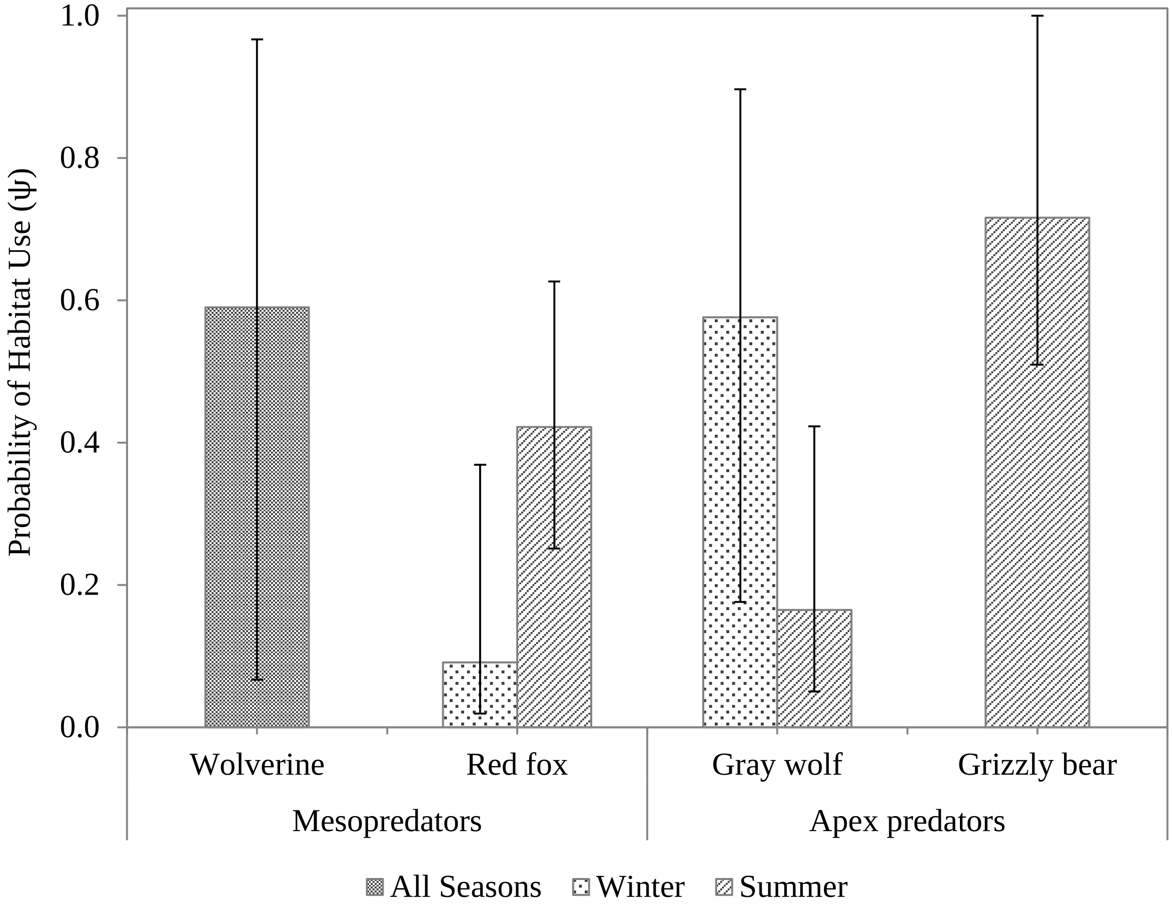

Figure 2.7. Habitat use (ψ) estimates for mesopredators and apex predators. Study site differences were not supported for wolverine, red fox, or gray wolf. Grizzly bear habitat use was only estimated for the Molybdenum Ridge study site due to insufficient data from the Black Rapids Training Area study site. Presented with 95% confidence intervals.

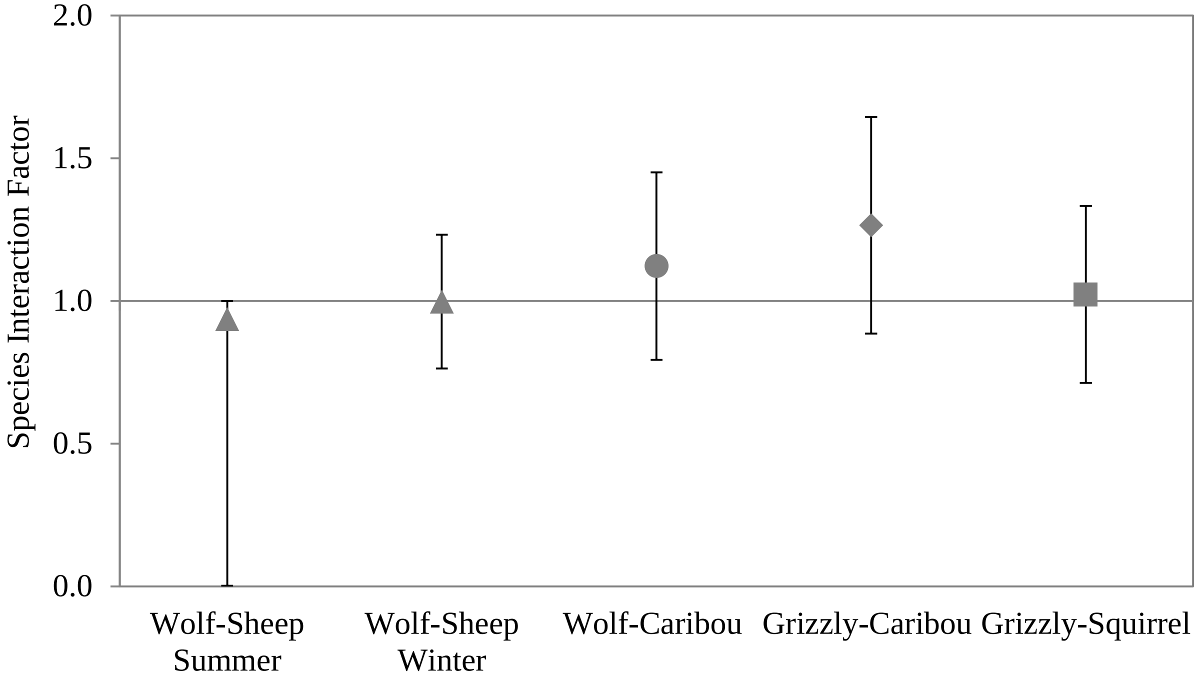

Figure 2.8. Species Interaction Factors for wolf interactions with sheep and caribou and grizzly bear interactions with caribou and squirrel on Molybdenum Ridge. There were no temporal differences found between interactions in bears and prey species, in part due to bear hibernation reducing available data. Grizzly-caribou found some support for co-occurrence of the species. Presented with 95% confidence intervals.

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APPENDIX I

VEGETATION PLOT SAMPLING DESIGN AT CAMERA LOCATIONS

Summary

One vegetation sampling transect was established at each camera location within the camera's 40 degree field of view. At every 5 m along a transect, quadrats of 0.25 m^2 were placed directly on the transect line with two other quads placed at varying distances perpendicular from the transect line. Coverage classes were measured within each quad; species composition was only measured at quads every 10 m on a transect.

Protocol

At each camera location, one researcher took an azimuth of the direction that the camera was facing, taking care so that the metal from the camera mount did not alter the compass reading. The researcher with the compass then directed another researcher with a measuring tape to establish the transect line by closely following that azimuth out 50 m. The first coverage quadrat was then established on the left-hand side of the transect (facing away from the camera), 2 paces (or about 2 m) perpendicular from the main measuring tape. The bottom left corner of the quad was placed at the ~ 2-meter mark with the bottom of the quadrat parallel with the main transect (**Fig. 1.4**). The second quadrat was then positioned at the 5-meter mark with the frame flush to the main measuring tape. Finally, the top left corner of the third quadrat was placed ~ 2 m away from the bottom left corner of the second quadrat.

After cover measurements were complete at the first three quadrats, researchers moved to the 10-meter mark of the main transect line. In addition to coverage measurements at these quadrats, species composition was completed at each of the three quadrats at this transect distance. All plant species, except for mosses and lichens, were identified to at least genus, and typically to species.

Contingency Plot Setup

Some of the cameras were in locations that the sampling design could only be partially completed or could not be implemented. In these instances, there were different courses of action depending on the situation.

First, if one of the offset perpendicular quads could not be positioned the full length away from the main transect, then measurements were started one meter closer to the camera, while still attempting to position the perpendicular plot the appropriate distance from the main transect. If this was not tenable, the quadrat was attempted one meter further from the camera along the main transect. If this was still not logistically possible, the quadrat was simply positioned as close to where it was supposed to be originally positioned.

Second, if the main transect was not possible, or if less than four plots seemed feasible (e.g., for safety considerations) then a random azimuth was generated, originating from the camera location. This random azimuth was treated as the camera-facing azimuth of the traditional sampling design. The transect line followed this azimuth and setup plots followed the normal study design. The random azimuth setup only occurred at two of the 54 sampling locations.

APPENDIX II

PERCENT COVER AND SPECIES COMPOSITION MEASUREMENTS

Percent Coverage Measurements

Immediately after setup of the first quadrat, researchers began estimating percent cover of abiotic and biotic classes within the quadrat space. Coverage estimation was measured in percentage categories of 5 (i.e., 1-5%, 6-10%, 11-15% etc.). The highest number of the category was recorded as the percentage (i.e., record “10%” if it is within the 6-10% range). If the coverage percentage was < 1%, then it was record a “T” for trace.

Researchers measured two different measures of cover, aerial cover and ground level cover. Aerial coverage is the coverage of the top most layer of vegetation. For example, if a laser point were to shoot down on to a point on the plot you would count the first object that the laser intersects and ignore any other biotic or abiotic class that is below that initial class. Ground level coverage was measured as if you were to clip all the vegetation at the ground level and measure the coverage of all different classes on a 2-dimensional plane (that is flush with ground level). For example, a researcher only counted the root crown of a graminoid as the percent coverage in the ground cover measurement. Therefore, if an item in a coverage class is directly touching the ground plane then that item is counted in this coverage. If lichen is attached to rock than it is in direct contact with the ground surface, therefore, the lichen and not the rock should be counted as the ground coverage for that area.

Coverage estimates began with bare ground and then progressed through abiotic, non-vascular, and then vascular plant coverages (**Table A2.1**). Aerial coverage estimates were first recorded, followed by ground coverage estimates. This way researchers began by taking the measurements that disturbed the plants and substrate the least, then moved into the more quadrat altering measurements.

Species Composition Measurement

After cover measurements were completed in a quadrat, researchers began identifying vascular plant species. Unlike coverage estimation, plant species composition was only recorded in quadrats at the 10’s of meters on the transect (e.g., 10m, 20m, 30m, etc.). All species that were rooted or hanging over the quadrat were recorded for that quadrat. Moss and lichen species were not identified to species or genus, and were simply recorded as present in the quadrat. Specimens were collected of any species that a researcher could not identify quickly at the quadrat. These specimens were typically collected within ~ 20 m of the quadrat, rarely within the quadrat.

Table A2.1. Descriptions of the different vegetation coverage classes estimated within each quadrat.

Coverage Class	Comments
Bare ground	The percent cover within the quadrat of bare ground
Litter	The percent cover of litter in the quadrat; this included all downed and dead herbaceous material and woody debris that is not attached to a living plant/organism.
Gravel	The percent cover of gravel rock < 5 cm (~ 2 in.)
Rock	The percent cover of all rock > 5 cm (~ 2 in.).
Moss	The percent cover of moss in the quadrat
Lichen	The percent cover of lichen in the quadrat.
Forb	The percent cover of all forbs within the quadrat, including lower vascular plants under woody species.
Graminoid	The percent cover in the quadrat of grasses, sedges (e.g., *Carex* spp.), and rushes (e.g., *Juncus* spp.), only including live material
Dwarf Shrub	The percent coverage of any shrub species that is below 20 cm.
Shrub	The percent cover of shrubs in the quadrat, any shrub species that is greater than 20 cm in height.
Tree	The percent living tree coverage in the quadrat. There was only one camera location that had any tree presence.
Water	The amount of water that is either standing or flowing through the quadrat area.

