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Elizabeth M. Baum  
*Brigham Young University*

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Monitoring Domestic Sheep Energy Requirements and Habitat Selection on Summer  
Mountain Range Using Low-Cost GPS Collar Technology

Elizabeth M. Baum

A thesis submitted to the faculty of  
Brigham Young University  
in partial fulfillment of the requirements for the degree of  
Master of Science

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## ABSTRACT

### Monitoring Domestic Sheep Energy Requirements and Habitat Selection on Summer Mountain Range Using Low-Cost GPS Collar Technology

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Master of Science

With the advent of global position system (GPS) collar technology, we have developed a much greater understanding of the temporal and spatial distribution of livestock and their associated grazing patterns. While significant research using GPS collars has been reported for cattle, little research is available describing collar use in understanding the behavior of domestic sheep. The purpose of our research was to evaluate the energy requirements of sheep with the use of GPS collars. To accomplish this, we adapted a low-cost i-gotU GPS tracking device that is typically designed for cattle and modified it to fit sheep. Each collar was programmed to record sheep movements within four grazing habitat types during different times of the year. Habitat types included spring pasture (SP), spring low hill habitat (SH), summer mountain habitat (MH) and winter desert habitat (DH). We divided our research into two studies: 1) to track and compare energy expenditure of domestic sheep between four habitats using collars for recording sheep movements, and 2) to model summer mountain selection by sheep using the collar derived coordinate positions and environmental variables in an RSF model process. We hypothesized that there would more energy expended while out on desert habitat in comparison to other range habitats and sheep would select for sites on summer mountain habitat that were close to water, gentle in terrain, and higher in elevation. We used sheep energy equations to determine the energy requirement. Collar derived coordinates were used to measure the horizontal distance traveled on flat terrain or vertical distances both upslope and downhill across variable terrain. Our results found that total distance traveled was not different between SP, SH and MH at 6.7, 7.1 and 6.9 km/d, respectively, however, total movement was different ( $P < 0.05$ ) on DH at 10.5 km/d. Sheep movement was greater ( $P < 0.05$ ) on slopes (altitude change in 3m between waypoints) versus flat terrain (movement between waypoints  $> 20$ m). For example, sheep spent 65% of movement on slope and 39% on flat movement for SH, 86% of movement was spent on slope and 16% on flat terrain for MH, and 89% of movement was spent on slope and 11% movement was on flat for DH. Total energy required between the four habitats was different ( $P < 0.05$ ) at 5.9, 8.6, 7.1 and 13.9 Mcal ME/d for SP, SH, MH and DH respectively. While on summer MH sheep avoided slopes and rugged terrain, but selected for sites close to water, northern facing aspects and areas higher in elevation. We found that sheep expend the most energy on DH and sheep on MH will select for gentle terrain, areas close to water, northern facing slopes, higher elevation and avoid slopes. With this insight, sheep managers can better meet energy requirements needs and understand habitat utilization of their flocks.

Keywords: Sheep, grazing habitat, habitat selection, GPS, energy

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## CHAPTER 1

### Monitoring the Energy Requirements of Sheep on Four Different Rangeland Habitats Using Low-Cost GPS Tracking Collars

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#### ABSTRACT

The movement and energy use of livestock, in particular sheep, can be used to better understand forage requirements, maintain healthy sheep herds, and promote ecological sustainability. GPS collars have been developed to monitor livestock movement, grazing patterns, and animal behavior across heterogeneous landscapes. Our research objectives are to effectively characterize the temporal and spatial movement, energy use, and distribution of sheep in relation to habitat type. To achieve this objective, we used a low-cost GPS tracking collar to record sheep movements and energy use while rotating between four different range habitat types. As sheep were moved between four different grazing habitats (spring pasture, SP; spring low hill habitat, SH; summer mountain habitat, MH and winter desert habitat, DH), environmental factors, distance traveled, vegetation intake, and stage of reproduction were used in energy equations to determine energy expenditure of sheep while out on each different range habitats. GPS derived coordinate locations were used to determine the distance traveled by sheep on flat surfaces or up and down hilly terrain. Total distance traveled was not different between SP, SH and MH at 6.7, 7.1 and 6.9 km/d respectively, but they were different ( $P<0.05$ ) from DH at 10.5 km/d. Sheep movement was greater on sloped terrain (9 km/d) than on flat surfaces (1.22 km/d;  $P<0.05$ ). Sheep spent 65% of movement on slope and 39% on flat movement for SH, 86% of movement was spent on slope and 16% on flat terrain for MH, and 89% of movement was

spent on slope and 11% movement was on flat for DH. Total energy required between the four habitats was different ( $P<0.05$ ) at 5.9, 8.6, 7.1 and 13.9 Mcal ME/d for SP, SH, MH and DH, respectively. Three iterations of the i-gotU GPS collars were created in efforts to 1) improve issues with the jostling of the GPS unit components within the collar enclosure because of excess animal wear, 2) minimize moisture condensation and dust accumulation, and 3) improve battery life. We found that sheep expended most energy on DH, which was likely due to time spent searching for available forage. We found that the most effective GPS collar configuration had a larger memory, the i-gotU 600, which decreased jostling and improved ability to intake more waypoints and improved sealing, which kept at bay the moisture and dust. Battery life did continue to be an issue and still needs further investigation. This style of collar effectively recorded sheep movements and energy measurements by creating a cost-effective collar for sheep producers to utilize in order to better understand the temporal and spatial movements of their flocks. This information can be used in future research and management by informing managers while sheep are out on different range habitats and the amount of time spent on activity (i.e. movement on slope, movement on flat) has the most profound affect on energy expended. As well as grazing sheep out on DH has a tremendous drain on the energy requirements of sheep and may require additional supplements in the last trimester of gestation to assure healthy ewes coming off desert in preparation for lambing.

## INTRODUCTION

Domestic sheep (*Ovis aries*) production is considered the oldest organized industry in the world (Aaron and Ely 2014; Chessa et al. 2009). Utilized for their meat, wool, and milk, sheep have long been favored for their multifaceted uses (Aaron and Ely 2014; Chessa et al. 2009).

Research has been conducted on maximizing the production of sheep through an improved understanding of their energy requirements (Cannas et al. 2004; Chessa et al. 2009). These requirements have been found to be significantly influenced by a number of factors including topography, weather, feed quality and reproductive stage (Cannas et al. 2004). These factors can now be taken into account when considering energy requirements with the aid of GPS tracking devices and maintenance equations (Bailey et al. 2017).

Recently, the advent and improvement of GPS tracking technology has been used to track both temporal and spatial grazing distribution and activity patterns of livestock (Anderson et al. 2012; Augustine and Derner 2013a; Bailey et al. 2017; Knight et al. 2018). Anderson et al. (2012) monitored the spatial distribution of free-ranging collared cattle to provide a greater understanding of how to better manage herds. Bailey et al. (2017) used GPS collars to evaluate cattle behavior, distribution patterns, and energy use to validate the possibilities of these findings being used in genetic selection.

Of the 5 million sheep being raised in the United states, 300,000 of those are in the state of Utah, ranking it 5<sup>th</sup> nationally (Utah Wool Growers Association 2017). Located in the Intermountain West of the United States, Utah's land is 80% rangeland that is too dry, rocky and mountainous for raising farm crops. Even in areas where cultivation is unsuitable, sheep can utilize plant biomass and convert that energy into profitable commodities (i.e. wool, milk, meat; Aaron and Ely 2014). These conditions favor a traditional system of rotating herds through different range habitats throughout the year due to the variation in climate, vegetation availability and terrain (Holechek 1983). While research has been published describing the energy requirements of sheep, the literature lacks information on the range of ewe energy expenditure as

they transition between different production stages and range (habitat) types (i.e. gestation and lactation; ecological sites).

There are three major contributors to energy expenditure in livestock: maintenance, environment, and stage of production (Cannas et al. 2004). A portion of maintenance is defined as activity spent on resting, locomotion (flat or sloped terrain) and grazing (Lachica et al. 1997). With the recent affordability of GPS tracking devices and the advances in tracking and distribution, GPS trackers are becoming more accessible to the public (Allan et al. 2013; Augustine and Derner 2013a; Karl and Sprinkle 2019). Therefore, maintenance can be closely monitored with the aid of GPS collars as it tracks the movements of livestock across a heterogenous landscape.

The second major contributor to energy expenditure is climatic conditions (i.e. wind, snow, rain) that negatively affect the homeostasis of sheep. These conditions play a major role in how metabolizable energy is used (NRC 2007). Even though the sheep are equipped with wool, wind and rain can greatly reduce the thermal regulation that wool provides for the animal (Cannas et al. 2004; Cottle and Pacheco 2017). The combined effects of cold temperatures, wind, and precipitation can increase the maintenance requirements up to three times (Cannas et al. 2004). Thus, thermal stress caused by extreme temperatures, wind and rain, negatively affects the profitability of sheep production due to increased maintenance requirements resulting in a reduction in total body weight gain and a decrease in the efficiency of feed utilization (Pluske et al. 2010).

The various reproductive stages a ewe undergoes throughout the year greatly impacts energy expenditure (ASI 1996). Early gestation takes place after breeding in the fall. As winter sets in, they enter mid to late gestation. Ranchers will then remove sheep from the desert range to begin

the lambing season. After ewes have lambed, they are placed in paddocks to allow for lamb and ewe to bond before being released out on range habitat to prevent ewes from losing lambs amongst the entire herd of ewes and lambs. During this time, ewes are beginning the early stages of lactation. After bonding time is allowed, ewes are placed out on spring lambing pastures. From the lambing pasture, ewes and lambs are moved initially to the spring low hills range for short-term grazing and then to the summer range where they remain throughout the summer. From gestation to lactation, each stage requires different amounts of energy in order to maintain homeostasis (ASI 1996; Cannas et al. 2004). For example, gestation requires greater amounts of energy towards the end of the gestational period, when the majority of foetal growth occurs in the final 60 days (Paganoni and Roberts 2018). As well as the energy requirements of lactating ewes is much higher than those of gestating ewes (Cannas et al. 2004). It becomes evident that in order to determine energy requirements of sheep, understanding the different stages of life and different habitats energy demands a ewe experiences throughout a year cycle, is imperative.

The purpose of our study was to characterize the movement of sheep and determine their energy requirements as they transition between different life stages and range habitats. To accomplish this, we equipped sheep with a GPS tracking device to monitor their movements and detect energy expenditure. We predicted their energy requirements would be different between the range habitats.

## MATERIALS AND METHODS

### *GPS collars*

The GPS collars were developed by modifying and adapting cattle collars described by Knight et al. (2018) to fit sheep. The collars were constructed using an enclosure (#BT2310 Polycase, Avon, OH, USA) attached to a 1” x 27” nylon dog collar using 73mm wide black Gorilla tape (Gorilla Glue, Inc, Cincinnati, OH, USA). An i-gotU GT-600 GPS unit (Mobile Action Technologies, New Taipei City, Taiwan) was modified by removing the back of the unit, leaving the electronic board in its case, and removing the internal battery at the battery terminals. The leads from a JST PH 2-pin 200mm male header cable (#3814 Adafruit, New York, NY, USA) were fed through a 0.5mm hole in the end of the enclosure and soldered to the leads from the GPS unit. The back of the GPS unit was then reattached. A 6600 mAh 3.7V lithium-ion battery pack (#353 Adafruit, New York, NY, USA) that has a JST PH 200mm 2-pin female header attaches to the GPS unit leads (see Fig. 1.3). The batteries were charged using a Sabrent 60 W 10 port charger (#HB-BU10, Sabrent, Los Angeles, CA, USA). The battery pack was also attached to the collar using Gorilla tape. With the GPS unit and battery attached, both were wrapped twice using 44mm duct tape (Shuretape Technologies, Avon, OH, USA; Fig. 1.2).

The GPS unit was programmed to collect waypoints every 5 minutes. At the end of the collection period the collars were removed from the ewes and the GPS unit removed from the enclosure. The data was downloaded using @Trip software (Mobile Action Technologies, New Taipei City, Taiwan) then exported as a csv file. The data file was inspected and waypoints that were out of the grazing perimeter were removed along with movement values greater than 72 m/minute (Agostinho et al. 2012). As an example of waypoint numbers, most data files had approximately 27,327 GPS waypoints recorded from each collar.

