**CALIFORNIA DEPARTMENT OF FISH & WILDLIFE**

**LARGE MAMMAL ADVISORY COMMITTEE**
**APPROVED PROJECT**

# Evaluating the Feasibility of Reintroducing Desert Bighorn Sheep into the Northern Sierra Nevada Mountain Range of North Central California

## Applying GIS Models to Identify Potential Summer and Winter Range Habitat

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TABLE OF CONTENTS

## Contents

# LIST OF TABLES

## LIST OF FIGURES

## Abstract

Understanding habitat suitability and the risk of disease transmission is vital for evaluating a reintroduction site for desert bighorn sheep in California. Desert bighorn sheep were once part of the northern Sierra Nevada ecosystem in 1848, but were believed to be extirpated due to the gold rush settlers that brought the transmission of disease with domestic sheep and goats, habitat loss and unregulated hunting. In 2007 to 2008, 6 GPS collared California bighorn sheep ewes from the Virginia mountain range in Nevada were tracked crossing into the eastern Sierra Nevada mountains of California. Although reintroductions have expanded the historical distribution and population of bighorn sheep in California, a full feasibility is necessary to determine if a bighorn sheep reintroduction could be successful.

This study used geographic information system (GIS) habitat suitability models to identify and quantify winter and summer home range habitat conditions and applied density figures to determine if the home ranges could support a viable population of bighorn sheep (100-125 individuals). A risk analysis was also conducted to evaluate the proximity of active domestic sheep allotments to each potential study plot.

Our results found that all six plots exceeded the amount of year round habitat needed to support a herd of 100-125 bighorn sheep. Five out of six plots surpassed $6.25 km^2$ of snow-free winter habitat in 2003 and 2011, which may strongly indicate the majority of plots could support a bighorn sheep herd in the harshest of winters. The risk analysis was the limiting factor for this feasibility study as it indicated that only two study plots were greater than 23 km away from an active domestic sheep allotment and had sufficient suitable habitat for a reintroduction. The results from this study have provided initial insight into studying and monitoring the possible natural recolonization event of wandering ewes and rams occurring near the Nevada-California border. It also supports recommendations to form a California Bighorn Sheep Technical Working Group (CBST) to further reduce domestic sheep risk in order to reintroduce 10-15 collared bighorn sheep for phase II of the reintroduction plan.

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## Introduction

Desert bighorn sheep (*Ovis canadensis nelsoni*) are native to North America and once populated California, Nevada, Oregon, Washington, Utah, New Mexico and British Columbia. Before the arrival of European man, bighorn sheep were initially distributed from the mountains of southeastern California to Canada wherever suitable habitats and winter range existed (Bighorn Sheep Advisory Group, 1991). In the northern reach of the Sierra Nevada mountain range (northern Sierra Nevada), historical accounts in 1848 documented sightings of several bands of mountain sheep along the Truckee River drainage and Soda Springs in Placer County, California (Schulz & Simons, 1973;Graydon, 1989). Most of these wild sheep populations in the northern Sierra Nevada and northeastern California disappeared by the mid-1800s and early 1900s as gold miners and domestic livestock invaded the mountains that once belonged to wild sheep (Wehausen, 1988). Without sufficient historical documents from the last century, many bighorn sheep populations disappeared in the gold rush era without leaving a trace of their existence (Blankinship, Bleich, & Wehausen, 1988). The only documentation recorded of bighorn sheep's presence in the northern Sierra Nevada is from a hunter who killed two bighorn sheep on the Truckee River route in 1848 (Graydon, 1989) and from an archeological researcher site that found hunting ritual pictographs of wild sheep in 1973 (Schulz & Simons, 1973). In addition to these recorded documentations, California Department of Fish and Wildlife (CDFW) have recently received two internal reports of unconfirmed bighorn sheep sightings at Tinker Knob and Squaw Valley from residential hikers in the past 10 years (Regina Abella and Jason Holley, CDFW, personal communication, January 2014). These limited records and sightings of bighorn sheep in the northern Sierra Nevada have allowed us to assign two historical range plots in this feasibility study and has prompted this study to ask whether these historical locations contain enough quality habitat to support a reintroduced bighorn sheep herd.

In the 1980s, the state of Nevada successfully reintroduced a California bighorn sheep herd (*Ovis canadensis californiana*) into the Virginia Mountains, 19 kilometers (km) from the California border and northwest of Reno, Nevada. Based on GPS collar data from 2007 to 2008, 6 California bighorn sheep ewes from the Virginia Mountains have been tracked crossing U.S Highway 395 into Red Rock Valley, California 16 km north of the Hallelujah Junction Wildlife Area. In addition to ewes, the CDFW has also received internal photographs and sightings of rams crossing U.S Highway 395 into Hallelujah Junction Wildlife Area to graze on December 21st 2009 (J. Dawson, CDFW, personal communication, September 2013). The documented intermountain dispersal of bighorn sheep ewes into California suggests that suitable habitat may exist in the northern Sierra Nevada.