APPENDIX III

FIRST ROUND OF DALL SHEEP MODEL RESULTS AND TOTAL DETECTIONS

Table A3.1. Dall sheep AIC$_c$ habitat use table of model results investigating habitat use (ψ) structures while holding detection probability (p) constant for all models. Models with AIC$_c$ $w_i \geq 0.01$ were included in the model results.

Model[a]	**AIC$_c$**	**ΔAIC$_c$**	**AIC$_c$ w_i**[b]	**ML**[c]	**K**[d]
ψ(Seasons,EweS567*Site+Escape*Sex+Slope+Snow+Forb+Firingpt) p(.)	1470.356	0.000	0.034	1.000	28
ψ(Seasons,EweS567*Site+Escape*Sex+Slope+Snow+Gram+Firingpt) p(.)	1470.631	0.276	0.029	0.871	28
ψ(Seasons,EweS567*Site+Escape*Sex+Slope+Snow+Gram+Forb+Firingpt) p(.)	1470.954	0.598	0.025	0.742	29
ψ(Seasons,EweS567*Site+Escape*Sex+Slope+Snow+Gram+SpRich+Firingpt) p(.)	1471.598	1.243	0.018	0.537	29
ψ(Seasons,EweS567*Site+Escape*Sex+Slope+Snow+Forb+Firingpt+Training) p(.)	1471.634	1.279	0.018	0.528	29
ψ(Seasons,EweS567*Site+Escape*Sex+Slope+Snow+Forb+SpRich+Firingpt) p(.)	1471.916	1.560	0.015	0.459	29
ψ(Seasons,EweS567*Site+Escape*Sex+Slope+Snow+Firingpt) p(.)	1472.015	1.659	0.015	0.436	27
ψ(Seasons,EweS567*Site+Escape*Sex+Slope+Snow+Gram+Firingpt+Training) p(.)	1472.065	1.710	0.014	0.426	29
ψ(Seasons,EweS567*Site+Escape*Sex+Slope+Snow+Gram+Elevation) p(.)	1472.118	1.762	0.014	0.414	28
ψ(Seasons,EweS567*Site+Escape*Sex+Slope+Snow+Forb+Firingpt+Viewshed) p(.)	1472.228	1.873	0.013	0.392	29
ψ(Seasons,EweS567*Site+Escape*Sex+Slope+Snow+Gram+Forb+Firingpt+Training) p(.)	1472.291	1.936	0.013	0.380	30
ψ(Seasons,EweS567*Site+Escape*Sex+Slope+Snow+Gram) p(.)	1472.355	1.999	0.012	0.368	27
ψ(Seasons,EweS567*Site+Escape*Sex+Slope+Snow+Forb+Elevation+Firingpt) p(.)	1472.398	2.043	0.012	0.360	29
ψ(Seasons,EweS567*Site+Escape*Sex+Slope+Snow+Gram+Elevation+Firingpt) p(.)	1472.400	2.044	0.012	0.360	29
ψ(Seasons,EweS567*Site+Escape*Sex+Slope+Snow+Gram+Forb+SpRich+Firingpt) p(.)	1472.402	2.047	0.012	0.359	30
ψ(Seasons,EweS567*Site+Escape*Sex+Slope+Snow+Elevation) p(.)	1472.404	2.049	0.012	0.359	27
ψ(Seasons,EweS567*Site+Escape*Sex+Slope+Snow+Forb+Dshrub+Firingpt) p(.)	1472.432	2.077	0.012	0.354	29

ψ(Seasons,EweS567*Site+Escape*Sex+Slope+Snow+Gram+Forb) p(.)	1472.742	2.386	0.010	0.303	28
ψ(Seasons,EweS567*Site+Escape*Sex+Slope+Snow+Elevation+Firingpt) p(.)	1472.756	2.400	0.010	0.301	28
ψ(Seasons,EweS567*Site+Escape*Sex+Slope+Snow+Gram+Dshrub+Firingpt) p(.)	1472.757	2.401	0.010	0.301	29
ψ(Seasons,EweS567*Site+Escape*Sex+Slope+Snow+Gram+Firingpt+Viewshed) p(.)	1472.762	2.406	0.010	0.300	29

[a] Defintions of habitat use and detection variables in model results can be found in Table 1.1.

[b] ‘AIC_c w_i’ is the Aikaike Information Criterion with correction for small sample size model weight.

[c] ‘ML’ is the model likelihood.

[d] ‘K’ is the number of parameters in each model.

Table A3.2. Dall sheep AIC_c habitat use table of model results, investigating detection probability (p) structures while holding habitat use (ψ) constant in all models. All models with AIC_c $w_i \geq 0.01$ were included in the model results.

Model[a]	$\mathbf{AIC_c}$	$\mathbf{\Delta AIC_c}$	$\mathbf{AIC_c}$ $\boldsymbol{w_i}$[b]	**ML**[c]	**K**[d]
ψ(.) p(Site+Sex+Trail+View)	1572.394	0.000	0.987	1.000	6
ψ(.) p(Trail+View)	1582.162	9.768	0.007	0.008	4
ψ(.) p(Site+Trail+View)	1582.839	10.445	0.005	0.005	5
ψ(.) p(Site+Trail)	1597.439	25.045	0.000	0.000	4
ψ(.) p(Trail)	1603.480	31.086	0.000	0.000	3
ψ(.) p(View)	1670.366	97.972	0.000	0.000	3
ψ(.) p(Site+View)	1672.386	99.992	0.000	0.000	4
ψ(.) p(.)	1694.317	121.923	0.000	0.000	2
ψ(.) p(Site)	1694.401	122.007	0.000	0.000	3

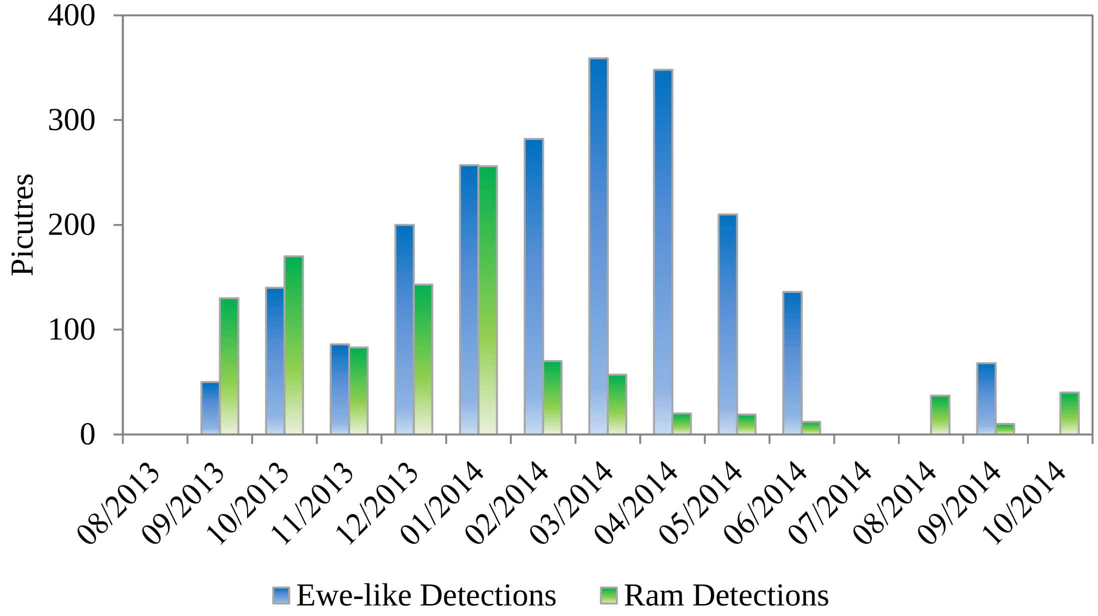
[a] Defintions of habitat use and detection variables in model results can be found in Table 1.1.

[b] 'AIC_c w_i' is the Aikaike Information Criterion with correction for small sample size model weight.

[c] 'ML' is the model likelihood.

[d] 'K' is the number of parameters in each model.

a. Molybdenum Ridge



b. Black Rapids Training Area

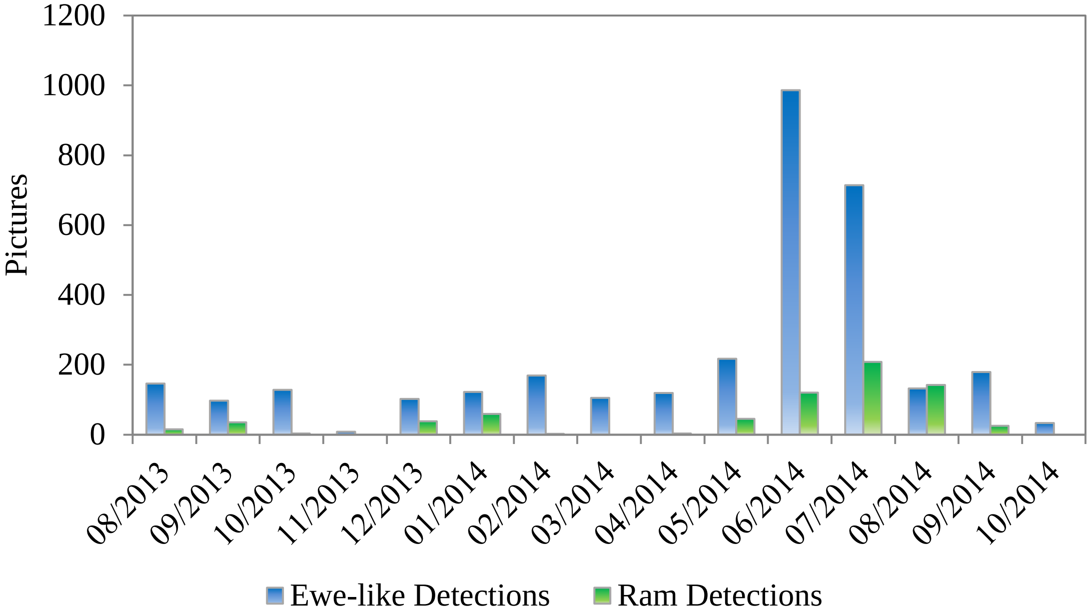


Figure A3.1. Total number of ewe-like and ram detections (i.e., all individual pictures) on (a) Molybdenum Ridge and (b) Black Rapids Training Area separated by month. Note: y-axes are different for the two figures; October 2014 data only until October 19th 2014.

APPENDIX IV

FIRST ROUND OF MAMMAL COMMUNITY ANALYSIS MODEL RESULTS

Table A4.1. Abbreviations and definitions of variables used to model habitat use and detection of the ten different mammal species.

Variable	Variable Abbreviation	Variable Definition
Late-summer/fall 2013	S1	Time period from August to early-October 2013
Early-winter 2013	S2	Time period from mid-October 2013 to early-January 2014
Winter 2014	S3	Time period from late-January to mid-April 2014
Spring/early-summer 2014	S4	Time period from early-May to early-July 2014
Late-summer/fall 2014	S5	Time period from August to early-October 2014
Study Site	Site	Difference between Molybdenum Ridge and Black Rapids Training Area
Plant species richness	SpRich	Estimated richness of vascular plant species at a camera site
Rock cover (%)	Rock	Estimated percent cover of rock at a camera site
Lichen cover (%)	Lichen	Estimated percent cover of all lichen at a camera site
Graminoid cover (%)	Gram	Estimated percent cover of graminoids at a camera site
Forb cover (%)	Forb	Estimated percent cover of forb species at a camera site
Dwarf shrub (%)	Dshrub	Estimated percent cover of dwarf shrub species (shrub ≤ 20 cm tall) at a camera site
Shrub (%)	Shrub	Estimated percent cover of shrub species at a camera site
Elevation (m)	Elevation	Elevation of a camera site
Slope (%)	Slope	Average slope of a 500m radius circle around each camera
Distance to escape terrain	Escape	Distance from a camera to barren/rocky terrain with a slope greater than 60%
Snow depth (cm)	Snow	Estimated average snow depth at each camera site
Wildlife trails	Trail	If a camera is capturing an image of a wildlife trail or not
Camera viewshed (ha)	Viewshed	The land surface area that a camera is capturing within each image

Table A4.2. Hoary marmot habitat use table of model results investigating habitat use (ψ) structures while holding detection probability (p) constant for all models. Models with AIC_c $w_i \geq 0.01$ were included in the model results. Reference Table A4.1 for variable definitions.