*Sheep flock*

A commercial sheep flock consisting of Rambouillet crossbreed white-face ewes (600 ewes;  $4.2 \pm 0.9$  years of age) was used as the basis for this study. Collars were attached to the ewes prior to the flock being moved to individual grazing habitat and then removed when the sampling period was complete. Sheep flocks were moved sequentially through the four different grazing habitats which included spring pasture (SP), spring low hills (SH), summer mountain habitat (MH), and winter desert habitat (DH).

### *Spring pasture*

Two weeks post-lambing the ewes and lambs were moved from the lambing pens through three pastures (SP) from mid- April to the end of May 2020 near Fountain Green, Utah, USA. The first pasture ( $39.67^\circ$ ,  $-111.643^\circ$  N,  $39.615^\circ$ ,  $-111.641^\circ$  E), consisted of 15 acres at an elevation of 1,779 m (Fig. 1.3). The second pasture ( $39.666^\circ$ ,  $-111.674^\circ$  N,  $39.662^\circ$ ,  $-111.660^\circ$  E) consisted of 61 acres at an elevation of 1,920 m (Fig. 1.3). The third pasture ( $39.666^\circ$ ,  $-111.661^\circ$  N,  $39.651^\circ$ ,  $-111.646^\circ$ ) was 80 acres at 1,880 m elevation (Fig. 1.3). The vegetation was similar between pastures and consisted predominantly of alfalfa (*Medicago sativa*), Kentucky bluegrass (*Poa pratensis*), western wheatgrass (*Pascopyrum smithii*), and bluebunch wheatgrass (*Pseudoroegneria spicata*). The climate was characterized by cool summer temperatures ( $20^\circ\text{C}$  mean air temperature) and cold winters ( $-4^\circ\text{C}$  mean air temperature) with an annual precipitation of 38 cm. Average annual temperature ranged from 15 to  $20^\circ\text{C}$  during the summer and  $-5$  to  $-3^\circ\text{C}$  during the Winter (PRISM 2004).

### *Spring low hills*

From the early spring pasture, the sheep were moved to a 3,000-acre private allotment on spring low hills habitat (SH) for June 2020 ( $39.705^\circ$ ,  $-111.590^\circ$  N,  $39.686^\circ$ ,  $-111.559^\circ$  E; Fig.1.4). Elevation ranged from 2,150 to 2,506 m with hilly terrain. Ungulates on the property



that could potentially compete with sheep included elk (*Cervus canadensis*) and mule deer (*Odocoileus hemionus*). Vegetation included bluebunch wheatgrass, Indian ricegrass (*Achnatherum hymenoides*), antelope bitterbrush (*Purshia tridentata*), Wyoming big sagebrush (*Artemisia tridentata ssp wyomingensis*), Utah juniper (*Juniperus osteosperma*), and two-needle pinyon (*Pinus edulis*). The climate was characterized by cool summer temperature (15°C mean air temperature) and cold winter temperature (-4°C mean air temperature) with annual precipitation of 53 cm. Average annual temperature ranged from 13 to 18°C during the summer and -4 to -2°C during the winter (PRISM 2004).

#### *Summer mountain habitat*

From July to September 2020 the sheep were moved to mountain habitat (MH) near Scofield Reservoir (39.91°, -111.16° N, 39.88°, -111.12° E; Utah County, UT, USA) on 2,500 acres (Fig. 1.5). Elevation ranged from 2,191 to 2,550m with open meadows climbing to mountain ridges. Ungulates on the property that could potentially compete with sheep included elk and mule deer. Vegetation included quaking aspen (*Populus tremuloides*), subalpine fir (*Abies lasiocarpa*), gambel oak (*Quercus gambelii*), Wyoming big sagebrush, Utah serviceberry (*Amelanchier utahensis*), bluebunch wheatgrass, timothy grass (*Phleum pratense*) and broom snakeweed (*Gutierrezia sarothrae*) found in the open meadows. The climate was characterized by cool summer temperatures (15°C mean air temperature) and cold winters (-5°C mean air temperature) with annual precipitation of 50 cm. Average annual temperature ranged from 43 to 70°C during the summer and -11 to 1°C during the winter (PRISM 2004).

#### *Winter desert habitat*

From late December to late February 2020-2021, the sheep were grazing on BLM winter desert habitat (DH) located in the western desert of Utah (39.62°, -113.41° N, 39.45°, -113.33°

E) covering approximately 35,000 acres (Fig. 1.5). Elevation ranged from 1,400 to 1,700 m with open hilly terrain. Vegetation included, Indian ricegrass, squirreltail (*Elymus elymoides*), bud sagebrush (*Picrothamnus desertorum*), shadscale saltbush (*Atriplex confertifolia*), broom snakeweed, winterfat (*Krascheninnikovia lanata*), black sagebrush (*Artemisia nova*), and Utah juniper dotting the landscape. The climate was characterized by warm summers (24°C mean air temperature) and cold winters (-1°C mean air temperature). Average annual temperature ranged from 19 to 24°C during the summer and -1 to 1°C during the winter with annual precipitation of 22 cm (PRISM 2004).

#### *Energy determination*

The energy requirement of the sheep was calculated based on the environmental factors, habitat type, and lifestage. A weather station (Davis 6152C) was placed on each of the habitats to provide temperature, wind, and rain environmental measurements in order to calculate cold stress factors. Energy requirement was determined using equations from NRC (2007), Cannas et al. (2004) and Tedeschi and Fox (2020a and 2020b).

#### *Equation 1*

$$ME_m = ([SBW^{0.75} * a1 * S * a2 * \exp(-0.03 * AGE)] + (0.09 * MEI * k_m) + ACT + NE_{msc} + UREA) / k_m$$

Where,

SBW = shrunk body weight (96% of body weight (FBW; kg))

$$a1 = 0.062 \text{ Mcal} * NE_m / \text{kg}^{0.75}$$

S = multiplier for gender; 1 for ewes and wethers, 1.15 for rams

$$a2 = \text{effects of previous months temperature; } 1 + 0.09 * (20 - (\text{previous month temperature}))$$

AGE = years 1 to 6

MEI = ME intake; Mcal/d

$k_m$  = efficiency constant; 0.644

### Equation 2

ACT = activity;  $(0.00062 * FBW * \text{flat distance (km)} + 0.00669 * FBW * \text{slope distance (km)})$

### Equation 3

$NE_{msc}$  = cold stress,  $SA * (LCT - \text{Current Temp}) * k_m / IN$

$$SA = 0.09 * SBW^{0.75}$$

$$LCT = 39 + E * EI - IN * HE / SA$$

$$HE = MEI - (RE + NE_{pr} + NE_{lr})$$

$$IN = TI (1 - 0.3 * (1 - \exp(-1.5 * rf / WD))) * EI$$

$$EI = [(1.759 - 0.0707 * \text{wind (km/hr)} + 0.6095 * \text{wool (cm)}) * MUD * \text{hide}] * 0.239.$$

Urea = cost of excreting N as urea;  $[(g \text{ ruminal N balance} - g \text{ recycled N} + g \text{ excess N from MP})$

$$* 0.0073] * k_m$$

### Equation 4

$$NE_{preg} = 36.9644 * \exp[-11.465 * \exp(-0.00643 * t) - 0.00643 - t] * (LBW/4)$$

Where,

LBW = birth weight of lambs combined

$$ME_{\text{preg}} = NE_{\text{preg}} / 0.13$$

*Equation 5*

$$NE_1 = [(251.73 + 89.64 * MF + 37.85 * (MP / 0.95) * 0.001 * MY] / k_m$$

Where,

MF = milk fat %

MP = milk protein %

MY = milk yield kg/d

*Vegetation sampling*

Vegetation samples were taken at every site to determine nutrient content. 100m transects were randomly placed throughout the habitat sites. A 1-square meter hoop was placed every 10 meters along the transect, alternating sides, and all vegetation within the hoop was clipped and placed into paper bags, stored in a freezer until all samples were collected. The number of transects per site was determined by area of habitat and vegetation type present. All vegetation samples were taken out of freezer and separated by site and type (i.e., forb, grass, shrub) and sent to DairyOne forage laboratory for a wet chemistry nutrient analysis for dry matter (DM), crude protein (CP), acid detergent fiber (ADF), neutral detergent fiber (NDF), and metabolizable energy (ME) content analysis (DairyOne Forage Laboratory, Ithaca, NY, USA).

### *Data analysis*

Latitude and longitude data were converted to UTM coordinates. UTM coordinates were then used to calculate distance traveled (m) between waypoints. GPS altitude differences were used to determine slope movement. Slope movement was counted as any increase or decrease of 3 m or more. The distance traveled on flat surfaces compared to sloped terrain was used to calculate activity (ACT; see equation 2). Energy requirement was determined for each ewe using the information collected. For each habitat, total energy required was calculated as the sum of  $NE_m$ ,  $NE_{preg}$  and  $NE_l$ . Each habitat energy requirement was the addition of these three NE amounts depending on the life stage of the ewes while on each habitat; SP  $NE_m + NE_l$ , SH  $NE_m + NE_l$ , MH  $NE_m + NE_l$  and DH  $NE_m + NE_{preg}$ .

Statistical analysis was conducted with the proc Mixed module in SAS (2002). Fixed main effects included habitat and day, while animal was random to account for repeated measures. Least square means for habitat were determined to be significant at  $P < 0.05$ . Habitat main effect comparisons were analyzed and expressed as least square means.

## RESULTS

### *Collar Data Collection*

Collars placed on ewes on the SP and SH habitats resulted in two of the 6 collars not collecting data, one did not record any data and the other recorded 6 days. The units where data was downloaded ranged from 30 to 49 days of GPS waypoints. Average time difference between the waypoints was  $5.0 \pm 2.7$  minutes. Five of the six units deployed on the SH provided data. One

unit did not collect waypoints. Twenty-seven to sixty-seven days of waypoints were collected from the five collars. Average time difference for waypoints for SH was  $9.3 \pm 6.8$  minutes. Because the percentage of collars deployed to provide data was less than desirable for SP, SH and MH, ten collars were deployed on the DH, of which, data was downloaded from nine collars. The tenth collar did collect waypoints, but the battery power ran out on day 3. Waypoints were collected between thirty-seven and fifty-nine days. The average time difference between waypoints for DH was  $8.7 \pm 4.5$  minutes.

### *Forage Measurements*

Habitat forage samples are presented in Table 1.1. Forage types from each site were combined to provide grass, forbs and browse values. SP habitat contained majority of grasses such as Kentucky bluegrass mixed with few forbs. SH habitat was located on uncultivated higher hilly country containing bluebunch wheatgrass, Indian ricegrass, antelope bitterbrush and Wyoming big sagebrush MH contained stands of mix forested fir trees, maples, and aspen stands, with meadows of slender wheatgrass (*Elymus trachycaulus*), saline wildrye, timothy grass, broom snakeweed, and mountain sagebrush. DH vegetation included, Indian ricegrass, squirreltail, bud sagebrush, shadscale saltbush broom snakeweed, winterfat, and black sagebrush. Percent of each forage type consumed came from Taylor Jr (1994) for each habitat. The total ME consumed was based on the percentage of forage type multiplied by the ME of each type.

### *Movement, Distribution, and Energy Use*

GPS files were downloaded were waypoints were divided into 24-hr periods. Latitude and longitude values were converted to Universal Transverse Mercator (UTM). Distance traveled between waypoints was determined using the UTM. The total movement was calculated and divided into slope or flat movement totals based on altimeter values. For each day, the Mcal ME

was determined using values found in Table 1.2. The total ME was calculated with the addition of net energy of gestation ( $NE_{gest}$ ) and net energy of lactation ( $NE_l$ ) to maintenance ( $NE_m$ ). Weight and flock average age were provided by the owner of the flock. Environmental values were collected from the weather station that was placed at each habitat site. Milk values are table values from the NRC (2007).