Model	AIC_c	ΔAIC_c	AIC_c w_i [a]	ML [b]	K [c]
ψ(Site+Elevation+Snow+Dshrub+Rock) p(.)	153.824	0.000	0.148	1.000	7
ψ(Site+Elevation+Snow+Dshrub+Gram+Rock) p(.)	155.142	1.318	0.077	0.517	8
ψ(Site+Elevation+Snow+Rock) p(.)	155.265	1.441	0.072	0.486	6
ψ(S1[d]+Site+Elevation+Snow+Dshrub+Rock) p(.)	155.861	2.038	0.053	0.361	8
ψ(Site+Elevation+Snow+Dshrub+Forb+Rock) p(.)	156.089	2.265	0.048	0.322	8
ψ(Site+Elevation+Dshrub+Rock) p(.)	156.564	2.740	0.038	0.254	6
ψ(Elevation+Snow+Dshrub+Rock) p(.)	156.732	2.908	0.035	0.234	6
ψ(Site+Elevation+Snow+Gram+Rock) p(.)	157.042	3.219	0.030	0.200	7
ψ(Site+Elevation+Dshrub+Gram+Rock) p(.)	157.181	3.357	0.028	0.187	7
ψ(S1+Site+Elevation+Snow+Rock) p(.)	157.212	3.389	0.027	0.184	7
ψ(S1+Site+Elevation+Snow+Dshrub+Gram+Rock) p(.)	157.318	3.494	0.026	0.174	9
ψ(Site+Elevation+Snow+Dshrub+Forb+Gram+Rock) p(.)	157.448	3.624	0.024	0.163	9
ψ(Site+Elevation+Snow+Forb+Rock) p(.)	157.489	3.665	0.024	0.160	7
ψ(S1+Site+Elevation+Snow+Dshrub+Forb+Rock) p(.)	158.038	4.214	0.018	0.122	9
ψ(Elevation+Snow+Dshrub+Forb+Rock) p(.)	158.094	4.270	0.017	0.118	7
ψ(S1+Elevation+Snow+Dshrub+Rock) p(.)	158.356	4.532	0.015	0.104	7
ψ(Site+Elevation+Dshrub+Forb+Rock) p(.)	158.677	4.853	0.013	0.088	7
ψ(S1+Site+Elevation+Dshrub+Rock) p(.)	158.720	4.896	0.013	0.087	7

ψ(Site+Elevation+Snow) p(.)	158.957	5.133	0.011	0.077	5
ψ(Elevation+Snow+Dshrub+Gram+Rock) p(.)	158.961	5.137	0.011	0.077	7
ψ(S1+Site+Elevation+Snow+Gram+Rock) p(.)	159.102	5.278	0.011	0.072	8
ψ(Site+Elevation+Snow+Forb+Gram+Rock) p(.)	159.281	5.457	0.010	0.065	8
ψ(S1+Site+Elevation+Dshrub+Gram+Rock) p(.)	159.305	5.481	0.010	0.065	8

[a] ‘AIC$_c$ w_i’ is the Aikaike Information Criterion with correction for small sample size model weight.

[b] ‘ML’ is the model likelihood.

[c] ‘K’ is the number of parameters in each model.

[d] ‘S1’ habitat use of late-summer/fall 2013 is different from 2014 seasons.

Table A4.3. Collared pika habitat use table of model results investigating habitat use (ψ) structures while holding detection probability (p) constant for all models. Models with AIC$_c$ $w_i \geq 0.01$ were included in the model results. Reference Table A4.1 for variable definitions.

Model	AIC$_c$	ΔAIC$_c$	AIC$_c$ w_i [a]	ML[b]	K[c]
ψ(S12[d]+Elevation+Slope+Dshrub+Rock) p(.)	175.266	0.000	0.163	1.000	7
ψ(Elevation+Slope+Dshrub+Rock+Snow) p(.)	175.323	0.057	0.159	0.972	7
ψ(Elevation+Slope+Dshrub+Rock+Gram) p(.)	175.854	0.588	0.122	0.745	7
ψ(Site+Elevation+Slope+Dshrub+Rock) p(.)	176.024	0.758	0.112	0.685	7
ψ(SpRich+Elevation+Slope+Dshrub+Rock) p(.)	176.077	0.810	0.109	0.667	7
ψ(Site+Elevation+Dshrub+Rock+Gram) p(.)	177.439	2.172	0.055	0.338	7
ψ(S12+Elevation+Dshrub+Rock+Gram) p(.)	178.898	3.632	0.027	0.163	7
ψ(Site+Elevation+Dshrub+Rock) p(.)	179.455	4.189	0.020	0.123	6
ψ(Slope+Dshrub+Rock) p(.)	179.537	4.270	0.019	0.118	5
ψ(Site+Elevation+Dshrub+Rock+Snow) p(.)	179.933	4.667	0.016	0.097	7
ψ(S12+Site+Elevation+Dshrub+Rock) p(.)	180.646	5.380	0.011	0.068	7
ψ(S12+SpRich+Slope+Dshrub+Rock) p(.)	180.769	5.503	0.010	0.064	7

[a] ‘AIC$_c$ w_i’ is the Aikaike Information Criterion with correction for small sample size model weight.

[b] ‘ML’ is the model likelihood.

[c] ‘K’ is the number of parameters in each model.

[d] ‘S12’ denotes the different habitat use in 2013 seasons versus the 2014 seasons

Table A4.4. Arctic ground squirrel habitat use table of model results investigating habitat use (ψ) structures while holding detection probability (p) constant for all models. Models with AIC$_c$ w_i ≥ 0.01 were included in the model results. Reference Table A4.1 for variable definitions.

Model	**AIC$_c$**	**ΔAIC$_c$**	**AIC$_c$ w_i**[a]	**ML**[b]	**K**[c]
ψ(Site+Forb) p(.)	523.747	0.000	0.054	1.000	4
ψ(Forb) p(.)	523.909	0.162	0.049	0.922	3
ψ(Gram+Forb) p(.)	525.001	1.255	0.029	0.534	4
ψ(Elevation+Forb) p(.)	525.462	1.715	0.023	0.424	4
ψ(Site+Gram+Forb) p(.)	525.662	1.915	0.021	0.384	5
ψ(Forb+Slope) p(.)	525.779	2.032	0.019	0.362	4
ψ(S1[d]+Site+Forb) p(.)	525.843	2.097	0.019	0.350	5
ψ(Site+Elevation+Forb) p(.)	525.845	2.099	0.019	0.350	5
ψ(Site+Forb+SpRich) p(.)	525.888	2.141	0.018	0.343	5
ψ(Site+Forb+Slope) p(.)	525.898	2.152	0.018	0.341	5
ψ(Site+Forb+Snow) p(.)	525.900	2.154	0.018	0.341	5
ψ(Site+Forb+Dshrub) p(.)	525.907	2.161	0.018	0.339	5
ψ(S1+Forb) p(.)	525.908	2.161	0.018	0.339	4
ψ(Forb+SpRich) p(.)	525.940	2.194	0.018	0.334	4
ψ(Forb+Dshrub) p(.)	525.959	2.213	0.018	0.331	4
ψ(Forb+Snow) p(.)	526.037	2.290	0.017	0.318	4
ψ(Elevation+Gram+Forb) p(.)	526.726	2.979	0.012	0.226	5
ψ(Gram+Forb+SpRich) p(.)	526.841	3.094	0.011	0.213	5
ψ(S1+Gram+Forb) p(.)	527.021	3.274	0.010	0.195	5

[a] ‘AIC_c w_i’ is the Aikaike Information Criterion with correction for small sample size model weight.

[b] ‘ML’ is the model likelihood.

[c] ‘K’ is the number of parameters in each model.

[d] ‘S1’ denotes different habitat use in the late-summer/fall 2013 season.

Table A4.5. Hoary marmot habitat use table of model results investigating detection probability (p) structures while holding habitat use (ψ) constant in all models. All models with AIC_c $w_i \geq 0.01$ were included in the model results. Reference Table A4.1 for variable definitions.

Model	AIC_c	ΔAIC_c	AIC_c w_i [a]	ML[b]	K[c]
ψ(.) p(S1&S5[d]+Site[e]+View[f])	149.066	0.000	0.639	1.000	5
ψ(.) p(S1&S5+Site+Trail+View)	150.529	1.464	0.308	0.481	6
ψ(.) p(S1&S5+Site+Trail)	155.353	6.287	0.028	0.043	5
ψ(.) p(S1&S5+Site)	155.624	6.559	0.024	0.038	4

[a] 'AIC_c w_i' is the Aikaike Information Criterion with correction for small sample size model weight.

[b] 'ML' is the model likelihood.

[c] 'K' is the number of parameters in each model.

[d] 'S1&S5' different habitat use in the late-summer/fall seasons.

Table A4.6. Collared pika habitat use table of model results investigating detection probability (p) structures while holding habitat use (ψ) constant in all models. All models with AIC_c $w_i \geq 0.01$ were included in the model results. Reference Table A4.1 for variable definitions.

Model	**AIC_c**	**ΔAIC_c**	**AIC_c w_i [a]**	**ML [b]**	**K [c]**
ψ(.) p(Snow)	188.248	0.000	0.246	1.000	3
ψ(.) p(Snow+View)	188.720	0.472	0.194	0.790	4
ψ(.) p(S23+Snow)	189.728	1.480	0.117	0.477	4
ψ(.) p(Site+Snow)	190.074	1.827	0.099	0.401	4
ψ(.) p(S23+Snow+View)	190.533	2.286	0.079	0.319	5
ψ(.) p(Site+Snow+View)	190.818	2.570	0.068	0.277	5
ψ(.) p(Site+S23+Snow)	191.770	3.522	0.042	0.172	5
ψ(.) p(S23+View)	192.358	4.111	0.032	0.128	4
ψ(.) p(S23+Site+Snow+View)	192.607	4.360	0.028	0.113	6
ψ(.) p(S23)	192.964	4.716	0.023	0.095	3
ψ(.) p(S23+Site)	193.663	5.415	0.016	0.067	4
ψ(.) p(View)	193.866	5.618	0.015	0.060	3
ψ(.) p(S23+Site+View)	194.112	5.864	0.013	0.053	5
ψ(.) p(.)	194.227	5.980	0.012	0.050	2

[a] 'AIC_c w_i' is the Aikaike Information Criterion with correction for small sample size model weight.

[b] 'ML' is the model likelihood.

[c] 'K' is the number of parameters in each model.

[d] 'S23' the probability of detection is the same during the early-winter 2013 and winter 2014 seasons.

Table A4.7. Arctic ground squirrel habitat use table of model results investigating detection probability (p) structures while holding habitat use (ψ) constant in all models. All models with AIC$_c$ w_i ≥ 0.01 were included in the model results. Reference Table A4.1 for variable definitions.

Model	**AIC$_c$**	**ΔAIC$_c$**	**AIC$_c$ w_i** [a]	**ML** [b]	**K** [c]
ψ(.) p(S1&S5+Site+View)	531.375	0.000	0.195	1.000	5
ψ(.) p(Site+View)	531.649	0.274	0.170	0.872	4
ψ(.) p(S1&S5+Site)	531.689	0.313	0.167	0.855	4
ψ(.) p(S1&S5+Site+Trail)	532.497	1.122	0.111	0.571	5
ψ(.) p(Site)	532.640	1.265	0.104	0.531	3
ψ(.) p(S1&S5+Site+View+Trail)	533.369	1.993	0.072	0.369	6
ψ(.) p(Site+View+Trail)	533.796	2.420	0.058	0.298	5
ψ(.) p(Site+Trail)	533.889	2.514	0.056	0.285	4
ψ(.) p(S1&S5+View)	535.481	4.106	0.025	0.128	4
ψ(.) p(View)	536.246	4.871	0.017	0.088	3
ψ(.) p(S1&S5+View+Trail)	537.495	6.119	0.009	0.047	5

[a] 'AIC$_c$ w_i' is the Aikaike Information Criterion with correction for small sample size model weight.

[b] 'ML' is the model likelihood.

[c] 'K' is the number of parameters in each model.

[h] 'S1&S5' different probability of detection in the late-summer/fall seasons.

Table A4.8. Moose habitat use table of model results investigating habitat use (ψ) structures while holding detection probability (p) constant for all models. Models with AIC_c w_i ≥ 0.01 were included in the model results. Reference Table A4.1 for variable definitions.

Model	AIC_c	ΔAIC_c	AIC_c w_i [a]	ML[b]	K[c]
ψ(S234[d]+Site+Elevation) p(.)	331.061	0.000	0.122	1.000	5
ψ(S234+Site+Elevation+Snow) p(.)	331.618	0.557	0.093	0.757	6
ψ(S234+Site+Elevation+Dshrub) p(.)	332.726	1.665	0.053	0.435	6
ψ(S234+Site+Elevation+Slope) p(.)	332.792	1.731	0.052	0.421	6
ψ(S234+Site+Elevation+Shrub+Snow) p(.)	333.037	1.976	0.046	0.372	7
ψ(S234+Site+Elevation+SpRich) p(.)	333.050	1.989	0.045	0.370	6
ψ(S234+Site+Elevation+Slope+Snow) p(.)	333.219	2.158	0.042	0.340	7
ψ(S234+Site+Elevation+Snow+SpRich) p(.)	333.652	2.592	0.034	0.274	7
ψ(S234+Site+Elevation+Slope+Shrub) p(.)	334.239	3.178	0.025	0.204	7
ψ(S234+Site+Elevation+Dshrub+Shrub) p(.)	334.258	3.197	0.025	0.202	7
ψ(S234+Site+Elevation+Shrub+SpRich) p(.)	334.332	3.271	0.024	0.195	7
ψ(S234+Site+Elevation+Slope+Dshrub) p(.)	334.718	3.657	0.020	0.161	7
ψ(S234+Elevation+Slope+Snow) p(.)	334.721	3.660	0.020	0.160	6
ψ(S234+Site+Elevation+Slope+Shrub+Snow) p(.)	334.864	3.803	0.018	0.149	8
ψ(S234+Site+Elevation+Dshrub+SpRich) p(.)	334.865	3.804	0.018	0.149	7
ψ(S234+Site+Elevation+Slope+SpRich) p(.)	334.900	3.840	0.018	0.147	7
ψ(S234+Elevation+Dshrub) p(.)	335.089	4.028	0.016	0.134	5
ψ(S234+Site+Elevation+Dshrub+Shrub+Snow) p(.)	335.106	4.045	0.016	0.132	8
ψ(S234+Site+Elevation+Shrub+Snow+SpRich) p(.)	335.126	4.065	0.016	0.131	8
ψ(S234+Site+Elevation+Slope+Dshrub+Snow) p(.)	335.309	4.248	0.015	0.120	8
ψ(S234+Elevation+Slope) p(.)	335.323	4.262	0.015	0.119	5

ψ(S234+Site+Elevation+Slope+Snow+SpRich) p(.)	335.372	4.311	0.014	0.116	8
ψ(S234+Elevation+Dshrub+Snow) p(.)	335.493	4.432	0.013	0.109	6
ψ(S234+Site+Elevation+Dshrub+Snow+SpRich) p(.)	335.622	4.561	0.013	0.102	8
ψ(S234+Elevation+Slope+Shrub+Snow) p(.)	335.643	4.582	0.012	0.101	7
ψ(S234+Elevation+Slope+Shrub) p(.)	335.981	4.920	0.010	0.085	6
ψ(S234+Elevation+Slope+Dshrub) p(.)	336.060	4.999	0.010	0.082	6

[a] ‘AIC$_c$ w_i’ is the Aikaike Information Criterion with correction for small sample size model weight.

[b] ‘ML’ is the model likelihood.

[c] ‘K’ is the number of parameters in each model.

[d] ‘S234’ denotes habitat use is the same from the early-winter 2013 through spring/early-summer 2014 seasons.

Table A4.9. Moose habitat use table of model results investigating detection probability (p) structures while holding habitat use (ψ) constant in all models. All models with $\text{AIC}_c\ w_i \geq 0.01$ were included in the model results. Reference Table A4.1 for variable definitions.

Model	**AIC_c**	**ΔAIC_c**	**$\text{AIC}_c\ w_i$**[a]	**ML**[b]	**K**[c]
ψ(.) p(Site+Shrub+View)	344.643	0.000	0.288	1.000	5
ψ(.) p(Shrub+p View)	344.876	0.233	0.257	0.890	4
ψ(.) p(Site+Shrub)	346.268	1.625	0.128	0.444	4
ψ(.) p(Site+p Shrub+p View+p Trail)	346.552	1.909	0.111	0.385	6
ψ(.) p(Shrub+Trail+View)	346.959	2.316	0.090	0.314	5
ψ(.) p(Shrub)	347.920	3.277	0.056	0.194	3
ψ(.) p(Site+Shrub+Trail)	348.342	3.699	0.045	0.157	5
ψ(.) p(Shrub+Trail)	349.553	4.910	0.025	0.086	4

[a] '$\text{AIC}_c\ w_i$' is the Aikaike Information Criterion with correction for small sample size model weight.

[b] 'ML' is the model likelihood.

[c] 'K' is the number of parameters in each model.

Table A4.10. Dall sheep habitat use table of model results investigating habitat use (ψ) structures while holding detection probability (p) constant for all models. Models with $\mathrm{AIC_c}$ $w_i \geq 0.01$ were included in the model results. Reference Table A4.1 for variable definitions.

Model	$\mathrm{AIC_c}$	$\Delta\mathrm{AIC_c}$	$\mathrm{AIC_c}$ w_i [a]	*ML* [b]	K [c]
ψ(S1,S23,S4[d]*Site+Sex[e]+Elevation+Slope+Escape+Gram+Snow) p(.)	1235.915	0.000	0.171	1.000	15
ψ(S1,S23,S4*Site+Sex+Slope+Escape+Gram+Snow) p(.)	1235.944	0.028	0.169	0.986	14
ψ(S1,S23,S4*Site+Sex+Elevation+Slope+Escape+Gram+SpRich+Snow) p(.)	1236.722	0.807	0.114	0.668	16
ψ(S1,S23,S4*Site+Sex+Slope+Escape+Gram+SpRich+Snow) p(.)	1236.998	1.083	0.100	0.582	15
ψ(S1,S23,S4*Site+Sex+Elevation+Slope+Escape+Gram+Forb+Snow) p(.)	1237.528	1.613	0.076	0.447	16
ψ(S1,S23,S4*Site+Sex+Elevation+Slope+Escape+Gram+Forb+SpRich+Snow) p(.)	1237.631	1.716	0.073	0.424	17
ψ(S1,S23,S4*Site+Sex+Slope+Escape+Gram+Forb+Snow) p(.)	1238.060	2.145	0.059	0.342	15
ψ(S1,S23,S4*Site+Sex+Slope+Escape+Gram+Forb+SpRich+Snow) p(.)	1239.009	3.094	0.036	0.213	16
ψ(S1,S23,S4*Site+Sex+Slope+Escape+Gram) p(.)	1241.393	5.478	0.011	0.065	13
ψ(S1,S23,S4*Site+Sex+Elevation+Slope+Escape+Snow) p(.)	1241.446	5.531	0.011	0.063	14
ψ(S1,S23,S4*Site+Sex+Slope+Escape+Gram+SpRich) p(.)	1241.527	5.611	0.010	0.061	14

[a] '$\mathrm{AIC_c}$ w_i' is the Aikaike Information Criterion with correction for small sample size model weight.

[b] 'ML' is the model likelihood.

[c] 'K' is the number of parameters in each model.

[d] 'S1,S23,S4' denotes habitat use between the five seasons except the early-winter 2013 and winter 2014 seasons (S23).

[e] 'Sex' is the difference between ewe-like and ram groups.

Table A4.11. Dall sheep habitat use table of model results investigating detection probability (p) structures while holding habitat use (ψ) constant in all models. All models with AIC_c $w_i \geq 0.01$ were included in the model results. Reference Table A4.1 for variable definitions.

Model	**AIC_c**	**ΔAIC_c**	**AIC_c w_i** [a]	**ML** [b]	**K** [c]
ψ(.) p(Site+Trail+View)	1337.459	0.000	0.584	1.000	5
ψ(.) p(Trail+View)	1338.206	0.747	0.402	0.688	4
ψ(.) p(Site+Trail)	1344.982	7.523	0.014	0.023	4

[a] 'AIC_c w_i' is the Aikaike Information Criterion with correction for small sample size model weight.

[b] 'ML' is the model likelihood.

[c] 'K' is the number of parameters in each model.

Table A4.12. Caribou habitat use table of model results investigating habitat use (ψ) structures while holding detection probability (p) constant for all models. Models with AIC_c $w_i \geq 0.01$ were included in the model results. Reference Table A4.1 for variable definitions.

Model	**AIC_c**	**ΔAIC_c**	**AIC_c w_i [a]**	**ML [b]**	**K [c]**
ψ(S234[d]+Elevation+Slope+Dshrub+Forb) p(.)	776.361	0.000	0.050	1.000	7
ψ(S234+Elevation+Slope+Dshrub+Forb+Lichen) p(.)	776.545	0.184	0.046	0.912	8
ψ(S234+Elevation+Slope+Dshrub+Forb+Snow) p(.)	776.888	0.528	0.038	0.768	8
ψ(S234+Elevation+Slope+Dshrub+Forb+SpRich) p(.)	777.063	0.703	0.035	0.704	8
ψ(S234+Elevation+Slope+Forb+SpRich) p(.)	777.209	0.848	0.033	0.654	7
ψ(S234+Elevation+Slope+Forb+Snow+SpRich) p(.)	777.430	1.069	0.029	0.586	8
ψ(S234+Elevation+Slope+Dshrub+Forb+Lichen+Shrub) p(.)	777.440	1.080	0.029	0.583	9
ψ(S234+Elevation+Slope+Dshrub+Forb+Lichen+Snow) p(.)	777.472	1.111	0.029	0.574	9
ψ(S234+Elevation+Slope+Dshrub+Forb+Lichen+SpRich) p(.)	777.698	1.338	0.026	0.512	9
ψ(S234+Elevation+Slope+Dshrub+Forb+Snow+SpRich) p(.)	777.795	1.434	0.024	0.488	9
ψ(S234+Elevation+Slope+Forb+Lichen+Shrub) p(.)	777.978	1.618	0.022	0.445	8
ψ(S234+Elevation+Slope+Forb+Lichen+SpRich) p(.)	778.078	1.718	0.021	0.424	8
ψ(S234+Elevation+Slope+Forb+Lichen+Shrub+SpRich) p(.)	778.148	1.787	0.020	0.409	9
ψ(S234+Elevation+Slope+Forb+Snow+Shrub+SpRich) p(.)	778.235	1.875	0.020	0.392	9
ψ(S234+Elevation+Slope+Dshrub+Forb+Snow+Shrub) p(.)	778.282	1.922	0.019	0.383	9
ψ(S234+Elevation+Slope+Dshrub+Forb+Lichen+Snow+Shrub) p(.)	778.401	2.040	0.018	0.361	10
ψ(S234+Elevation+Slope+Dshrub+Forb+Gram) p(.)	778.411	2.050	0.018	0.359	8
ψ(S234+Elevation+Slope+Forb+Lichen+Snow+SpRich) p(.)	778.541	2.181	0.017	0.336	9
ψ(S234+Elevation+Slope+Forb+Lichen+Snow+Shrub) p(.)	778.577	2.216	0.016	0.330	9
ψ(S234+Elevation+Slope+Dshrub+Forb+Lichen+Gram) p(.)	778.640	2.279	0.016	0.320	9
ψ(S234+Elevation+Slope+Dshrub+Forb+Shrub+SpRich) p(.)	778.665	2.304	0.016	0.316	9

ψ(S234+Elevation+Slope+Forb+Shrub) p(.)	778.670	2.309	0.016	0.315	7
ψ(S234+Elevation+Slope+Forb+Snow+Shrub) p(.)	778.696	2.335	0.016	0.311	8
ψ(S234+Elevation+Slope+Forb+Snow) p(.)	778.738	2.378	0.015	0.305	7
ψ(S234+Elevation+Slope+Dshrub+Forb+Lichen+Snow+SpRich) p(.)	778.749	2.388	0.015	0.303	10
ψ(S234+Elevation+Slope+Forb+Lichen+Snow+Shrub+SpRich) p(.)	778.764	2.404	0.015	0.301	10
ψ(S234+Elevation+Slope+Forb) p(.)	778.890	2.529	0.014	0.282	6
ψ(S234+Elevation+Slope+Dshrub+Forb+Lichen+Shrub+SpRich) p(.)	778.894	2.533	0.014	0.282	10
ψ(S234+Slope+Dshrub+Forb+Lichen) p(.)	778.896	2.535	0.014	0.282	7
ψ(S234+Elevation+Slope+Forb+Gram+SpRich) p(.)	779.171	2.810	0.012	0.245	8
ψ(S234+Elevation+Slope+Dshrub+Forb+Gram+SpRich) p(.)	779.183	2.822	0.012	0.244	9
ψ(S234+Elevation+Slope+Forb+Lichen) p(.)	779.191	2.830	0.012	0.243	7
ψ(S234+Elevation+Slope+Dshrub+Forb+Snow+Shrub+SpRich) p(.)	779.349	2.988	0.011	0.225	10
ψ(S234+Elevation+Slope+Forb+Snow+Gram+SpRich) p(.)	779.350	2.989	0.011	0.224	9
ψ(S234+Elevation+Slope+Forb+Lichen+Snow) p(.)	779.433	3.073	0.011	0.215	8
ψ(S234+Elevation+Slope+Dshrub+Forb+Lichen+Gram+Shrub) p(.)	779.508	3.147	0.010	0.207	10
ψ(S234+Elevation+Slope+Dshrub+Forb+Lichen+Snow+Gram) p(.)	779.537	3.177	0.010	0.204	10
ψ(S234+Elevation+Slope+Forb+Lichen+Gram+Shrub) p(.)	779.683	3.322	0.00948	0.19	9

[a] ‘AIC_c w_i’ is the Aikaike Information Criterion with correction for small sample size model weight.