Spring pasture (SP) sheep movement collected by the GPS collars is presented in Table 1.3. Since SP was flat, slope movement was not determined. There were differences ( $P<0.05$ ) between the three SP pastures for total movement and ME. Between the three pastures, there were differences ( $P<0.05$ ), where the 15-acre (P1) was 4.85 km, the 61-acre (P2) was 7.09 km and the 80-acre was 12.02 km (P3; Table 1.3). Maintenance Mcal/d was different ( $P<0.05$ ) at 5.09, 5.23 and 5.54 for P1, P2 and P3 respectively. Adding  $NE_l$  to  $NE_m$  total ME was different ( $P<0.05$ ) at 5.77, 5.90 and 6.22 Mcal/d.

Comparing the four habitats, DH total movement was different ( $P<0.05$ ) from the other three, with no other difference noted among the other habitat sites. Personal observation by the herder, and corroborated by the data, the first four days the sheep were on DH, they moved more (between 2.5 and 3 km) than the rest of the time on the habitat. Slope movement was different ( $P<0.05$ ) across the four habitats with SP at 0.0 because the habitat was flat (Table 1.4). Flat movement was highest at 6.7 km/d ( $P<0.05$ ) on SP compared to 2.8 km/d for SH and both different from MH and DH at 1.1 and 1.2 km/d, respectively. Percent of movement up and down slopes was different ( $P<0.05$ ) across all treatments, ranging from 0.0 for SP to 88.7% for DH. Flat percent was inverse to slope %.

The ACT value ranged from 0.27 to 4.5 Mcal ME/d with all habitats being different ( $P<0.05$ ; Table 1.3). Metabolizable energy was different ( $P<0.05$ ) between the treatments, ranging from

5.2 for SP to 13.6 Mcal ME/d for DH. Adding gestation or lactation NE increased ( $P<0.05$ ) the total ME/d requirement for SP at 5.9 and DH at 13.9 Mcal ME/d, SH was 8.6 and MH at 7.1 Mcal ME/d.

## DISCUSSION

We found the amount of time sheep spent moving across rangelands took a large toll on the amount of energy expended between each range habitat. While there has been research observing the activity and movement patterns of sheep, little research exists documenting differences in activity patterns across multiple diverse rangeland habitats during different seasons (Clapperton 1964a; Squires 1974; Warren and Mysterud 1991). Squires (1974), documented sheep distribution in Australia where temperatures ranged from 32-38°C, sheep averaged 14 to 18 km/d on hot summer range habitat. We found our sheep moved between 7 to 11 km/d on summer habitat where temperatures were not so severe. This could be due to the fact sheep in Australia spent more time walking to water sources to stay hydrated. SP had relatively flat ground with 0% of movement spent on slopes, there was an increase in movement as sheep were transferred to increasingly larger pastures (Fig. 1.3). We concluded the increase in movement was correlated to increase in size of pasture. This has also been observed in a study by Clapperton (1964b) where sheep kept in larger pastures moved greater distances than sheep in smaller pastures. P3 showed the greatest amount of movement (12.02 km) and was also the largest pasture. We also observed this on DH where the greatest total movement between range habitats took place on the largest allotment (35,000 acres). Though the pastures were similar in forage make-up, P3 biomass was less in comparison to P1 and P2, therefore possibly causing sheep to continuously moving for



forage consumption. These factors all could have contributed to the greatest movement occurring on P3 before they were taken up to SH. The total ACT of SP (0.27) accounted for only 5% of the total metabolizable energy expended. We attribute this to the easy terrain and readily available grasses and forbs. Sheep on the SP therefore did not need to as much time searching for forage and terrain allowed for easy movement.

SH, MH, and DH contained minimal movement on flat but majority of movement on slopes. Lachica et al. (1997) found net energy cost of slope movement is higher than for movement on flat terrain due to energy expended to work against gravity. This is congruent with our findings that all habitats that contained higher percentages of slope movement, required more energy to be expended (Table 1.4). A study conducted on mountain winter range in New Mexico found that sheep utilized slopes less than 45°, and slopes 50-75° decreased the utilization further (McDaniel and Tiedeman 1981). This is important to note that sheep will utilize slopes less when slope steepness increases. Though SH and MH had sloped terrain and steeper mountain sides when compared to the topography of DH, metabolizable energy was less on SH and MH in comparison to that of DH due to more slope movement taking place on DH. During mid to late summer while sheep were on SH and MH, forage was abundant and readily available, therefore sheep spent less time moving in search of food. Whereas sheep on DH, when snow was present, had to spend more time foraging to meet energy requirements needs and therefore possible utilizing unfavorable terrain in search of forage to meet energy requirement intake moving 10.5 km/d.

We found that movement on slope profoundly affected the amount of energy expended between range habitats. McDaniel and Tiedeman (1981) also showed sheep utilized sites located on tops of ridges. A similar observation was made in a study by Bowns (1971) who observed

range sheep in Northern Utah preferred to utilize higher elevation sites for safer bedding grounds and sought valley bottoms to graze during the day. In the forests of Norway, Warren and Mysterud (1991) reported sheep moving uphill at night for resting and predator protection. We found sheep utilized slopes on all habitats that contained hilly terrain. As slope movement increased, the total metabolizable energy also increased (Table 1.4). SP contained 0 % slope movement and required only 5.9 Mcal/d in comparison to SH, MH, which showed no difference in total movement from SP, but did show a difference in increased slope movement which resulted in higher metabolizable energy expended in both habitats (Table 1.4). This was also observed in our results as the energy expended on slopes was the greatest on DH and resulted in highest total metabolizable energy being expended on DH (13.87 Mcal/d). The difference between the readily available grass on SP to the sparse DH vegetation resulted in the sheep moving approximately 4 km/d more. The increase in movement on DH was movement up and down hilly terrain. The Mcal ME associated with DH slope movement accounts for 88.4% of the ACT ME, with ACT NE accounting for 33% of total ME required per day. Whereas the ACT for SP accounted for 5% of total daily ME required. Comparing the four habitats and knowing the impact slope movement has on energy requirement, SP would have the lower requirement even though the ewe's lactation requirement was included. Spring low hill and MH, on a percentage, have more inclines requiring the sheep to move up and down the terrain even with more readily available forage present. This in comparison to sheep on DH spending more time in search of vegetation across hilly terrain and therefore expended more energy.

From previous research we were able to adapt existing GPS units used in cattle research to create a low-cost GPS tracker for sheep movement. instead of cattle. Augustine and Derner (2013b) studied grazing patterns in cattle by combining Lotek 3300LR GPS collars with activity

sensors that recorded up and down and side-to-side movements of the head, to classify if the animal is grazing versus, traveling, bedding, or resting. They found rather than simply quantifying the distribution of cattle, they were able to examine foraging distribution. From this we can see the potential GPS collars have in improving understanding of animal behavior.

Knight et al. (2018) created a low-cost alternative to the Lotek 3300 GPS tracking collar using the i-gotU GT-120 GPS tracking collar and compared the performances of both. He discovered there was no difference for slope, location, and distance to water, but distance traveled was lower for Knight collars than for Lotek collars. Karl and Sprinkle (2019) developed a “commercial off-the-shelf (COTS) electronic components,” low-cost GPS unit and compared it to the Knight collar for accuracy. Both studies proved it possible to manufacture low-cost GPS tracking devices that best facilitate tracking more domestic animals in a herd for short durations of time. By adapting the Knight et al. (2018) i-gotU configuration to sheep we were able to track the movements of sheep across diverse landscapes to understand their energy expenditure between ranges.

## CONCLUSION AND MANAGEMENT IMPLICATION

With the use of GPS trackers, our predictions were confirmed that sheep grazing the four different habitats did affect energy requirement of the sheep. Energy requirement was greatly affected by the amount of time spent moving on hilly and sloped terrain. Activity had the greatest impact on total energy requirement between habitats. When compared to the other four habitats, SH, MH and DH had movement on slope resulting in higher amounts of Mcals/d. The total movement traveled was the greatest on DH, due to the lack of readily accessible and

palatable forage on the DH. Sheep consequently spent greater amounts of energy searching for food which possibly caused them to utilize more sloped terrain.

Due to the tremendous drain on energy requirements of the ewe while grazing on winter desert habitat in Utah, we advise additional supplements be given to sheep in their last trimester of gestation to assure healthy ewes coming off the desert and preparing for lambing and lactation. Energy supplementation is most useful under conditions of drought or heavy snow (Holechek and Herbel 1986). Due to the recent drought in the western United States, rangelands are struggling to provide enough forage for flocks and as a result, less animals have been allowed to graze. With challenging forage conditions, ewes are also challenged with energy demands imposed by the growing lamb in utero. Producers are highly advised to supplement ewes diet with grain during the last 4 weeks of gestation (ASI 1996). By offering energy supplements on DH before lambing, milk production can be maximized as well as heavier lambs born resulting in higher prices during fall lamb sale (ASI 1996).

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## FIGURES

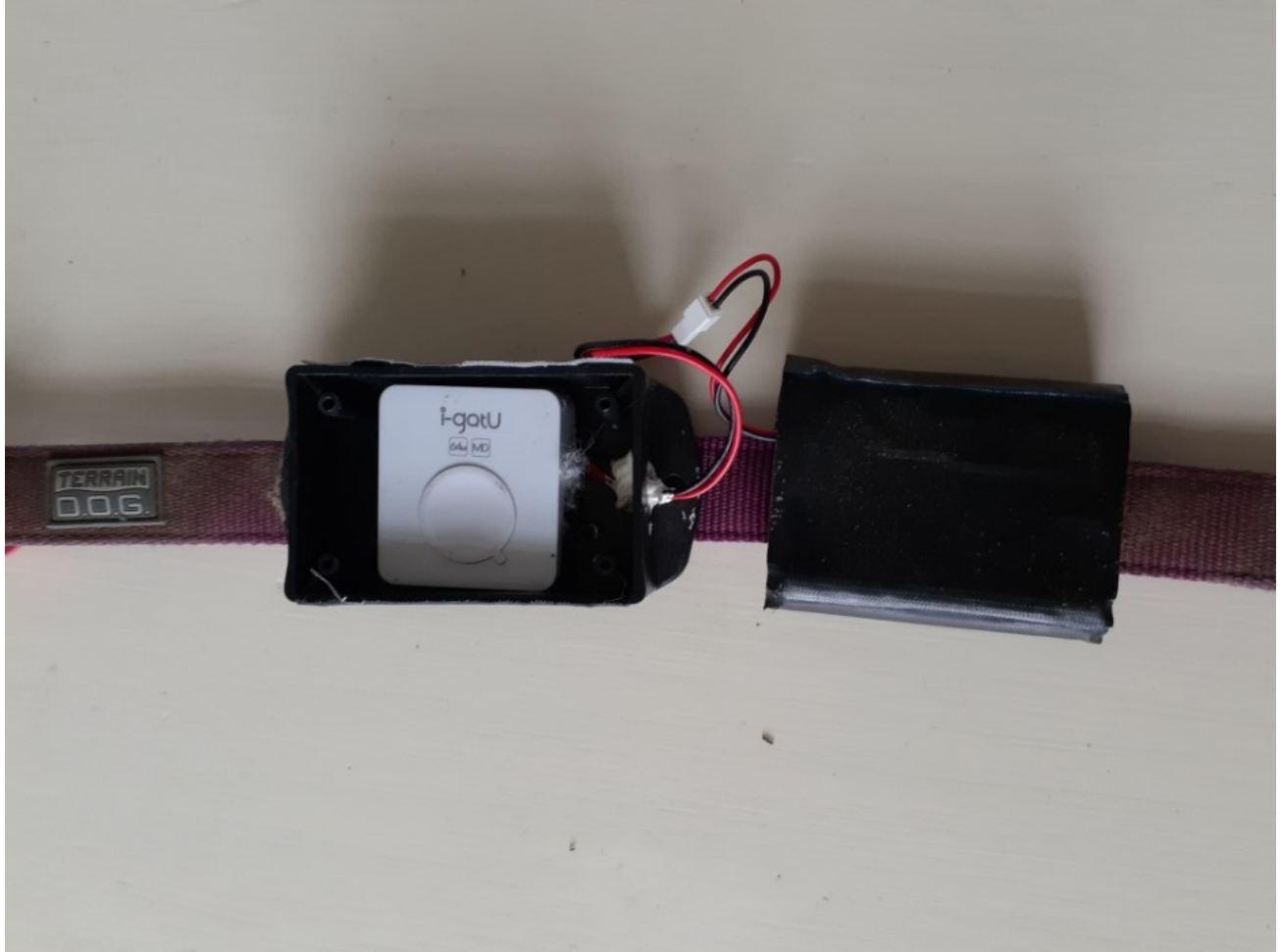


Figure 1.1 Constructed collars with i-gotU GT-600 powered by a 6600 mAh lithium battery





Figure 1.2 Spring pastures. First pasture (P1) (39.617°, -111.643° N, 39.615°, -111.641° E), second pasture (P2) (39.666°, -111.674° N, 39.662°, -111.660° E), third pasture (P3) (39.666°, -111.661° N, 39.651°, -111.646°). Pastures surround Fountain Green, UT. Cultivated land covered mostly with Kentucky bluegrass and alfalfa.