[b] ‘ML’ is the model likelihood.

[c] ‘K’ is the number of parameters in each model.

[d] ‘S234’ denotes habitat use is the same from the early-winter 2013 through spring/early-summer 2014 seasons.

Table A4.13. Caribou habitat use table of model results investigating detection probability (p) structures while holding habitat use (ψ) constant in all models. All models with AIC$_c$ $w_i \geq 0.01$ were included in the model results. Reference Table A4.1 for variable definitions.

Model	**AIC$_c$**	**ΔAIC$_c$**	**AIC$_c$ w_i** [a]	**ML** [b]	**K** [c]
ψ(.) p(.)	838.304	0.000	0.473	1	2
ψ(.) p(Trail)	839.479	1.175	0.263	0.556	3
ψ(.) p(View)	840.363	2.059	0.169	0.357	3
ψ(.) p(Trail+View)	841.491	3.187	0.096	0.203	4

[a] 'AIC$_c$ w_i' is the Aikaike Information Criterion with correction for small sample size model weight.

[b] 'ML' is the model likelihood.

[c] 'K' is the number of parameters in each model.

Table A4.14. Wolverine habitat use table of model results investigating habitat use (ψ) structures while holding detection probability (p) constant for all models. Models with AIC_c $w_i \geq 0.01$ were included in the model results. Reference Table A4.1 for variable definitions.

Model	AIC_c	ΔAIC_c	AIC_c w_i [a]	ML[b]	K[c]
ψ(S234[d]+Site+Forb+Snow) p(.)	158.767	0.000	0.081	1.000	6
ψ(S234+Site+Snow) p(.)	159.758	0.991	0.049	0.609	5
ψ(S234+Forb+Snow) p(.)	159.797	1.030	0.048	0.598	5
ψ(S234+Site+Slope+Snow) p(.)	159.927	1.160	0.045	0.560	6
ψ(S234+Site+Elevation+Snow) p(.)	159.980	1.213	0.044	0.545	6
ψ(S234+Snow+Slope) p(.)	160.190	1.423	0.040	0.491	5
ψ(S234+Snow+Forb+Slope) p(.)	160.204	1.437	0.039	0.488	6
ψ(S234+Site+Snow+Forb+Slope) p(.)	160.451	1.684	0.035	0.431	7
ψ(S234+Forb) p(.)	160.570	1.803	0.033	0.406	4
ψ(S234+Site+Elevation+Forb+Snow) p(.)	160.698	1.931	0.031	0.381	7
ψ(S234+Forb+Slope) p(.)	160.886	2.119	0.028	0.347	5
ψ(S234+Slope) p(.)	160.918	2.151	0.028	0.341	4
ψ(Forb) p(.)	161.162	2.395	0.024	0.302	3
ψ(S234+Site+Forb) p(.)	161.211	2.444	0.024	0.295	5
ψ(S234+Site+Elevation+Slope+Snow) p(.)	161.398	2.631	0.022	0.268	7
ψ(Site+Forb) p(.)	161.739	2.972	0.018	0.226	4
ψ(Forb+Slope) p(.)	161.765	2.998	0.018	0.223	4
ψ(S234+Elevation+Forb+Snow) p(.)	161.908	3.141	0.017	0.208	6
ψ(S234+Site+Elevation) p(.)	161.991	3.224	0.016	0.200	5
ψ(S234+Elevation+Slope+Forb+Snow) p(.)	162.276	3.509	0.014	0.173	7
ψ(S234+Elevation+Slope+Snow) p(.)	162.308	3.541	0.014	0.170	6

ψ(S234+Elevation+Slope) p(.)	162.338	3.571	0.014	0.168	5
ψ(S234+Site+Elevation+Forb) p(.)	162.342	3.575	0.014	0.167	6
ψ(S234+Site+Slope+Forb) p(.)	162.442	3.675	0.013	0.159	6
ψ(S234+Site+Elevation+Slope+Forb+Snow) p(.)	162.532	3.765	0.012	0.152	8
ψ(S234+Elevation+Forb) p(.)	162.544	3.777	0.012	0.151	5
ψ(S234+Site+Slope) p(.)	162.559	3.792	0.012	0.150	5
ψ(S234+Site+Elevation+Slope) p(.)	162.704	3.937	0.011	0.140	6
ψ(Slope) p(.)	162.861	4.094	0.010	0.129	3
ψ(S234+Elevation+Slope+Forb) p(.)	162.912	4.145	0.010	0.126	6
ψ(Forb+Snow) p(.)	163.054	4.287	0.009	0.117	4

[a] ‘AIC_c w_i’ is the Aikaike Information Criterion with correction for small sample size model weight.

[b] ‘ML’ is the model likelihood.

[c] ‘K’ is the number of parameters in each model.

[d] ‘S234’ denotes habitat use is the same from the early-winter 2013 through spring/early-summer 2014 seasons.

Table A4.15. Wolverine habitat use table of model results investigating detection probability (p) structures while holding habitat use (ψ) constant in all models. All models with $\mathrm{AIC_c}\ w_i \geq 0.01$ were included in the model results. Reference Table A4.1 for variable definitions.

Model	**$\mathrm{AIC_c}$**	**$\Delta\mathrm{AIC_c}$**	**$\mathrm{AIC_c}\ w_i$[a]**	**ML[b]**	**K[c]**
ψ(.) p(Trail+View)	152.963	0.000	0.375	1.000	4
ψ(.) p(Trail)	153.231	0.268	0.328	0.875	3
ψ(.) p(Site+Trail)	154.820	1.857	0.148	0.395	4
ψ(.) p(Site+Trail+View)	154.875	1.912	0.144	0.385	5

[a] ‘$\mathrm{AIC_c}\ w_i$’ is the Aikaike Information Criterion with correction for small sample size model weight.

[b] ‘ML’ is the model likelihood.

[c] ‘K’ is the number of parameters in each model.

Table A4.16. Red fox habitat use table of model results investigating habitat use (ψ) structures while holding detection probability (p) constant for all models. Models with $\mathrm{AIC_c}\ w_i \geq 0.01$ were included in the model results. Reference Table A4.1 for variable definitions.

Model	$\mathrm{AIC_c}$	$\Delta\mathrm{AIC_c}$	$\mathrm{AIC_c}\ w_i$ [a]	ML[b]	K[c]
ψ(S23[d]+Site+Snow) p(.)	364.928	0.000	0.043	1.000	5
ψ(S23+Snow) p(.)	365.186	0.258	0.037	0.879	4
ψ(S23+Snow+Slope) p(.)	365.554	0.626	0.031	0.731	5
ψ(S23+Forb+Snow+Slope) p(.)	366.280	1.352	0.022	0.509	6
ψ(S23+Dshrub+Snow) p(.)	366.313	1.385	0.021	0.500	5
ψ(S23+Site+Forb+Snow) p(.)	366.430	1.502	0.020	0.472	6
ψ(S23+Site+Snow+Slope) p(.)	366.534	1.606	0.019	0.448	6
ψ(Site+Forb) p(.)	366.577	1.648	0.019	0.439	4
ψ(S23+Site+Dshrub+Snow) p(.)	366.893	1.965	0.016	0.375	6
ψ(Site) p(.)	367.025	2.097	0.015	0.351	3
ψ(S23+Site+Shrub+Snow) p(.)	367.034	2.106	0.015	0.349	6
ψ(S23+Site+Elevation+Snow) p(.)	367.047	2.119	0.015	0.347	6
ψ(S23+Forb+Snow) p(.)	367.134	2.206	0.014	0.332	5
ψ(S23+Site+Slope+Forb+Snow) p(.)	367.193	2.265	0.014	0.322	7
ψ(S23+Shrub+Snow) p(.)	367.226	2.298	0.013	0.317	5
ψ(S23+Elevation+Snow) p(.)	367.276	2.348	0.013	0.309	5
ψ(S23+Elevation+Slope+Snow) p(.)	367.301	2.373	0.013	0.305	6
ψ(S23+Slope+Dshrub+Snow) p(.)	367.373	2.445	0.013	0.295	6
ψ(S23+Slope+Shrub+Snow) p(.)	367.512	2.584	0.012	0.275	6
ψ(Site+Slope+Forb) p(.)	367.605	2.676	0.011	0.262	5
ψ(Dshrub) p(.)	367.664	2.736	0.011	0.255	3
ψ(Site+Forb+Dshrub) p(.)	367.790	2.862	0.010	0.239	5

[a] ‘AIC_c w_i’ is the Aikaike Information Criterion with correction for small sample size model weight.

[b] ‘ML’ is the model likelihood.

[c] ‘K’ is the number of parameters in each model.

[d] ‘S23’ denotes that habitat use is the same during the early-winter 2013 and winter 2014 seasons.

Table A4.17. Red fox habitat use table of model results investigating detection probability (p) structures while holding habitat use (ψ) constant in all models. All models with AIC$_c$ $w_i \geq 0.01$ were included in the model results. Reference Table A4.1 for variable definitions.

Model	**AIC$_c$**	**ΔAIC$_c$**	**AIC$_c$ w_i** [a]	**ML** [b]	**K** [c]
ψ(.) p(Site+Trail+View)	357.411	0.000	0.496	1.000	5
ψ(.) p(Site+Trail)	358.146	0.735	0.344	0.693	4
ψ(.) p(Site+View)	360.198	2.787	0.123	0.248	4
ψ(.) p(Site)	365.065	7.654	0.011	0.022	3
ψ(.) p(View)	365.241	7.830	0.010	0.020	3
ψ(.) p(Trail+View)	365.359	7.948	0.009	0.019	4
ψ(.) p(Trail)	366.505	9.094	0.005	0.011	3
ψ(.) p(.)	368.914	11.503	0.002	0.003	2

[a] 'AIC$_c$ w_i' is the Aikaike Information Criterion with correction for small sample size model weight.

[b] 'ML' is the model likelihood.

[c] 'K' is the number of parameters in each model.

Table A4.18. Gray wolf habitat use table of model results investigating habitat use (ψ) structures while holding detection probability (p) constant for all models. Models with AIC$_c$ w_i ≥ 0.01 were included in the model results. Reference Table A4.1 for variable definitions.

Model	**AIC$_c$**	**ΔAIC$_c$**	**AIC$_c$ w_i**[a]	**ML**[b]	**K**[c]
ψ(S23[d]+Shrub) p(.)	202.565	0.000	0.071	1.000	4
ψ(S23+Shrub+Elevation) p(.)	203.460	0.895	0.045	0.639	5
ψ(Shrub+Snow) p(.)	203.652	1.087	0.041	0.581	4
ψ(S23+Shrub+Gram) p(.)	203.724	1.159	0.040	0.560	5
ψ(S23+Shrub+Dshrub) p(.)	204.188	1.622	0.032	0.444	5
ψ(S23+Shrub+Elevation+Gram) p(.)	204.440	1.875	0.028	0.392	6
ψ(S23+Shrub+Snow) p(.)	204.482	1.917	0.027	0.383	5
ψ(S23) p(.)	204.533	1.967	0.027	0.374	3
ψ(S23+Site+Shrub) p(.)	204.636	2.070	0.025	0.355	5
ψ(Shrub+Snow+Gram) p(.)	204.765	2.200	0.024	0.333	5
ψ(Snow) p(.)	204.980	2.415	0.021	0.299	3
ψ(S23+Shrub+Dshrub+Gram) p(.)	205.129	2.564	0.020	0.278	6
ψ(S23+Dshrub) p(.)	205.141	2.576	0.020	0.276	4
ψ(S23+Site+Shrub+Elevation) p(.)	205.306	2.740	0.018	0.254	6
ψ(Shrub+Snow+Elevation) p(.)	205.367	2.801	0.017	0.247	5
ψ(S23+Shrub+Elevation+Dshrub) p(.)	205.516	2.951	0.016	0.229	6
ψ(S23+Shrub+Snow+Elevation) p(.)	205.578	3.013	0.016	0.222	6
ψ(Site+Shrub+Snow) p(.)	205.581	3.016	0.016	0.221	5
ψ(S23+Shrub+Snow+Gram) p(.)	205.640	3.075	0.015	0.215	6

ψ(Shrub+Snow+Dshrub) p(.)	205.666	3.101	0.015	0.212	5
ψ(S23+Site+Shrub+Gram) p(.)	205.831	3.266	0.014	0.195	6
ψ(S23+Site+Shrub+Dshrub) p(.)	206.082	3.517	0.012	0.172	6
ψ(S23+Shrub+Snow+Dshrub) p(.)	206.263	3.698	0.011	0.157	6
ψ(S23+Snow) p(.)	206.291	3.726	0.011	0.155	4
ψ(Shrub) p(.)	206.308	3.742	0.011	0.154	3
ψ(S23+Gram) p(.)	206.388	3.822	0.010	0.148	4
ψ(Snow+Dshrub) p(.)	206.397	3.832	0.010	0.147	4
ψ(Shrub+Snow+Elevation+Gram) p(.)	206.410	3.845	0.010	0.146	6
ψ(S23+Shrub+Elevation+Dshrub+Gram) p(.)	206.454	3.889	0.010	0.143	7
ψ(Site+S23) p(.)	206.470	3.905	0.010	0.142	4
ψ(Site+S23+Shrub+Elevation+Gram) p(.)	206.518	3.953	0.010	0.139	7
ψ(Site+S23+Shrub+Snow) p(.)	206.530	3.965	0.010	0.138	6
ψ(S23+Shrub+Snow+Elevation+Gram) p(.)	206.580	4.015	0.010	0.134	7

[a] ‘AIC$_c$ w_i’ is the Aikaike Information Criterion with correction for small sample size model weight.

[b] ‘ML’ is the model likelihood.

[c] ‘K’ is the number of parameters in each model.

[d] ‘S23’ denotes that habitat use is the same during the early-winter 2013 and winter 2014 seasons.

Table A4.19. Gray wolf habitat use table of model results investigating detection probability (p) structures while holding habitat use (ψ) constant in all models. All models with AIC_c $w_i \geq 0.01$ were included in the model results. Reference Table A4.1 for variable definitions.

Model	AIC_c	ΔAIC_c	AIC_c w_i [a]	ML[b]	K[c]
ψ(.) p(Trail+View)	205.552	0.000	0.238	1.000	4
ψ(.) p(Trail)	206.064	0.511	0.184	0.774	3
ψ(.) p(Site+Trail)	206.247	0.694	0.168	0.707	4
ψ(.) p(Site+Trail+View)	206.366	0.814	0.158	0.666	5
ψ(.) p(.)	207.151	1.598	0.107	0.450	2
ψ(.) p(Site)	208.257	2.705	0.061	0.259	3
ψ(.) p(View)	208.416	2.864	0.057	0.239	3
ψ(.) p(Site+View)	209.877	4.325	0.027	0.115	4

[a] 'AIC_c w_i' is the Aikaike Information Criterion with correction for small sample size model weight.

[b] 'ML' is the model likelihood.

[c] 'K' is the number of parameters in each model.

Table A4.20. Grizzly bear habitat use table of model results investigating habitat use (ψ) structures while holding detection probability (p) constant for all models. Models with $\mathrm{AIC_c}\ w_i \geq 0.01$ were included in the model results. Reference Table A4.1 for variable definitions.

Model	**$\mathrm{AIC_c}$**	**$\Delta\mathrm{AIC_c}$**	**$\mathrm{AIC_c}\ w_i$**[a]	**ML**[b]	**K**[c]
ψ(Forb+Slope) p(.)	209.254	0.000	0.118	1.000	4
ψ(Elevation+Forb+Slope) p(.)	210.014	0.760	0.081	0.684	5
ψ(Elevation+Slope) p(.)	210.470	1.216	0.064	0.544	4
ψ(Elevation+Slope+Forb+Dshrub) p(.)	210.704	1.450	0.057	0.484	6
ψ(Slope+Forb+Dshrub) p(.)	210.962	1.708	0.050	0.426	5
ψ(S1[d]+Slope+Forb) p(.)	210.980	1.726	0.050	0.422	5
ψ(Slope+Forb+Snow) p(.)	211.243	1.989	0.044	0.370	5
ψ(S1+Forb) p(.)	211.481	2.227	0.039	0.328	3
ψ(Elevation+Slope+Dshrub) p(.)	211.970	2.716	0.030	0.257	5
ψ(Elevation+Slope+Forb+Snow) p(.)	212.139	2.885	0.028	0.236	6
ψ(S1+Elevation+Slope+Forb) p(.)	212.231	2.977	0.027	0.226	6
ψ(S1+Forb+Snow) p(.)	212.260	3.006	0.026	0.223	4
ψ(S1+Elevation+Slope) p(.)	212.379	3.125	0.025	0.210	5
ψ(Elevation+Slope+Snow) p(.)	212.569	3.315	0.023	0.191	5
ψ(S1+Slope+Forb+Dshrub) p(.)	212.953	3.699	0.019	0.157	6
ψ(S1+Slope+Forb+Snow) p(.)	213.063	3.809	0.018	0.149	6
ψ(Slope) p(.)	213.104	3.850	0.017	0.146	3
ψ(Slope+Forb+Dshrub+Snow) p(.)	213.205	3.951	0.016	0.139	6
ψ(Elevation+Dshrub) p(.)	213.241	3.987	0.016	0.136	4
ψ(Dshrub) p(.)	213.310	4.056	0.016	0.132	3
ψ(S1+Forb+Elevation) p(.)	213.333	4.079	0.015	0.130	4

ψ(Forb) p(.)	213.659	4.405	0.013	0.111	3
ψ(.) p(.)	213.685	4.431	0.013	0.109	2
ψ(Dshrub+Snow) p(.)	213.869	4.615	0.012	0.100	4
ψ(S1+Slope) p(.)	213.957	4.704	0.011	0.095	4
ψ(Elevation+Slope+Dshrub+Snow) p(.)	214.205	4.951	0.010	0.084	6
ψ(Forb+Dshrub) p(.)	214.244	4.990	0.010	0.083	4

[a] ‘$\mathrm{AIC_c}$ w_i’ is the Aikaike Information Criterion with correction for small sample size model weight.

[b] ‘ML’ is the model likelihood.

[c] ‘K’ is the number of parameters in each model.

[d] ‘S1’ denotes different habitat use in the late-summer/fall 2013 season.

Table A4.21. Grizzly bear habitat use table of model results investigating detection probability (p) structures while holding habitat use (ψ) constant in all models. All models with AIC_c $w_i \geq 0.01$ were included in the model results. Reference Table A4.1 for variable definitions.

Model	AIC_c	ΔAIC_c	AIC_c w_i [a]	ML [b]	K [c]
ψ(.) p(Trail)	211.781	0.000	0.495	1.000	3
ψ(.) p(Trail+View)	213.209	1.428	0.242	0.490	4
ψ(.) p(.)	213.685	1.904	0.191	0.386	2
ψ(.) p(View)	215.649	3.869	0.072	0.145	3

[a] ‘AIC_c w_i’ is the Aikaike Information Criterion with correction for small sample size model weight.

[b] ‘ML’ is the model likelihood.

[c] ‘K’ is the number of parameters in each model.

APPENDIX V

SECOND ROUND OF MAMMAL COMMUNITY ANALYSIS TABLES OF MODEL RESULTS

Table A5.1. Hoary marmot table of habitat use model results. All models with AIC$_c$ $w_i \geq 0.01$ were included in the model results. Reference Table A4.1 for variable definitions.

Model	**AIC$_c$**	**ΔAIC$_c$**	**AIC$_c$ w_i** [a]	**ML**[b]	**K**[c]
ψ(Site+Elevation+Rock+Snow) p(S1&S5[d]+View)	141.334	0.000	0.130	1.000	8
ψ(Rock+Dshrub+Snow) p(S1&S5+Site+View)	141.680	0.345	0.110	0.841	8
ψ(Site+Elevation+Rock+Snow) p(S1&S5+Site+p View)	142.339	1.005	0.079	0.605	9
ψ(Site+Elevation+Rock+Dshrub+Snow) p(S1&S5+View)	142.790	1.456	0.063	0.483	9
ψ(Elevation) p(S1&S5+Site+View)	142.982	1.648	0.057	0.439	6
ψ(Site+Elevation+Rock) p(S1&S5+View)	143.091	1.757	0.054	0.416	7
ψ(Site+Elevation+Rock) p(S1&S5+Site+View)	143.298	1.964	0.049	0.375	8
ψ(Elevation+Rock+Dshrub) p(S1&S5+Site+View)	143.598	2.264	0.042	0.322	8
ψ(Site+Elevation) p(S1&S5+Site+View)	143.995	2.661	0.034	0.264	7
ψ(Site+Elevation+Rock+Dshrub) p(S1&S5+View)	144.271	2.936	0.030	0.230	8
ψ(Elevation+Rock+Snow) p(S1&S5+Site+View)	144.412	3.078	0.028	0.215	8
ψ(Elevation+Rock+Dshrub+Snow) p(S1&S5+Site+View)	144.512	3.178	0.027	0.204	9
ψ(Elevation+Rock) p(S1&S5+Site+View)	144.518	3.184	0.027	0.204	7
ψ(Elevation+Snow) p(S1&S5+Site+View)	145.150	3.816	0.019	0.148	7
ψ(Elevation+Dshrub) p(S1&S5+Site+View)	145.201	3.867	0.019	0.145	7
ψ(Site+Elevation) p(S1&S5+View)	145.411	4.076	0.017	0.130	6
ψ(Site+Elevation+Snow) p(S1&S5+Site+View)	146.188	4.854	0.012	0.088	8
ψ(Site+Elevation+Dshrub p(S1&S5+Site+View))	146.246	4.912	0.011	0.086	8

[a] ‘AIC_c w_i’ is the Aikaike Information Criterion with correction for small sample size model weight.

[b] ‘ML’ is the model likelihood.

[c] ‘K’ is the number of parameters in each model.

[d] ‘S1&S5’ different probability of detection in the late-summer/fall seasons.

Table A5.2. Collared pika table of habitat use model results. All models with AIC$_c$ $w_i \geq 0.01$ were included in the model results. Reference Table A4.1 for variable definitions.

Model	AIC$_c$	ΔAIC$_c$	AIC$_c$ w_i [a]	ML [b]	K [c]
ψ(Elevation+Slope+Dshrub+Rock) p(Snow)	172.861	0.000	0.527	1.000	7
ψ(Elevation+Slope+Dshrub+RockLichen p(.)	173.963	1.102	0.304	0.577	6
ψ(Elevation+ Dshrub+RockLichen) p(Snow)	177.770	4.909	0.045	0.086	6
ψ(Slope+ Dshrub+ Rock) p(Snow)	178.176	5.315	0.037	0.070	6
ψ(Elevation+ Dshrub+ Rock) p(.)	179.254	6.393	0.022	0.041	5
ψ(Slope+ Dshrub+ Rock) p(.)	179.537	6.675	0.019	0.036	5
ψ(Elevation+ RockLichen) p(Snow)	179.991	7.130	0.015	0.028	5
ψ(Elevation+ Slope+ Rock) p(Snow)	180.381	7.520	0.012	0.023	6

[a] 'AIC$_c$ w_i' is the Aikaike Information Criterion with correction for small sample size model weight.