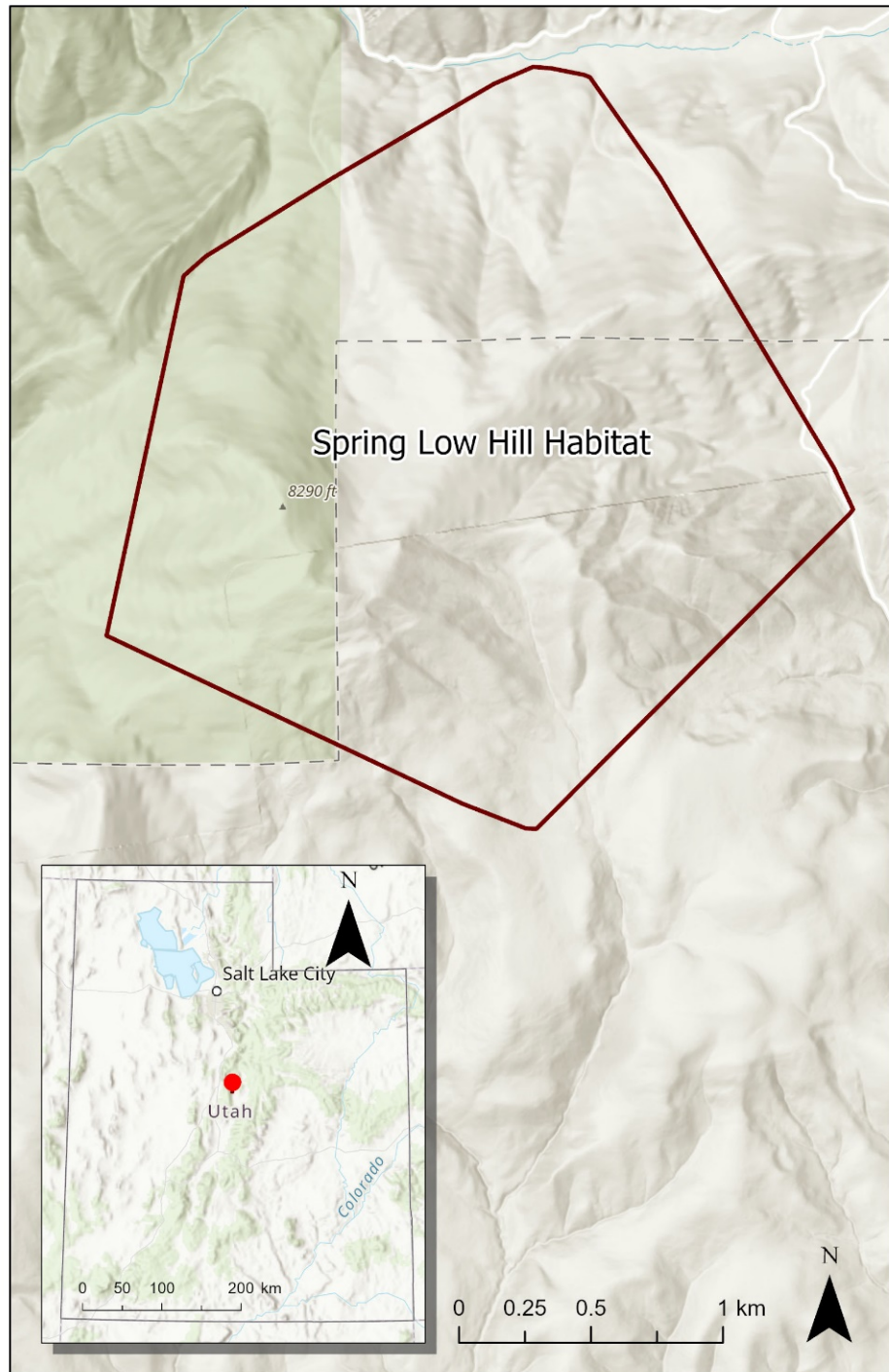


Figure 1.3 Spring low hill pastures (SH) (39.705° , -111.590° N, 39.686° , -111.559° E) located Northeast of Fountain Green, UT. Vegetation includes: scrub oak, Utah juniper, mountain big sagebrush, and indian rice grass.

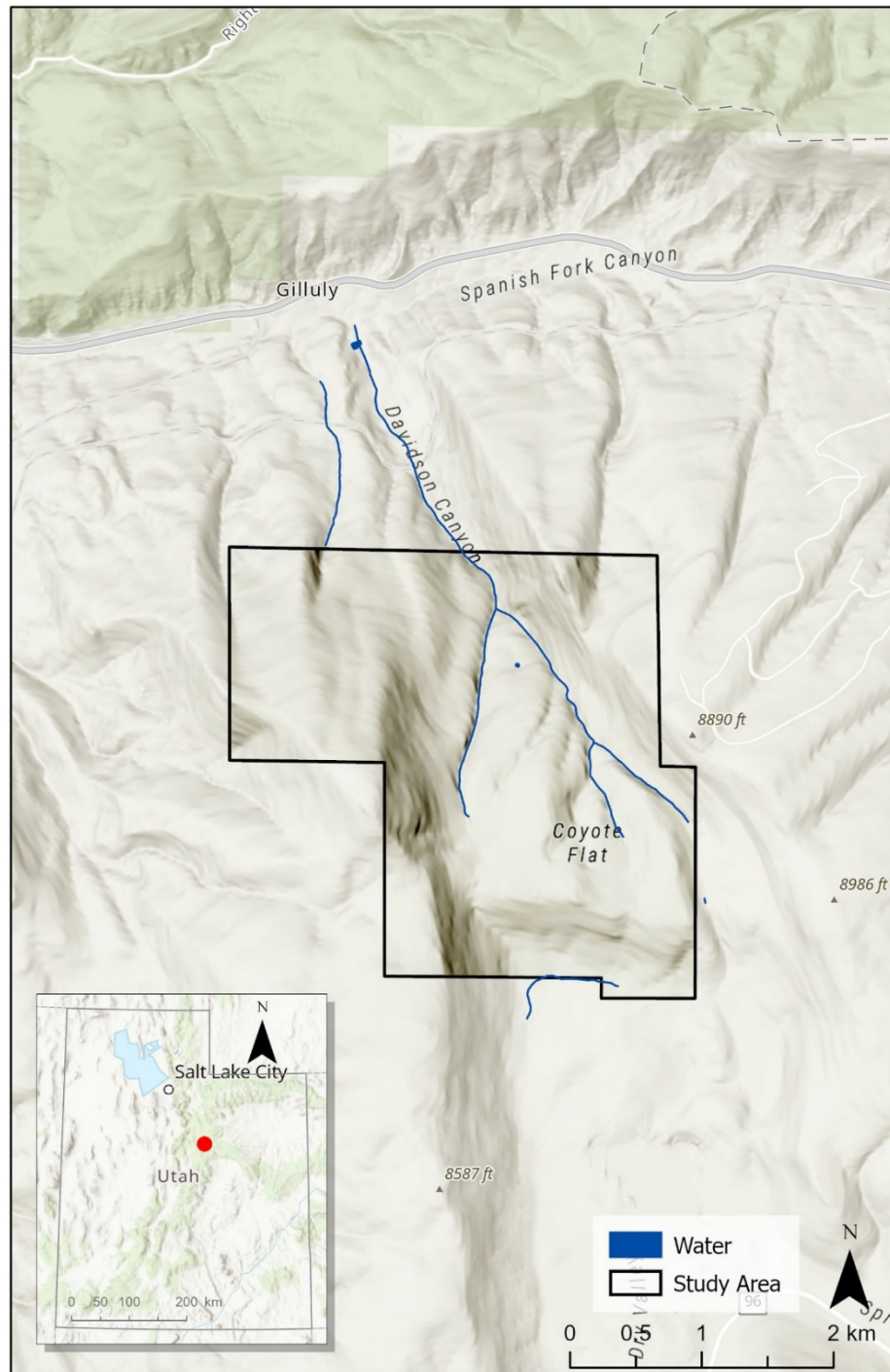


Figure 1.4 Mountain summer range (39.91°, -111.16° N, 39.88°, -111.12° E) located North of Scofield reservoir. Vegetation includes: mountain big sagebrush, aspen, gambel oak, broom snake weed, and Indian rice grass.

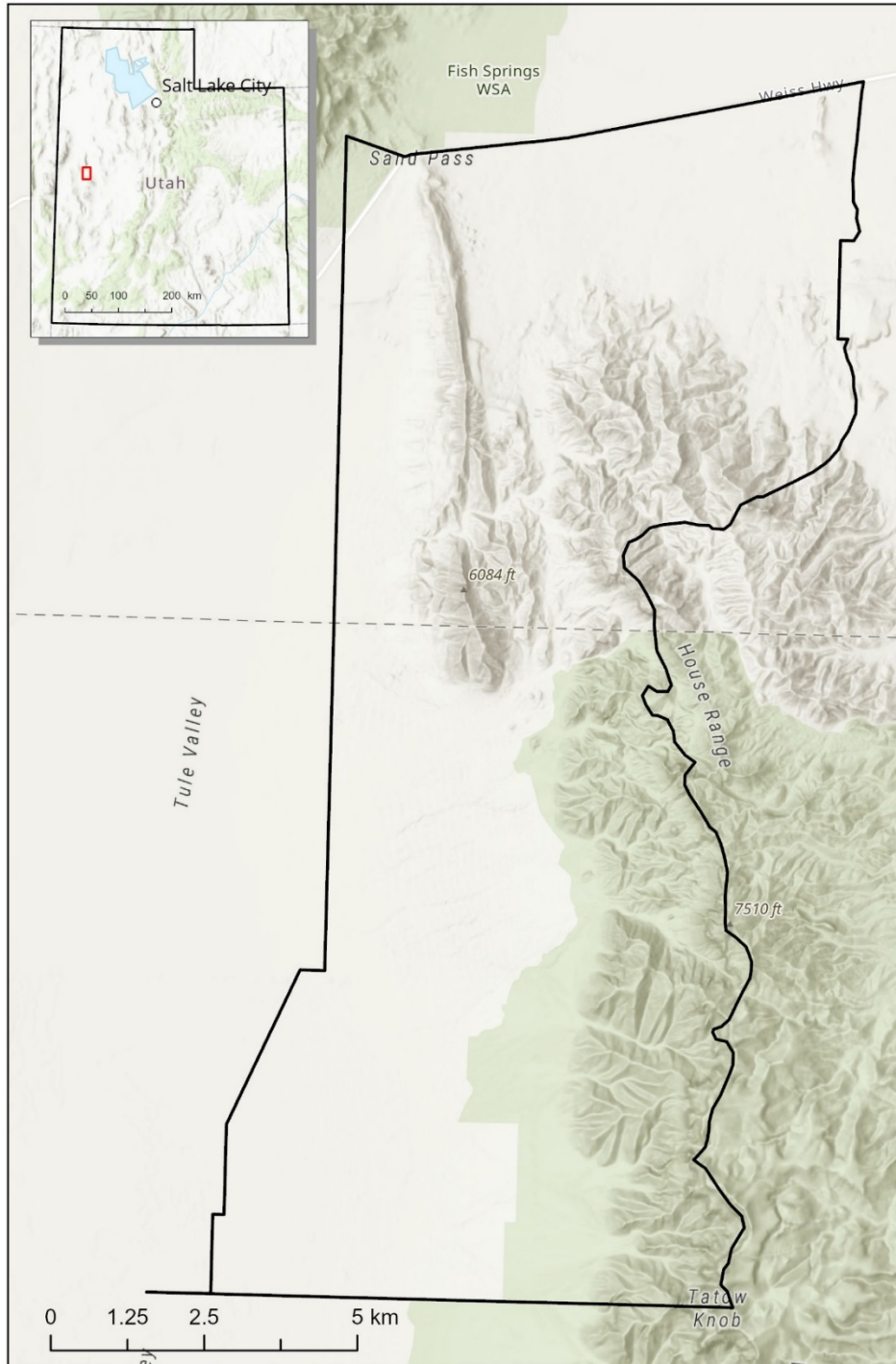


Figure 1.5 Winter Desert Range (39.62°, -113.41° N, 39.45°, -113.33° E) located in on BLM land in the West deserts of Utah. Vegetation includes: shadscale saltbush, bud sagebrush, black sagebrush, winterfat, indian ricegrass and Utah juniper.

## TABLES

Table 1.1 Forage analysis of feeds on each grazing habitat

	DM, %	CP, %	NDF, %	ADF, %	NFC, %	ME, Mcal/kg
<b>Spring pasture, SP</b>						
Grass	47.1	12.5	51.1	36.1	26.7	2.42
Forbs	47.9	24.0	27.1	20.1	38.4	2.68
<b>Spring low hills, SH</b>						
Grass	45.9	9.0	55.6	31.9	25.7	2.32
Forbs	39.3	11.3	46.9	36.7	21.4	2.23
Browse	68.3	9.9	36.9	28.5	42.7	2.33
<b>Mountain, MH</b>						
Grass	83.9	6.5	66.1	42.8	18.2	1.99
Forbs	73.5	9.6	32.5	25.7	47.5	2.39
Browse	69.8	9.9	32.3	25.2	47.4	2.40
<b>Winter desert, DH</b>						
Grass	87.1	5.4	75.0	50.1	10.5	1.88
Forbs	84.6	5.6	64.2	52.1	20.9	2.00
Browse	64.0	8.5	50.3	41.8	30.8	2.15

Table 1.2 Input values for energy equations

	Grazing Habitat <sup>a</sup>			
	SP	SH	MH	DH
Weight, kg	66	66	69	70
Age, years	4.2	4.2	4.2	4.2
ADG, g/d	40	40	40	40
Previous Temp	6	12	16	4
Current Temp	12	16	13 (9.9)	-0.6
Rain, mm	0	2	0	0.25
Wind, km/h	8.0	3.1	3.3	5.9
Wool Depth, mm	12	14	20	51
Milk yield, l/d	1.7	0.75	0.25	0.0
Milk fat, %	2.85	2.85	2.85	0.0
Milk protein, %	2.53	2.53	2.53	0.0

<sup>a</sup>Sp = spring pasture, SH = spring low hill habitat, MH = mountain habitat, DH = winter desert habitat.

Table 1.3 Movement and energy requirements of ewes on spring lambing pastures (SP) of different sizes.

	Pasture <sup>a</sup>			SEM
	P1	P2	P3	
Total movement, km	4.85 <sup>e</sup>	7.09 <sup>f</sup>	12.02 <sup>g</sup>	0.22
ACT, ME Mcal/d <sup>b</sup>	0.20 <sup>e</sup>	0.28 <sup>f</sup>	0.49 <sup>g</sup>	0.01
NE <sub>m</sub> , Mcal/d <sup>c</sup>	5.09 <sup>e</sup>	5.23 <sup>f</sup>	5.54 <sup>g</sup>	0.01
Total ME, Mcal/d <sup>d</sup>	5.77 <sup>e</sup>	5.90 <sup>f</sup>	6.22 <sup>g</sup>	0.01

<sup>a</sup>Pasture P1 = 15 acres, P2 = 61 acres, P3 = 80 acres.

<sup>b</sup>ACT= distances traveled on slopes and flat surfaces.

<sup>c</sup>NE<sub>m</sub> = ([SBW<sup>0.75</sup> \* a1 \* S \* a2 \* exp(-0.03 \* AGE)] + (0.09 \* MEI \* k<sub>m</sub>) + ACT + NE<sub>msc</sub> + UREA) / k<sub>m</sub>

<sup>d</sup>Total ME = NE<sub>m</sub> + NE<sub>l</sub>.

<sup>e</sup><sup>f</sup><sup>g</sup>Rows values with differing superscripts differ at P<0.05.

Table 1.4 Energy requirements needed for each grazing habitat.

	Grazing Habitat <sup>a</sup>				SEM
	SP	SH	MH	DH	
Total movement, km	6.66 <sup>f</sup>	7.09 <sup>f</sup>	6.89 <sup>f</sup>	10.52 <sup>g</sup>	0.19
Slope movement, km	0.00 <sup>f</sup>	4.46 <sup>g</sup>	5.91 <sup>h</sup>	9.30 <sup>i</sup>	0.14
Flat movement, km	6.66 <sup>h</sup>	2.82 <sup>g</sup>	1.12 <sup>f</sup>	1.22 <sup>f</sup>	0.14
Slope % <sup>b</sup>	0.0 <sup>f</sup>	64.7 <sup>g</sup>	85.6 <sup>h</sup>	88.7 <sup>i</sup>	0.92
Flat % <sup>b</sup>	100 <sup>i</sup>	38.7 <sup>h</sup>	16.3 <sup>g</sup>	11.3 <sup>f</sup>	1.07
ACT, ME Mcal/d <sup>c</sup>	0.27 <sup>f</sup>	2.06 <sup>g</sup>	2.76 <sup>f</sup>	4.49 <sup>i</sup>	0.07
NE <sub>m</sub> , Mcal/d <sup>d</sup>	5.20 <sup>f</sup>	7.91 <sup>h</sup>	6.92 <sup>g</sup>	13.55 <sup>i</sup>	0.11
Total ME, Mcal/d <sup>e</sup>	5.88 <sup>f</sup>	8.59 <sup>h</sup>	7.08 <sup>g</sup>	13.87 <sup>i</sup>	0.11

<sup>a</sup>Sp = spring pasture, SH = spring low hill habitat, MH = mountain habitat, DH = winter desert habitat.

<sup>b</sup>Percent of total movement on slope or flat terrain.

<sup>c</sup>ACT= distances traveled on slopes and flat surfaces

<sup>d</sup>NE<sub>m</sub> =  $([SBW^{0.75} * a1 * S * a2 * \exp(-0.03 * AGE)] + (0.09 * MEI * k_m) + ACT + NE_{msc} + UREA) / k_m$

<sup>e</sup>Total ME = NE<sub>m</sub> + NE<sub>preg</sub> + NE<sub>l</sub>.

<sup>fghi</sup>Rows values with differing superscripts differ at P<0.05.



## CHAPTER 2

### Resource Selection of Domestic Sheep on Mountainous Summer Pasture

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#### ABSTRACT

Past research has documented livestock grazing patterns and dynamics across pastoral landscapes. We used domestic sheep locations derived from coordinate positions obtained from GPS collars to study sheep habitat selection on summer mountain habitat North of Scofield Reservoir Utah, USA. Data was collection between the months of July to September, 2020. We developed a resource selection function (RSF) model to determine the influence of slope, distance to water, aspect, ruggedness, elevation, and vegetation types on sheep habitat selection while grazing on summer mountain habitat. We found sheep selected for sites closer to water, with more gentle terrain, higher in elevation and north-facing slopes. Vegetation types were less reliable due to the lack of species composition information and the possibility of sheep being herded to avoid areas of overuse. Although it is often assumed that sheep utilize slopes more than their heavier and larger cattle counterparts, they overall tended to avoid steep slopes compared to all other predictor variables. While remaining in relatively close proximity to water, seeking high elevation sites with gentle terrain and on north-facing slopes, this information regarding sheep summer grazing selection can be used to improve livestock management practices including flock management that increases sheep foraging patterns and energy efficiency.

## INTRODUCTION

Effective livestock management requires an understanding of the temporal and spatial distribution of livestock on pastoral landscapes (Liao et al. 2018). Factors that affect the distribution of livestock include both abiotic factors (i.e. slope, ruggedness, elevation, aspect, distance to water) and biotic factors (i.e. vegetation types; Bailey et al. 1996; Cook 1966; Senft et al. 1987; Squires 1974; Warren and Mysterud 1991). The selection for or against these factors can determine the temporal and spatial distribution of livestock across a heterogenous landscape. By understanding habitat selection by livestock, managers can better meet the resource needs and energy requirements of their animals.

Several studies have identified general relationships between domestic sheep (*Ovis aries*) foraging patterns and habitat characteristics (i.e. ruggedness of terrain, steepness of slope, availability of water). For instance, grazing can be influenced by both distance of vegetation from water and steepness of slope (Bailey et al. 1996; Senft et al. 1987; Squires 1974). Squires (1974) found that the highest grazing use and foraging patterns of Merino in Australia were less than 0.8km from water. Beyond this distance individual plants that remained ungrazed were significantly higher (Squires 1974). The distribution of livestock, in particular cattle, is limited by the steepness of the slope and unevenness of the terrain (Cook 1966; Mueggler 1965; Patton 1971). McDaniel and Tiedeman (1981) found sheep on mountain winter range in New Mexico, utilized slopes less than 45%, but utilization was reduced by 50-75% on steeper slopes. They discovered sheep normally utilize sites located on tops of ridges and tops of upper slopes before descending to the valley floor. Bowns (1971) found that an unherded flock of range sheep in

Northern Utah, USA preferred to bed on higher elevation terrain at night and sought valley bottoms to graze during the day. This behavior is congruent with moving and resting behavior of sheep in the coniferous forests of Norway where Warren and Mysterud (1991) reported sheep moving uphill at night for resting and sleeping on higher ground where they gain protection from predators. Abiotic factors such as slope, elevation, and distance to water have a major impact on the distribution and habitat selection of sheep.

Biotic factors, including the availability and quality of forage have been shown to affect sheep grazing distribution patterns (Bailey et al. 1996; Senft et al. 1987). Sheep are intermediate feeders which suggests they have a high capacity to adjust their feeding habits to meet forage availability to meet their energy and nutrient intake requirements (Holechek 1984). In the Intermountain West, sheep are considered the best adapted of all ungulate species at meeting their requirement needs due to their foraging adaptability, by utilizing the available forage resources (i.e. grasses, forbs, shrubs) and plant communities they come in contact with (Holechek 1984). In a recent study conducted on two separate range ewe herds in Wyoming, Scasta et al. (2020) found that sheep grazing on different allotments at different elevations, experienced shifts in diet selection and forage preference. A herd grazing at 1829-2438 m had a diet made up of 51% grass and 31% forbs while the other herd grazing at 2438-3048 m had a diet made up of 42% forbs, 14% shrubs and 13% grasses. Similar studies have also indicated that sheep diets are more varied than that of cattle, and when nonspecific diet is available, sheep will sustain a mixed diet of forbs, grasses, and shrubs (Grant et al. 1985; Parsons et al. 1994). It is reasonable to conclude that the diet of sheep is as variable as the heterogenous landscapes where they graze.

The use of geospatial tools has been valuable in quantifying the use and movement of animals across heterogeneous landscapes. The development of geographic information systems (GIS) and GPS collars technology has been important in quantifying the resource selection of the greater sage-grouse (*Centrocercus urophasianus*), where Baxter et al. (2017), using geographic information system (GIS) and resource selection mechanism, revealed habitat preferences that allowed for better management of this species. Resource selection was used along with birth-site selection of American bison (*Bison bison*) to predict in greater accuracy of areas most likely to be the best habitat for birthing sites (Kaze et al. 2016). While resource selection has been commonly used in wildlife research, little has been done with using this method to analysis the habitat selection in domestic livestock.

Domestic sheep herds in the intermountain west have been utilizing rangelands since 1847, with approximately 300,000 sheep grazing Utah rangelands today (Utah Wool Growers Association 2017). Utah's landscape consists of 80% rangeland making it unsuitable for farming but ideal for raising domestic livestock. In the Intermountain West, sheep are commonly rotated through different rangeland habitats within a year cycle. GPS locations from GPS collars on range ewes grazing on summer mountain habitat to identify use areas, we analyzed environmental features within the habitat at multiple spatial scales and measured the influence of slope, aspect, ruggedness, distance to water, and vegetation types in relation to use sites of the sheep. We then used model-averaged coefficients to produce a GIS model of habitat selection for sheep on the mountain summer habitat. The purpose of our research is to identify the biotic and abiotic variables selected by sheep in a quantifiable way, in hopes of providing fundamental information for sheep managers to effectively improve livestock management. We hypothesize that sheep will select and show preference for high elevation, gentle terrain and close to water.