[b] 'ML' is the model likelihood.

[c] 'K' is the number of parameters in each model.

Table A5.3. Arctic ground squirrel table of habitat use model results. All models with AIC$_c$ $w_i \geq 0.01$ were included in the model results. Reference Table A4.1 for variable definitions.

Model	AIC$_c$	ΔAIC$_c$	AIC$_c$ w_i [a]	ML [b]	K [c]
ψ(Forb) p(Site+View)	516.453	0.000	0.304	1.000	5
ψ(Forb) p(S1&S5[d]+Site+View)	517.508	1.055	0.179	0.590	6
ψ(Forb) p(S1&S5+Site)	517.947	1.494	0.144	0.474	5
ψ(Forb) p(Site)	518.041	1.588	0.137	0.452	4
ψ(Forb) p(View)	518.113	1.660	0.132	0.436	4
ψ(Forb) p(S1&S5+View)	518.98	2.528	0.086	0.283	5
ψ(Forb) p(S1&S5)	523.23	6.778	0.010	0.034	4
ψ(Forb) p(.)	523.909	7.456	0.007	0.024	3

[a] 'AIC$_c$ w_i' is the Aikaike Information Criterion with correction for small sample size model weight.

[b] 'ML' is the model likelihood.

[c] 'K' is the number of parameters in each model.

[d] 'S1&S5' different probability of detection in the late-summer/fall seasons.

Table A5.4. Moose table of habitat use model results. All models with $\mathrm{AIC_c}\ w_i \geq 0.01$ were included in the model results. Reference Table A4.1 for variable definitions.

Model	**$\mathrm{AIC_c}$**	**$\Delta\mathrm{AIC_c}$**	**$\mathrm{AIC_c}\ w_i$** [a]	**ML** [b]	**K** [c]
ψ(S234[d]+Elevation) p(Site+Shrub)	321.095	0.000	0.233	1.000	6
ψ(S234+Elevation) p(Site+Shrub+View)	321.631	0.536	0.178	0.765	7
ψ(S234+Site+Snow) p(Shrub)	322.171	1.076	0.136	0.584	6
ψ(S234+Site+Snow) p(Shrub+View)	322.310	1.215	0.127	0.545	7
ψ(S234+Site+Snow) p(Site+Shrub)	322.693	1.598	0.105	0.450	7
ψ(S234+Site+Snow) p(Site+Shrub+View)	323.347	2.252	0.075	0.324	8
ψ(S234+Elevation) p(Shrub+View)	323.379	2.284	0.074	0.319	6
ψ(S234+Elevation) p(Shrub)	324.471	3.376	0.043	0.185	5

[a] ‘$\mathrm{AIC_c}\ w_i$’ is the Aikaike Information Criterion with correction for small sample size model weight.

[b] ‘ML’ is the model likelihood.

[c] ‘K’ is the number of parameters in each model.

[d] ‘S234’ denotes habitat use is the same from the early-winter 2013 through spring/early-summer 2014 seasons.

Table A5.5. Dall sheep table of habitat use model results. All models with AIC$_c$ w_i ≥ 0.01 were included in the model results. Reference Table A4.1 for variable definitions.

Model	AIC$_c$	ΔAIC$_c$	AIC$_c$ w_i [a]	ML [b]	K [c]
ψ(S1,S23,S4[d]*Site+Sex[e]+Slope+Escape+Gram+Snow) p(Trail)	1214.041	0.000	0.451	1.000	15
ψ(S1,S23,S4*Site+Sex+Slope+Escape+Gram+Snow) p(Trail+View)	1215.915	1.874	0.177	0.392	16
ψ(S1,S23,S4*Site+Sex+Slope+Escape+Gram+Snow) p(Site+Trail)	1216.113	2.071	0.160	0.355	16
ψ(S1,S23,S4*Site+Sex+Slope+Escape+Gram+Snow) p(Site+Trail+View)	1217.825	3.783	0.068	0.151	17
ψ(S1,S23,S4+Site+Sex+Slope+Escape+Gram+Snow) p(Trail)	1219.569	5.527	0.028	0.063	12
ψ(S1,S23,S4*Site+Slope+Escape+Gram+Snow) p(Trail)	1221.231	7.189	0.012	0.028	14
ψ(S1,S23,S4+Site+Sex+Slope+Escape+Gram+Snow) p(Trail+View)	1221.357	7.315	0.012	0.026	13
ψ(S1,S23,S4+Site+Sex+Slope+Escape+Gram+Snow) p(Site+Trail)	1221.395	7.353	0.011	0.025	13

[a] 'AIC$_c$ w_i' is the Aikaike Information Criterion with correction for small sample size model weight.

[b] 'ML' is the model likelihood.

[c] 'K' is the number of parameters in each model.

[d] 'S1,S23,S4' different estimates of habitat use between the five seasons except the early-winter 2013 and winter 2014 seasons.

[e] 'Sex' is the difference between ewe-like and ram groups.

Table A5.6. Caribou table of habitat use model results. All models with AIC$_c$ w_i ≥ 0.01 were included in the model results. Reference Table A4.1 for variable definitions.

Model	**AIC$_c$**	**ΔAIC$_c$**	**AIC$_c$ w_i**[a]	**ML**[b]	**K**[c]
ψ(S234[d]+Elevation+Slope+Forb+Dshrub) p(.)	776.361	0.000	0.357	1.000	7
ψ(S234+Elevation+Slope+Lichen+Forb+Dshrub) p(.)	776.544	0.184	0.326	0.912	8
ψ(S234+Elevation+Slope+Forb) p(.)	778.890	2.529	0.101	0.282	6
ψ(S234+Slope+Lichen+Forb+Dshrub) p(.)	778.896	2.535	0.101	0.282	7
ψ(S234+Elevation+Slope+Lichen+Forb) p(.)	779.191	2.830	0.087	0.243	7
ψ(S234+Slope+Forb+Dshrub) p(.)	782.065	5.705	0.021	0.058	6

[a] 'AIC$_c$ w_i' is the Aikaike Information Criterion with correction for small sample size model weight.

[b] 'ML' is the model likelihood.

[c] 'K' is the number of parameters in each model.

[d] 'S234' denotes habitat use is the same from the early-winter 2013 through spring/early-summer 2014 seasons.

Table A5.7. Wolverine table of habitat use model results. All models with AIC$_c$ $w_i \geq 0.01$ were included in the model results. Reference Table A4.1 for variable definitions.

Model	AIC$_c$	ΔAIC$_c$	AIC$_c$ w_i[a]	ML[b]	K[c]
ψ(S234[d]+Snow) p(Trail)	151.511	0.000	0.132	1.000	5
ψ(S234) p(Trail+View)	152.073	0.562	0.100	0.755	5
ψ(S234+Forb) p(Trail)	152.281	0.770	0.090	0.680	5
ψ(S234) p(Trail)	152.453	0.943	0.082	0.624	4
ψ(Snow+Forb) p(Trail)	152.502	0.992	0.080	0.609	5
ψ(Forb) p(Trail)	152.606	1.096	0.076	0.578	4
ψ(.)p(Trail+View)	152.963	1.453	0.064	0.484	4
ψ(Snow) p(Trail+View)	153.011	1.501	0.062	0.472	5
ψ(Forb) p(Trail+View)	153.223	1.713	0.056	0.425	5
ψ(.) p(Trail)	153.231	1.721	0.056	0.423	3
ψ(Snow) p(Trail)	153.719	2.209	0.044	0.331	4
ψ(S234+Site) p(Trail)	154.379	2.868	0.031	0.238	5
ψ(Site+Snow) p(Trail)	154.399	2.888	0.031	0.236	5
ψ(Site+Forb) p(Trail)	154.459	2.948	0.030	0.229	5
ψ(Site) p(Trail)	154.949	3.439	0.024	0.179	4
ψ(Site) p(Trail+View)	155.004	3.494	0.023	0.174	5

[a] 'AIC$_c$ w_i' is the Aikaike Information Criterion with correction for small sample size model weight.

[b] 'ML' is the model likelihood.

[c] 'K' is the number of parameters in each model.

[d] 'S234' denotes habitat use is the same from the early-winter 2013 through spring/early-summer 2014 seasons.

Table A5.8. Red fox table of habitat use model results. All models with AIC$_c$ $w_i \geq 0.01$ were included in the model results. Reference Table A4.1 for variable definitions.

Model	AIC$_c$	ΔAIC$_c$	AIC$_c$ w_i [a]	ML[b]	K[c]
ψ(S23[d]+Psi Snow) p(Site+Trail+View)	356.334	0.000	0.163	1.000	7
ψ(S23+Psi Snow) p(Site+Trail)	357.121	0.786	0.110	0.675	6
ψ(S23+Site+Psi Snow) p(Site+Trail+View)	357.325	0.991	0.099	0.609	8
ψ(.) p(Site+Trail+View)	357.411	1.077	0.095	0.584	5
ψ(.) p(Site+Trail)	358.146	1.811	0.066	0.404	4
ψ(S23+Psi Snow) p(Site+View)	358.168	1.834	0.065	0.400	6
ψ(S23) p(Site+Trail+View)	358.514	2.180	0.055	0.336	6
ψ(Snow) p(Site+Trail+View)	359.367	3.033	0.036	0.220	6
ψ(S23) p(Site+Trail)	359.467	3.133	0.034	0.209	5
ψ(S23+Site+Snow) p(Trail+View)	359.532	3.198	0.033	0.202	7
ψ(S23+Site+Snow) p(View)	359.802	3.468	0.029	0.177	6
ψ(Snow) p(Site+Trail)	359.992	3.658	0.026	0.161	5
ψ(.) p(Site+View)	360.198	3.864	0.024	0.145	4
ψ(Site) p(Trail+View)	360.481	4.147	0.020	0.126	5
ψ(S23+Snow) p(View)	361.083	4.749	0.015	0.093	5
ψ(S23) p(Site+View)	361.263	4.929	0.014	0.085	5
ψ(Site) p(View)	361.580	5.246	0.012	0.073	4
ψ(S23+Site+Psi Snow) p(Trail)	361.631	5.297	0.012	0.071	6
ψ(S23+Psi Snow) p(Trail+View)	361.783	5.449	0.011	0.066	6
ψ(S23+Site) p(Trail+View)	361.814	5.480	0.011	0.065	6

[a] ‘AIC$_c$ w_i’ is the Aikaike Information Criterion with correction for small sample size model weight.

[b] ‘ML’ is the model likelihood.

[c] ‘K’ is the number of parameters in each model.

[d] ‘S23’ denotes that habitat use is the same during the early-winter 2013 and winter 2014 seasons.

Table A5.9. Gray wolf table of habitat use model results. All models with AIC$_c$ $w_i \geq 0.01$ were included in the model results. Reference Table A4.1 for variable definitions.

Model	**AIC$_c$**	**ΔAIC$_c$**	**AIC$_c$ w_i**[a]	**ML**[b]	**K**[c]
ψ(S23[d]+Shrub) p(Trail)	199.816	0.000	0.578	1.000	5
ψ(S23+Shrub) p(.)	202.565	2.749	0.146	0.253	4
ψ(S23) p(Trail)	203.178	3.361	0.108	0.186	4
ψ(S23) p(.)	204.533	4.716	0.055	0.095	3
ψ(Shrub) p(Trail)	204.670	4.854	0.051	0.088	4
ψ(.) p(Trail)	206.064	6.247	0.025	0.044	3
ψ(Shrub) p(.)	206.308	6.491	0.023	0.039	3
ψ(.) p(.)	207.151	7.334	0.015	0.026	2

[a] 'AIC$_c$ w_i' is the Aikaike Information Criterion with correction for small sample size model weight.

[b] 'ML' is the model likelihood.

[c] 'K' is the number of parameters in each model.

[d] 'S23' denotes that habitat use is the same during the early-winter 2013 and winter 2014 seasons.