## MATERIALS AND METHODS

### *Study Area*

Our study was conducted on private land north of Scofield Reservoir (39.91° -111.16° N, 39.88°, -111.12° E) in Utah County, Utah, on 2,500 acres (Fig. 2.1). Elevation ranged from 2,191 to 2,550m and included a variety of terrain from gentle sloping meadows to steeper forested hillsides. Ungulates on the summer grazing allotment that could potentially compete with sheep included elk (*Cervus canadensis*) and mule deer (*Odocoileus hemionus*). Vegetation included quaking aspen (*Populus tremuloides*), subalpine fir (*Abies lasiocarpa*), Gambel oak (*Quercus gambelii*), mountain big sagebrush (*Artemisia tridentata subsp. vaseyana*), Utah serviceberry (*Amelanchier utahensis*), bluebunch wheatgrass (*Pseudoroegneria spicata*), timothy grass (*Phleum pratense*) and broom snakeweed (*Gutierrezia sarothrae*). The climate was characterized by cool summer temperatures (15°C mean air temperature) and cold winters (-5°C mean air temperature) with annual precipitation of 50 cm. Average annual temperature ranged from 43 to 70°C during the summer and -11 to 1°C during the winter (PRISM 2004). Human related activity was minimal except for the full-time sheep herder.

### *Sheep GPS Tracking*

During the summer of July to September 2020, we placed six global positioning system (GPS) collars on six ewes from a herd of 600 adult Rambouillet crossbreed white-face ewes (71±1.2 kg; 4.2±0.9 years old; 1.65 lambs/ewe). The GPS collars were modified from Knight et

al. (2018) as follows: An enclosure (#BT2310 Polycase, Avon, OH, USA) was attached to a 1” x 27” nylon dog collar using 73mm wide black Gorilla tape (Gorilla Glue, Inc, Cincinnati, OH, USA). An i-gotU GT-600 GPS tracker (Mobile Action Technologies, New Taipei City, Taiwan) was modified by removing the internal battery and attaching a JST PH 2-pin 200mm male header cable. A 6600 mAh 3.7V lithium-ion battery pack (#353 Adafruit, New York, NY, USA) that has a JST PH 200mm 2-pin female header attaches to the GPS tracker. The battery pack was also attached to the collar using the Gorilla tape. The GPS tracker was housed in the enclosure and sealed with silicone. With the GPS unit and battery attached, both were wrapped twice using 44mm duct tape (Shuretape Technologies, Avon, OH, USA; Fig. 1.3).

The GPS tracker was programmed to collect waypoints every 5 minutes. At the end of the collection period the collars were removed from the ewes. The data was downloaded using @Trip software (Mobile Action Technologies, New Taipei City, Taiwan) then exported as a csv file. The data was inspected and waypoints removed that were out of the grazing perimeter. In total 27,327 GPS coordinate points from all each collar were recorded.

### *Predictor Variables*

Following the method used by Johnson (1980), a second order selection was used to conduct the resource selection function (RSF) by deliniating our study area and comparing the home range of the sheep to the total grazingland available within study area as defined by the property fencing was used. We obtained environmental data, (i.e. elevation, water location) from the Utah Automated Geographic Reference Center (AGRC 2021). ArcGIS to was used to generate slope, aspect, and ruggedness from elevation data (ESRI 2021). All environmental data was in raster format with a 10m spatial resolution. We binned aspect into seven different directions including: north, northeast, northwest, south, southeast, southwest, and west. Vegetation data was collected

from landfire raster dataset (LANDFIRE 2016) and using the Society of American Foresters-Society for Range Management (SAF-SRM) cover type we grouped vegetation into 20 different groups based on dominant vegetation type. The raster layer for streams was taken from the Utah Automated Geographic Reference Center (AGRC 2021). A point feature was used to designate where the man-made pond was located within the allotment. No anthropogenic features were included in this study (i.e. distance to roads, power lines), because there were very few and unlike wildlife, domesticated animals, are less affected by human related features and activity. Using the ArcGIS Extract MultiValues to Points tool in the Spatial Analyst toolbox, we extracted cell values at locations specified in a point feature class from all rasters and recorded values to the point feature class attribute table (ESRI 2021). The vegetation vector was joined using the Spatial Join tool in the Spatial Analyst toolbox (ESRI 2021).

#### *Resource selection functions and hotspot analysis*

The RSF predictions were generated from a logistic regression which utilizes data from use and non-use sites and includes the set of predictor variables previously described to provide pixel or polygon resource unit probability (Boyce et al. 2002; Manly et al. 2007). To model habitat use of sheep on the allotment, we checked for multi-collinearity among the explanatory variables and found no evidence of collinearity between variables. The Create Random Points tool in the Spatial Analyst toolbox was used to generate the same number of random locations as there were use locations (n=20,958) in order to ensure adequate characterization of the study area (ESRI 2021). A 0 was assigned to random locations and 1 to use location sites in the attribute table (Boyce et al. 2002). With the “lme4” package in R, we used a linear mixed-effects logistic regression with a random intercept for individuals (Team 2021). We compared predictor variables at use locations versus random locations within the study area (Bates et al. 2014;

Gillies et al. 2006; Manly et al. 2007; Team 2021). Akaike's Information Criterion (AIC) was used to select the most parsimonious models that best fit the data using the R package 'MuMIn' (Akaike 1973; Team 2021). To create a raster heat map, we converted the 10m DEM to points and ran the Extract Multi Values to Points tool in the Spatial Analyst toolbox to create a sample grid and exported the attribute table with the coordinates and habitat variable measurements to a csv file. We then used the variable coefficients from our selected model and the variable values from the 10m sample grid (n= 110,615) to generate heat map that visually shows in different colors a prediction of utilization at each sample site (Fig. 2.3). A csv file containing the coordinates and prediction for each 10m cell was exported as a csv file and imported as a point layer in ArcGIS Pro using the XY Table to Point tool in the Data Management toolbox. The point layer was then converted to a raster using the Point to Raster tool in the Conversion toolbox.

## RESULTS

### *Resource selection function*

A total of 27,327 locations for ewes were collected on the grazing habitat from 5 of the 6 GPS collars from July to September 2020. We evaluated 20 models for habitat-use of the sheep (Table 2.1). The top model had an AIC weight of 0.819 and the delta score between the first and second model was 3.34, indicating that our top model was the best fit for our data. Based on AIC, our global model, which included every coefficient (i.e. vegetation types, aspect directions, slope, elevation, water proximity, and ruggedness), had the best fit data for summer use on Scofield (Table 2.1). Slope was highly significant in the best-fit model ( $P < 0.001$ ). The



coefficient value for slope was negative and was estimated for each one degree increase in slope, with the probability of use by sheep declining by -0.9 (Table 2.2, Fig. 2.2). All three of our top models included water proximity as a significant variable ( $P < 0.001$ ; Table 2.1). Proximity to water had the second strongest negative beta estimate (-0.15) meaning that as distance from water increased by one meter, utilization of habitat decreased by -0.15 (Table 2.2). The ruggedness coefficient was significant ( $P < 0.05$ ) against rugged terrain and showed sheep avoided ruggedness (Table 2.2). Sheep showed preference for higher elevation sites, meaning as elevation increased by 1 meter, sheep utilization increased by 0.03 ( $P < 0.05$ ; Table 2.2). The ewes selected for north, northwest, southwest and west facing slopes ( $P < 0.05$ ; Table 2.2, Fig. 2.2).

The vegetation analysis compared every type to the intercept in preference selection. We selected the intercept “bristlecone” (*Pinus longaeva*), due to the high avoidance sheep showed toward the bristlecone vegetation type. Compared to bristlecone pine, the significant (positive values) vegetation types that were selected for were herbaceous, engelmann spruce (*Picea engelmannii*)-subalpine fir, douglas fir (*Pseudotsuga menziesii*), white fir (*Abies concolor*), aspen, mountain big sagebrush, tall forbs, alpine rangeland, chokecherry-serviceberry-rose, and juniper- (*Juniperus osteosperma*) pinyon (*Pinus edulis*) woodland vegetation types (Table 2.2). The most avoided vegetation type (negative values) was bigtoothed maple because it had the most negative beta estimate of -3.83 ( $P < 0.05$ ; Table 2.2). It is important to note that bigtoothed maple covered less than one percent of study area (0.53%; Fig. 2.4). Whereas the most common, mountain big sagebrush, covered 43% of the study area, aspen cover 33% and gambel oak 12% of total study area (Fig. 2.4).

### *SJ Plot and Hotspot analysis map*

An “sjplot” was created in R showing all the predictor value estimates, including significant and non-significant variables at  $P > 0.05$  and sorting them in descending order with the highest selected variables on top to the most avoided variables on the bottom (Fig. 2.2; Team 2021). Further right from the neutral line indicates a strong selection for (in blue), while further left indicates a stronger avoidance (in red). The plot visually displays which variables were highly selected for (i.e. vegetation types, aspect types, elevation) to variables that were selected against (i.e. slope, distance from water, vegetation types, ruggedness, aspect types). Herbaceous, white fir, and douglas fir, were the top three vegetation types strongly selected for in comparison to bristlecone pine with small standard errors, all of which showed significance ( $P < 0.05$ ; Table 2.2; Fig. 2.2). The significant aspect variables show sheep using northern, northwestern, southwestern and western facing slopes (Table 2.2; Fig. 2.2). Variables such as ruggedness and elevation shown closer to the neutral line indicate strength of selection of use for elevation and avoidance of use for ruggedness (Table 2.2; Fig. 2.2). While bigtooth maple has a stronger avoidance by the ewes, being further from the neutral line (Fig. 2.2). Slope was highly avoided with a small standard error of 0.01 indicating slopes were avoided by sheep.

The raster heat map displayed hot spot analysis indicating the areas most likely to be used by the ewes in red and the areas most likely to be avoided in green (Fig. 2.3). For example, the steeper areas on the allotment are covered in green indicating a lack of usage by the sheep (Fig.

2.3). Whereas the gentler terrain on the allotment is generally covered in red and orange indicating higher usage sites (Fig 2.3).

## DISCUSSION

Central to understanding sheep behavior, is understanding the way sheep utilize their environment (Johnson 1980). By using a resource selection functions (RSF) we were able to statistically analyze and identify the habitat features selected by sheep in order to provide understanding of resource usage by animals across a landscape (Manly et al. 2007). The results of our analysis support our hypothesis that sheep selected for higher elevations, avoided steep slopes, and preferred areas closer in proximity to water. Our model representing habitat use on mountainous summer rangelands found that slope was the most important continuous variable for characterizing sheep use. Slope had the highest negative beta estimate (-0.9, SE 0.01,  $P < 0.001$ ; Table 2.2) of all the continuous variables, meaning that, when compared to the other continuous variables, sheep strongly avoided steep slopes on the allotment (Fig. 2.2; Fig. 2.3). Other research has documented that sheep generally utilize steeper slopes more than cattle, and seek higher ground (Bowns 1971; Cook 1966; McDaniel and Tiedeman 1981; Mueggler 1965). Bowns (1971) and Glimp and Swanson (1994) found that sheep are less intimidated by steeper slopes than cattle and tend to prefer upland grazing sites. McDaniel and Tiedeman (1981) found increasing slope steeper than 45% negatively decreased utilization. Compared to other livestock species, sheep utilize steeper slopes more often, being less negatively impacted as slope increases (McDaniel and Tiedeman 1981). It is important to note that sheep were accompanied

by a herder during their time on the summer mountain habitat. We acknowledge that the presence of a herder affects sheep movement across the landscape. While there are times when sheep movement is manipulated by the herder, majority of the time the sheep are left to make habitat selections uninfluenced. The RSF was performed to determine the habitat selection of sheep grazing on summer mountainous range located in central Utah, USA. While the strong selection against steep slopes could be partially attributed to the ewes being herded, sheep tend to take the path of least resistance if presented with one (McDaniel and Tiedeman 1981).

Distance to water is a consistent primary determinant in predicting livestock grazing distribution (Bailey et al. 1996; Senft et al. 1987; Squires 1974). Our model showed as distance from water increased, utilization decreased (beta estimate of -0.16, SE 0.01;  $P < 0.001$ ; Table 2.2; Fig. 2.2; Fig. 2.3). Our findings are corroborated by other published research regarding sheep use of habitat (El Aich et al. 1991; James et al. 1999; Squires 1974). Squires (1974) and El Aich et al. (1991) found that as distance from forage to water increased, forage intake decreased. James et al. (1999), observed merino sheep in Australia are normally found within 3 km of a water site. However, McDaniel and Tiedeman (1981) found distance from water did not limit forage intake. They found a similar amount of forage was consumed from 2,000 to 2,400 m from water as from 0 to 500 m from water. This could be a result of additional water sources supplied on the pasture and stock tanks located on the bottoms and tops of the mountain slope. As well as periodic snows that provided additional moisture. Habitat selection is clearly influenced by distance to water for our sheep grazing on the summer mountain habitat.

Sappington et al. (2007) defines rugged terrain as broken, uneven, rocky terrain. We predicted sheep would choose more gentle terrain that included less rugged habitat. Ruggedness had a negative beta estimate (-0.023, SE 0.01;  $P < 0.02$ ; Table 2.2, Fig. 2.2; Fig. 2.3), meaning the

sheep on the allotment avoided rugged terrain. Ruggedness was found to be in the best-fit model but was not a significant variable in our second best-fit model that held 14% of the weight. McDaniel and Tiedeman (1981) documented when terrain becomes especially rough, sheep passed through the area leaving available forage untouched. While there is a deficiency in data for sheep utilizing rugged terrain, this behavior could be attributed to accessibility of gentler areas that allow for easier mobility and grazing. The sheep on our summer mountain habitat reflected this behavior and avoided rugged terrain.

Sheep have shown to select for higher elevation habitat where they graze on the tops of ridges, and upper slopes, and move uphill for bedding down at night (Bowns 1971; Glimp and Swanson 1994; McDaniel and Tiedeman 1981; Warren and Mysterud 1991). Even though the selection for higher elevation was not as strong as it was for slope avoidance (beta estimate of 0.04, SE 0.01;  $P < 0.004$ ; Table 2.2, Fig. 2.2; Fig. 2.3), this could be attributed to the lack of high elevation flat areas in our allotment for bedding down. Often, if left unmonitored, sheep will bed down in the same locations, on higher elevated ground, and overutilize rangeland vegetation within the area (Bowns 1971; Warren and Mysterud 1991). The sheep in our study were herded, therefore the likelihood of overutilization of sites decreased, due to herders selecting different bedding locations. It has also been proposed that this uphill movement for higher-lying ground at night is not seen so much as a response to nutritional needs, but rather to provide other advantages, such as predator avoidance and offer safest bedding sites (Warren and Mysterud 1991). From our study and others, there is evidence for sheep to seek for higher ground.

The vegetation types selected for or against in this study were all in comparison to the avoided bristlecone pine vegetation type. The vegetation type sheep selected against was bigtooth maple, but they showed preference for herbaceous, Engelmann spruce-subalpine fir,

douglas fir, white fir, aspen, mountain big sagebrush, tall forbs, alpine rangeland, chokecherry-serviceberry-rose, and juniper-Pinyon pine woodland type. It is important to note that these vegetation types describe the dominant vegetation and exclude several palatable species that could be the true attraction to sheep but are undocumented. A plausible explanation for the vegetation selection could also be attributed to the herder preference and pushing sheep through areas to avoid over utilization of other sites. Another important factor to consider is the percent each vegetation type covers on the study area (Fig. 2.4). Though bigtooth maple was strongly selected against, that could also be due to it covering less than one percent of the study area (0.53%). Therefore, it is not common on the landscape and the chance of sheep encountering this vegetation type is much lower than mountain big sagebrush which covers 43% of the landscape (Fig. 2.4). During the beginning weeks on the mountainous summer range, GPS points showed sheep predominantly grazing on open fields of herbaceous graminoids, forbs, and shrubs before being moved down into forest stands of douglas and white fir stands. Douglas fir (*Pseudotsuga menziesii*) is the third most common forest type in Utah (USU 2004). While sheep showed selection for douglas fir, it could be likely that douglas fir vegetation type was more dominant across our mountain habitat therefore sheep spent more time grazing in it and not necessarily due to selection. Sheep prefer to subsist on graminoids, but can adjust their feeding habits to available forages (i.e. forbs, shrubs; Holechek 1984). Therefore, even though there was selection for and against vegetation types on the allotment, it remains difficult to conclude the significance of our findings due to the variation in percentage of cover between vegetation types, sheep being herded, and a lack of knowledge of other types of vegetation within the dominate vegetation type.

The aspects on our allotment habitat that were variables in the best-fit model were northern, northwest, southwest and west facing slopes (Table 2.2). Aspect plays a critical role in influencing soil quality and vegetation patterns (Farzam and Ejtehadi 2017; Singh 2018; Yang et al. 2020). Differences in aspect can alter vegetation structure and composition by effecting air and soil temperature, moisture content, and evaporation (Farzam and Ejtehadi 2017; Singh 2018). North-facing aspects receive less sunlight and therefore retain moisture more effectively, giving life to thicker and denser vegetation (Farzam and Ejtehadi 2017). Whereas, sunnier south-facing aspect's vegetation is sparse and thin and therefore prone to erosion (Farzam and Ejtehadi 2017; Singh 2018). While the literature is lacking specific examples of sheep selecting for certain aspects, these studies give a possible reason our sheep selected northern aspects over southern aspects. Northern facing slopes provide sheep with better foraging habitat as well as protection from the hot summer sun.

Our results demonstrate sheep habitat selection on summer mountain range. However, additional improvements to this study could allow for further extrapolation of data. Our data is from one flock and the addition of more flocks would provide a more complete data set for habitat selection from other mountainous habitat sites. While we placed collars to represent 10% of the flock, increasing collar sample size to estimate herd movement would increase the validity and accuracy of our findings (Biau et al. 2008). Not only would increasing sample size improve our research but monitoring sheep throughout several years and on different rangelands would provide additional insights to habitat selection. By extending the length of time out on habitats and continuing to monitor sheep as they transferred between locations throughout a year, would allow data to be compared between sites and create a holistic view of sheep habitat selection throughout a regular grazing year. Another noticeable limitation when using RSF is the lack of

existing data layers that also provide accurate information. For example, our vegetation layer describes dominant cover type but provides no further information of total species composition of area. Without a comprehensive knowledge of plant communities, it becomes difficult to draw any meaningful conclusions from this data layer. With improvements made to sample size, length of study and data layers, the study of habitat selection in sheep could be extrapolated for other similar range habitats for the improvement of livestock management.

## CONCLUSION

Sheep grazing on our mountainous summer range avoided slopes, and preferred higher elevation, northern aspects, gentle terrain, and remained closer to water. Vegetation selected for and against, lacked reliability to make inferences, due to the GIS layer limitations in knowledge of species composition in areas and sheep being herded. Our results highlight what other studies have recorded in sheep habitat selection (Bowns 1971; El Aich et al. 1991; Holechek 1984; McDaniel and Tiedeman 1981; Squires 1974; Warren and Mysterud 1991). With the use of geospatial technology to generate an RSF for sheep grazing on mountainous summer range, we were able to quantify sheep habitat use in order to improve summer grazing management of sheep. Improvements could come by altering herding strategies to better utilize sheep friendly habitats and avoid those that are not beneficial. Further work using the tools outlined in this research and addressing outlined limitations is needed to look more closely at habitat selection of sheep.



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## FIGURES

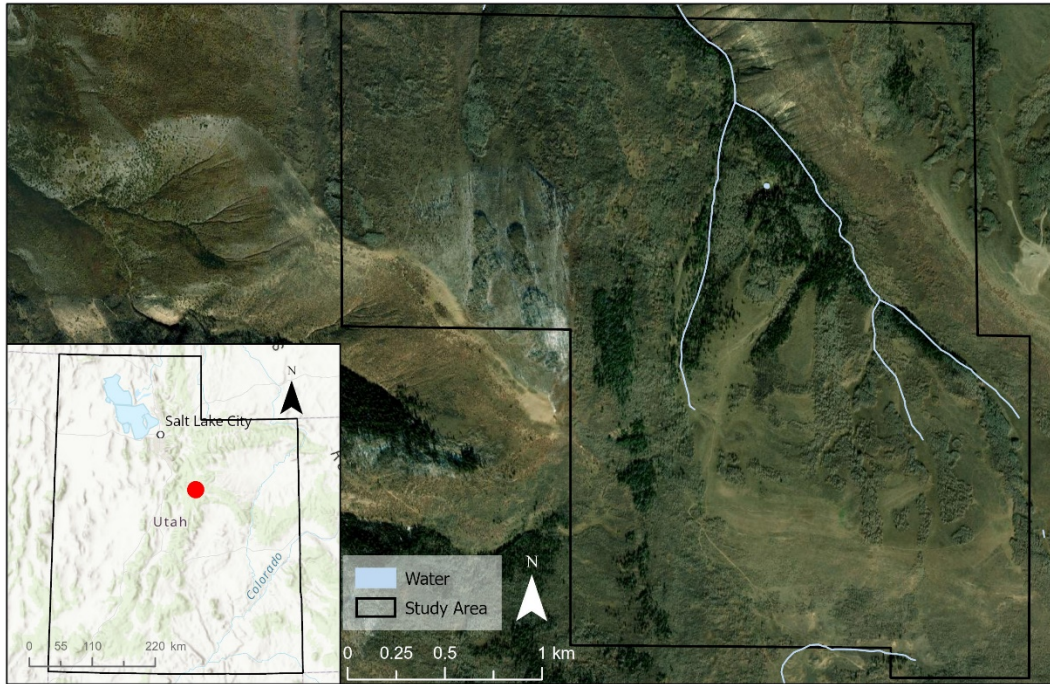


Figure 2.1 Study site location north of Scofield Reservoir, UT. Polygon represents the mountainous range where sheep grazed from July 2020 to September 2020.