Table A5.10. Grizzly bear table of habitat use model results. All models with AIC$_c$ $w_i \geq 0.01$ were included in the model results. Reference Table A4.1 for variable definitions.

Model	AIC$_c$	ΔAIC$_c$	AIC$_c$ w_i [a]	ML [b]	K [c]
ψ(Slope+Forb) p(Trail)	207.022	0.000	0.448	1.000	5
ψ(Slope) p(Trail)	207.892	0.870	0.290	0.647	4
ψ(Slope+Forb) p(.)	209.254	2.232	0.147	0.328	4
ψ(.) p(Trail)	211.781	4.759	0.042	0.093	3
ψ(Slope) p(.)	213.104	6.081	0.021	0.048	3
ψ(Forb) p(Trail)	213.308	6.286	0.019	0.043	4
ψ(Forb) p(.)	213.659	6.637	0.016	0.036	3
ψ(.) p(.)	213.685	6.663	0.016	0.036	2

[a] 'AIC$_c$ w_i' is the Aikaike Information Criterion with correction for small sample size model weight.

[b] 'ML' is the model likelihood.

[c] 'K' is the number of parameters in each model.

APPENDIX VI

TWO-SPECIES OCCUPANCY MODEL RESULTS

Table A6.1. Wolf-caribou two-species table of model results for habitat use (ψ), detection probabilities (p), and detection conditional on the presence or absence of the other species (r). Wolf was considered the dominate species (A) and caribou the subordinate species (B). All models with $\mathrm{AIC_c}\ w_i \geq 0.01$ were included in the model results. For definitions of model parameters see Table 2.5.

Model	**$\mathrm{AIC_c}$**	**$\Delta\mathrm{AIC_c}$**	**$\mathrm{AIC_c}\ w_i$** [a]	**ML**[b]	**K**[c]
ψA(.) ψBA(.) ψBa(.) pA(.) rA(.) pB(.) rBA(.)=rBa(.)	997.059	0.000	0.197	1.000	7
ψA(.) ψBA(.) ψBa(.) pA(.) pB(.) rA(.) rBA(.) rBa(.)}	997.111	0.051	0.192	0.975	8
ψA(.) ψBA(.)=ψBa(.) pA(.) pB(.) rA(.) rBA(.) rBa(.)}	997.124	0.065	0.190	0.968	7
ψA(Shrub[d]) ψBA(.)=ψBa(.) pA(.) pB(.) rA(.) rBA(.) rBa(.)	997.782	0.722	0.137	0.697	8
ψA(.) ψBA(.)=ψBa(.) pA(.)=rA(.) pB(.) rBA(.)=rBa(.)	998.162	1.103	0.113	0.576	5
ψA(.) ψBA(.)=ψBa(.) pA(.)=rA(.) pB(.) rBA(.) rBa(.)	998.286	1.226	0.106	0.542	6
ψA(Shrub) ψBA(.) ψBa(.) pA(.) pB(.) rA(.) rBA(.) rBa(.)	999.281	2.222	0.065	0.329	9

[a] '$\mathrm{AIC_c}\ w_i$' is the Aikaike Information Criterion with correction for small sample size model weight.

[b] 'ML' is the model likelihood.

[c] 'K' is the number of parameters in each model.

[d] 'Shrub' is the estimated percent cover of shrub species at a camera site.

Table A6.2. Wolf-sheep two-species table of model results for habitat use (ψ), detection probabilities (p), and detection conditional on the presence or absence of the other species (r). Wolf was considered the dominate species (A) and sheep the subordinate species (B). All models with AIC$_c$ $w_i \geq 0.01$ were included in the model results. For definitions of model parameters see Table 2.5.

Model	**AIC$_c$**	**ΔAIC$_c$**	**AIC$_c$ w_i**[a]	**ML**[b]	**K**[c]
ψA(S23[d]) ψBA(Slope[e])=ψBa(Slope) pA(Trail[f]) rA(Trail) pB(Trail) rBA(Trail) rBa(Trail)	1056.770	0.000	0.512	1.000	11
ψA(S23) ψBA(Slope+S234[g])=ψBa(Slope+S234) pA(Trail) rA(Trail) pB(Trail) rBA(Trail) rBa(Trail)	1058.506	1.736	0.215	0.420	12
ψA(S23) ψBA(Slope) ψBa(Slope+S234) pA(Trail) rA(Trail) pB(Trail) rBA(Trail) rBa(Trail)	1060.343	3.574	0.086	0.168	13
ψA(S23) ψBA(Slope+S234) ψBa(Slope) pA(Trail) rA(Trail) pB(Trail) rBA(Trail) rBa(Trail)	1060.875	4.105	0.066	0.128	13
ψA(S23) ψBA(Slope+S234) ψBa(Slope+S234) pA(Trail) rA(Trail) pB(Trail) rBA(Trail) rBa(Trail)	1062.211	5.442	0.034	0.066	14
ψA(S23) ψBA(Slope)=ψBa(Slope) pA(.) rA(.) pA(.) rA(.) pB(Trail) rBA(Trail) rBa(Trail)	1062.466	5.696	0.030	0.058	10
ψA(S23) ψBA(S234+Slope)=ψBa(S234+Slope) pA(.) rA(.) pB(Trail) rBA(Trail) rBa(Trail)	1064.274	7.505	0.012	0.024	11
ψA(.) ψBA(Slope)=ψBa(Slope) pA(Trail) rA(Trail) pB(Trail) rBA(Trail) rBa(Trail)	1064.275	7.505	0.012	0.024	10

[a] 'AIC$_c$ w_i' is the Aikaike Information Criterion with correction for small sample size model weight.

[b] 'ML' is the model likelihood.

[c] 'K' is the number of parameters in each model.

[d] 'S23' denotes that habitat use is the same during the early-winter 2013 and winter 2014 seasons.

[e] 'Slope' is the average percent slope grade in a 500 meter radius around each camera location.

[f] 'Trail' denotes if the camera was on a wildlife trail or not on a trail.

[g] 'S234' denotes habitat use is the same from the early-winter 2013 through spring/early-summer 2014 seasons.

Table A6.3. Grizzly bear-squirrel two-species table of model results for habitat use (ψ), detection probabilities (p), and detection conditional on the presence or absence of the other species (r). Grizzly bear was considered the dominate species (A) and squirrel the subordinate species (B). All models with AIC$_c$ w_i ≥ 0.01 were included in the model results. For definitions of model parameters see Table 2.5.

Model	**AIC$_c$**	**ΔAIC$_c$**	**AIC$_c$ w_i** [a]	**ML** [b]	**K** [c]
ψA(.) ψBA(.)=ψBa(.) pA(.) rA(.) pB(.) rBA(.) rBa(.)	609.702	0.000	0.645	1.000	7
ψA(.) ψBA(.)=ψBa(.) pA(.)=rA(.) pB(.)=rBA(.)=rBa(.)	613.076	3.374	0.119	0.185	4
ψA(.) ψBA(.)=ψBa(.) pA(.)=rA(.) pB(.) rBA(.)=rBa(.)	613.731	4.029	0.086	0.133	5
ψA(.) ψBA(.) ψBa(.) pA(.)=rA(.) pB(.)=rBA(.)=rBa(.)	613.839	4.137	0.082	0.126	5
ψA(.) ψBA(.)=ψBa(.) pA(.)=rA(.) pB(.) rBA(.) rBa(.)	615.910	6.208	0.029	0.045	6
ψA(.) ψBA(.) ψBa(.) pA(.)=rA(.) pB(.) rBA(.)=rBa(.)	615.913	6.211	0.029	0.045	6

[a] 'AIC$_c$ w_i' is the Aikaike Information Criterion with correction for small sample size model weight.

[b] 'ML' is the model likelihood.

[c] 'K' is the number of parameters in each model.

Table A6.4. Grizzly bear-caribou two-species table of model results for habitat use (ψ), detection probabilities (p), and detection conditional on the presence or absence of the other species (r). Grizzly bear was considered the dominate species (A) and caribou the subordinate species (B). All models with AIC$_c$ w_i ≥ 0.01 were included in the model results. For definitions of model parameters see Table 2.5.

Model	**AIC$_c$**	**ΔAIC$_c$**	**AIC$_c$ w_i** [a]	**ML**[b]	**K**[c]
ψA(.) ψBA(Slope[d]) ψBa(Slope) pA(.)=rA(.) pB(.) rBA(.)=rBa(.)	765.770	0.000	0.420	1.000	7
ψA(.) ψBA(Slope) ψBa(Slope) pA(Trail[e])=rA(Trail) pB(Trail) rBA(Trail)=rBa(Trail)	766.691	0.920	0.265	0.631	10
ψA(.) ψBA(Slope)=ψBa(Slope) pA(Trail)=rA(Trail) pB(Trail) rBA(Trail)=rBa(Trail)	767.055	1.285	0.221	0.526	8
ψA(.) ψBA(Slope) ψBa(Slope) pA(.)=rA(.) pB(Trail) rBA(Trail)=rBa(Trail)	769.301	3.530	0.072	0.171	9
ψA(.) ψBA(Slope)=ψBa(Slope) pA(.)=rA(.) pB(Trail) rBA(Trail)=rBa(Trail)	771.861	6.090	0.020	0.048	8

[a] 'AIC$_c$ w_i' is the Aikaike Information Criterion with correction for small sample size model weight.

[b] 'ML' is the model likelihood.

[c] 'K' is the number of parameters in each model.

[d] 'Slope' is the average percent slope grade in a 500 meter radius around each camera location.

[e] 'Trail' denotes if the camera was on a wildlife trail or not on a trail.

APPENDIX VII

BETA VALUES OF PREDICTION MODEL PARAMETERS

Table A7.1. Beta values for parameters in prediction model of each species. Values are in the logit scale and are presented with standard error values in parentheses. Reference Table A4.1 for covariate definitions.

		Small Herbivores			Large Herbivores			Mesopredators		Apex Predators	
Parameter	Variables	Hoary marmot	Collared pika	Arctic ground squirrel	Moose	Sheep	Caribou	Wolverine	Red fox	Gray wolf	Grizzly bear
Habitat Use (ψ)	S1[a]					1.501 (0.690)					
	S23[b]					3.351 (0.900)			-1.986 (0.934)	1.931 (0.858)	
	S234[c]				-2.186 (0.685)		-1.911 (0.509)				
	S4[d]					1.302 (0.714)					
	Site	3.340 (1.350)				3.370 (1.309)					
	S1*Site					-3.573 (1.556)					
	S23*Site					-4.064 (1.439)					
	S4*Site					-2.608 (1.667)					
	Sex					1.075 (0.364)					
	Elevation (m)	-0.011 (0.006)	-0.007 (0.003)		-0.008 (0.002)		-0.004 (0.002)				

Habitat Use (ψ)	Slope (%)		-0.081 (0.031)			0.135 (0.025)	-0.094 (0.025)				-0.139 (0.070)
	Rock	0.126 (0.070)	0.172 (0.049)								
	Lichen						-0.029 (0.021)				
	Graminoid					0.203 (0.064)					
	Forb			2.324 (1.027)			1.126 (0.326)				0.940 (1.028)
	Dwarf Shrub		0.104 (0.039)				0.066 (0.033)				
	Shrub									0.780 (0.417)	
	Distance to Escape Terrain (m)					-0.002 (0.0005)					
	Snow (cm)	-3.548 (2.156)				-0.851 (0.277)			0.692 (0.352)		
Detection (p)	Temporal	-1.865 (0.564)									
	Site	0.977 (0.895)		0.560 (0.287)	-1.573 (0.780)				-1.883 (0.712)		
	Viewshed	-0.502 (0.183)		-0.114 (0.051)					-0.119 (0.070)		
	Trail					0.929 (0.192)		2.362 (0.660)	0.875 (0.440)	1.172 (0.509)	1.116 (0.567)
	Snow (cm)		-0.462 (0.300)								
	Shrub				0.398 (0.125)						

[a] ‘S1’ denotes habitat use in the late-summer/fall 2013 season.

[b] ‘S23’ denotes the habitat use of early-winter 2013 and winter 2014 seasons.

[c] ‘S234’ denotes habitat use is the same from the early-winter 2013 through spring/early-summer 2014 seasons.

[d] ‘S4’ denotes the habitat use of spring/early-summer 2014 seasons.