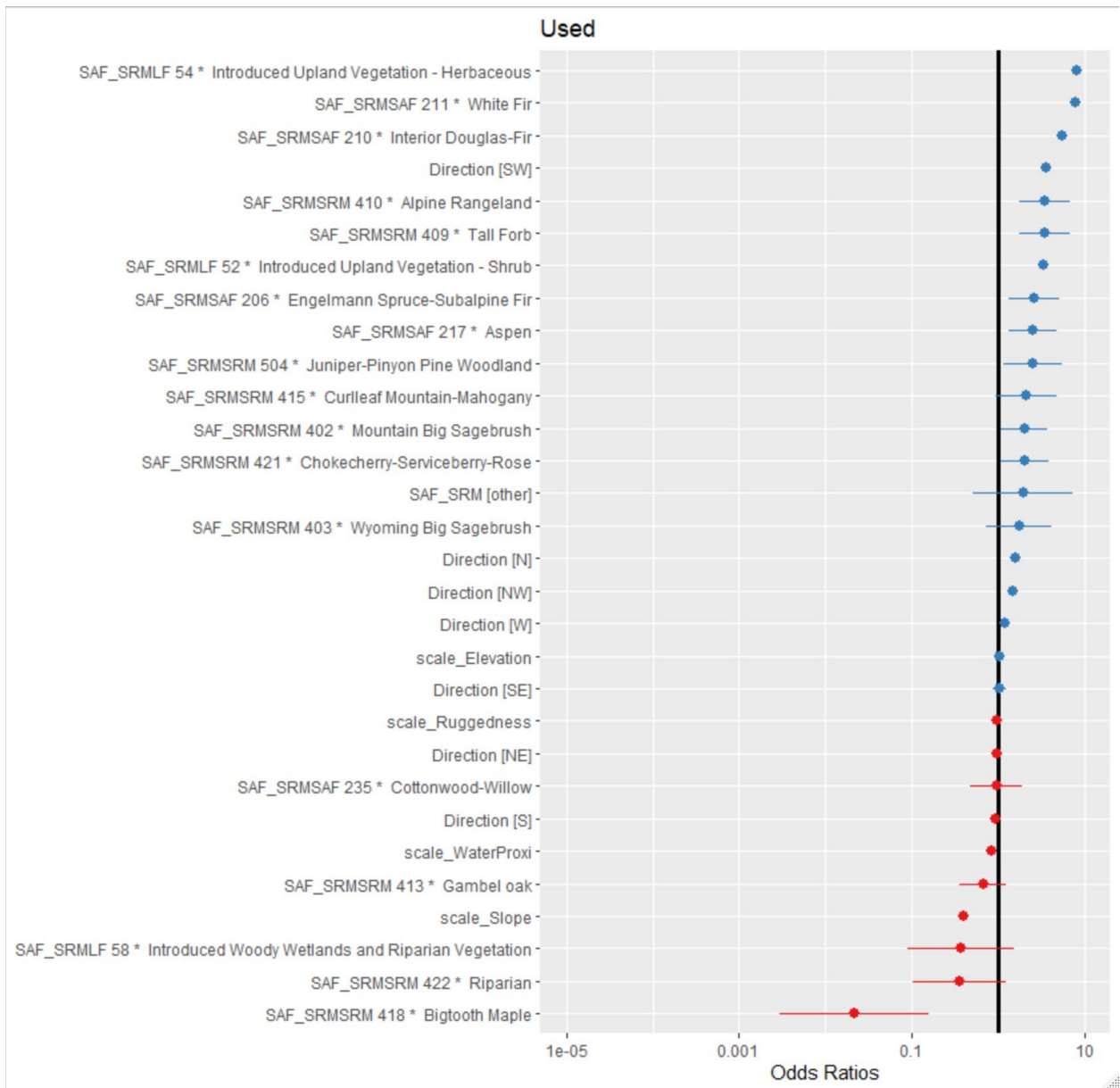


Figure 2.2 "sjplot" showing predictor value estimates with standard error bars in descending order with the highest selection on top in blue to the highest avoidance on the bottom in red. The "neutral" line, that is thicker than the rest indicates no effect. The vegetation types come from forest cover types of the United states and Canada (SAF) and the society for range management (SRM).

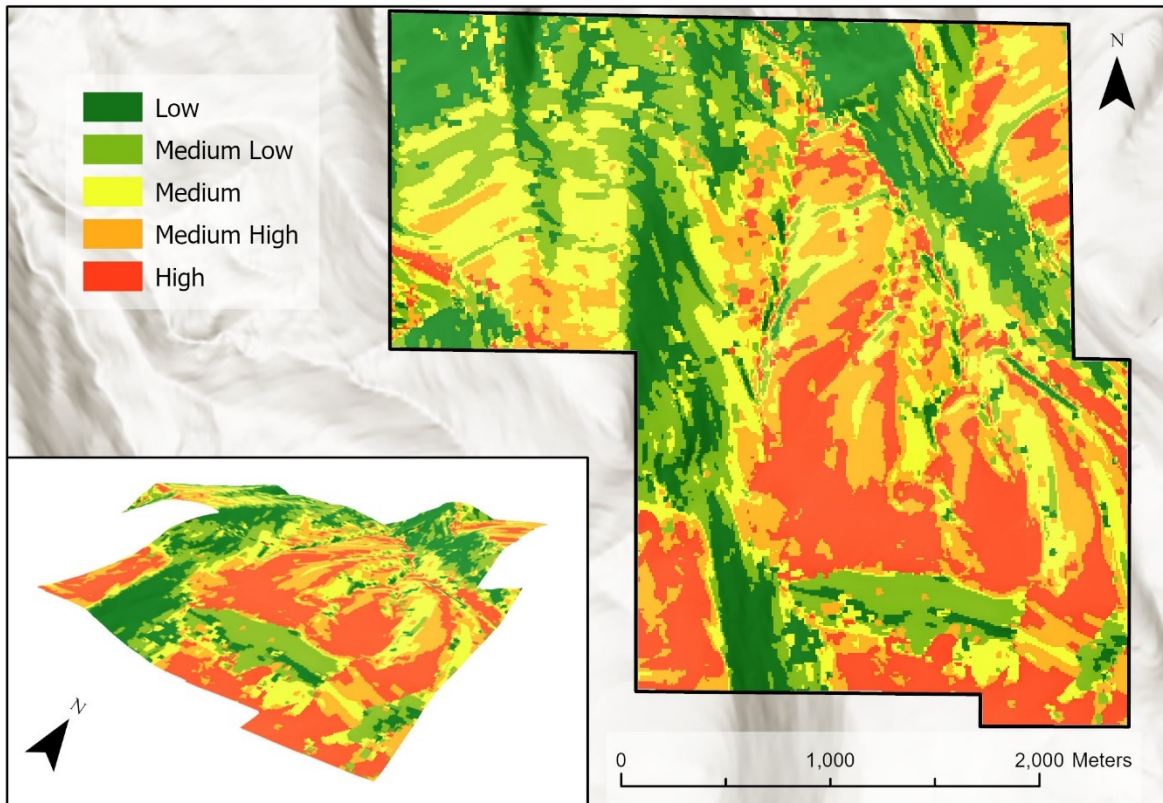


Figure 2.3 Heat map analysis of study area showing the relative probabilities of selection by domestic sheep binned into five categories from low (dark green) to high (red).



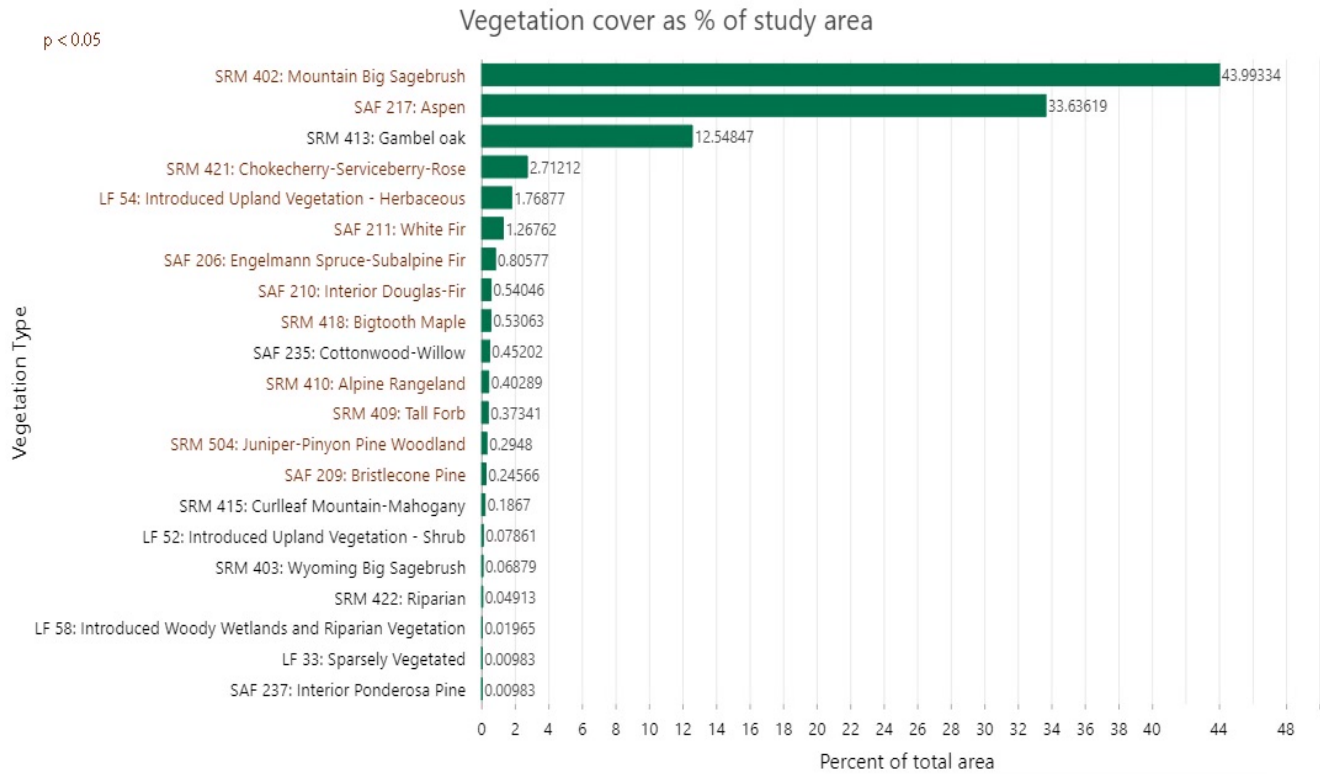


Figure 2.4 Vegetation cover as percentage of study area.

## TABLES

Table 2.1 Model selection table showing 20 models, the number of parameters (k), the difference in Akaike's Information Criterion from the top model ( $\Delta AIC$ ), and the model weight for 20 a priori models for sheep habitat selection on mountainous summer range.

Model No.	Model Structure	df	AIC $\Delta$	Weight
M8	Vegetation+Aspect+Elevation+Ruggedness+Slope+WaterProxi	32	0.00	0.819
M9	Vegetation+Aspect+Elevation+ Slope+WaterProxi	31	3.45	0.146
M12	Vegetation+Aspect+Ruggedness+Slope+WaterProxi	31	6.26	0.036
M15	Vegetation+Aspect+Elevation+Ruggedness+Slope	31	174.47	0.00
M10	Vegetation+Elevation+Ruggedness+Slope+WaterProxi	25	1722.60	0.00
M11	Vegetation+Elevation+Slope+WaterProxi	24	1726.25	0.00
M13	Vegetation+Slope+WaterProxi	23	1764.94	0.00
M20	Aspect+Elevation+Slope+WaterProxi	12	2119.79	0.00
M14	Aspect+Elevation+Ruggedness+Slope+WaterProxi	13	2121.44	0.00
M16	Aspect+Elevation+Ruggedness+WaterProxi	12	2653.03	0.00
M19	Aspect+Elevation+Slope	11	2657.22	0.00
M2	Slope	3	4873.91	0.00
M17	Vegetation+Aspect+Elevation+Ruggedness+WaterProxi	31	5397.86	0.00
M18	Vegetation+Elevation+Ruggedness+WaterProxi	24	7874.49	0.00
M7	Vegetation	21	8345.67	0.00
M3	Aspect	9	10431.73	0.00
M4	Elevation	3	13101.52	0.00
M5	Ruggedness	3	15622.73	0.00
M1	Intercept only model	2	15646.70	0.00
M6	WaterProxi	3	15647.90	0.00

Table 2.2 Model coefficients from best-fit model for habitat selection of sheep grazing on mountainous range located north of Scofield UT, USA.

<b>Significant Coefficients</b>	<b>Beta Estimate</b>	<b>Standard Error</b>	<b>P Value</b>
<b>Topography</b>			
<i>Slope</i>	-0.907542	0.013590	< 0.001
<i>WaterProxi</i>	-0.159241	0.012157	< 0.001
<i>Elevation</i>	0.039046	0.013579	0.004
<i>Ruggedness</i>	-0.022930	0.009817	0.019
<b>Aspect</b>			
<i>Direction N</i>	0.468430	0.045034	< 0.001
<i>Direction NW</i>	0.410669	0.043689	< 0.001
<i>Direction SW</i>	1.264073	0.046279	< 0.001
<i>Direction W</i>	0.172613	0.046250	0.000190
<b>Vegetation Type</b>			
<i>Bristlecone Pine</i>	-1.332760	0.331533	< 0.001
<i>Bigtooth Maple</i>	-3.836484	1.012389	0.000151
<i>Herbaceous</i>	2.089378	0.323017	< 0.001
<i>Englemann Spruce-Subalpine Fir</i>	0.959606	0.342799	0.005121
<i>Interior Douglas-Fir</i>	1.706320	0.348417	< 0.001
<i>White fir</i>	2.049769	0.328012	< 0.001
<i>Aspen</i>	0.926217	0.319575	0.003752
<i>Mountain Big Sagebrush</i>	0.708248	0.319086	0.026445
<i>Tall Forb</i>	1.243699	0.341405	0.000270
<i>Alpine Rangeland</i>	1.257119	0.344002	0.000258
<i>Chokecherry-Serviceberry-Rose</i>	0.696006	0.326403	0.032978
<i>Juniper-Pinyon Pine Woodland</i>	0.924872	0.391449	< 0.001