Although reintroduction of desert bighorn sheep has occurred in other parts of the state and has been successful in Nevada, the potential for success has not been evaluated for this section of the northern Sierra Nevada. Reintroduction has been discussed several times in the last 20 years, but a full feasibility study was never completed and is necessary to determine if a reintroduction could be successful. Evaluating the reintroduction implications of bighorn sheep in the northern Sierra Nevada is an important first step before taking action to translocate bighorn sheep into a new ecosystem. The benefits of reintroducing a big game species back into a historical range can include reestablishing a long term conservation effort for wild sheep within their native habitat, protecting corridors and connectivity for other big game mammals that live in large home ranges, providing recreational viewing and education to the public and increasing sustainable hunting opportunities for Northern California.

While offering many benefits, reintroduction and translocation programs that introduce wild sheep into a new territory are also associated with many risks and concerns. Reintroductions of bighorn sheep can be labor-intensive, costly and dangerous to transplanted animals (Gilad, Wu, & Armstrong, 2013). They also present habitat management implications for other species that live in the area. Failed reintroduction efforts in the Lava Beds and Warner Mountains of northeastern California in the 1970s have been attributed to the lack of habitat evaluation and investigation of nearby active domestic sheep allotments (Wehausen & Charles, 1982; Wehausen, 2013).

To facilitate the evaluation for a successful reintroduction effort, we developed geographic information system (GIS) habitat suitability models to identify and quantify areas that provide appropriate habitat conditions that would allow bighorn sheep to survive and reproduce (Johnson, Bleich, & Stephenson, 2005). By comparing habitat models and criteria from other research, we identified research variables important in describing winter and summer habitat selection in the northern Sierra Nevada and then applied density figures to determine how much habitat would be needed in summer and winter range to support a long-term minimum viable population size of bighorn sheep (100-125 individuals). The variables we used to define our habitat suitability models were: escape terrain, horizontal visibility, snow cover, slope, southerly aspect and proximity to domestic sheep (Smith, Flinders, & Winn, 1991; Montana Fish, 2010; O'brien, 1997).

The overall goal of this feasibility study was to assess whether suitable habitat conditions exist in the northern Sierra Nevada to support a viable reintroduced bighorn sheep herd. The restoration efforts to return bighorn sheep to their historical range is supported by the mission of the California Department of Fish and Wildlife and the management policy for bighorn sheep set forth in Section 4900 of the Fish and Game Code (CDFW Code, 2014). GIS habitat suitability models were developed to evaluate historical and currently available habitat in order to quantify potential summer and winter home ranges for a theoretical desert bighorn sheep reintroduction effort. The specific objectives for this feasibility study were to (1) research historical literature of bighorn sheep sightings and use expert opinion to identify suitable habitat plots, (2) create a GIS habitat suitability model that uses researched habitat variables to identify potential summer and winter habitat for bighorn sheep, (3) determine the amount of summer and winter habitat needed in each plot to support a minimum viable herd of 100-125 sheep, and (4) evaluate the proximity of domestic sheep to each study plot in order to assess the associated disease risk.

## Study Area

Our study evaluated six plots located in CDFW's North Central Region within the Sierra Nevada Mountains of Plumas, Sierra, Nevada, Placer, El Dorado and Alpine counties. A reconnaissance flight was flown to evaluate escape terrain and habitat on October 14, 2013, with Dr. John Wehausen, a Wildlife Population Ecologist with extensive knowledge of mountain sheep habitat and Breanna Duplisea CDFW Scientific Aid. Due to a lack of snow in the winter of 2014, a second reconnaissance flight was unnecessary and further focus was placed on developing a winter range GIS snow depth model. The study plots were selected based on bighorn sheep presence and Global Positioning System (GPS) collar data, historical range locations based on cited literature and expert knowledge of mountain sheep habitat (Fig. 1). Each study area was defined with GIS vertices to create a rectangle plot of 30 km by 20 km, totaling an area of 600 square kilometers ($km^2$) per plot. Consistent 600 $km^2$ rectangles allowed us to assess habitat variables independently based on plot location or as a comparison of total plot area.

California’s Sierra Nevada is a vast mountain range with gentle western slopes and steep eastern ridges that encompasses approximately 645 km from the Mojave Desert in the south and extends through the Cascade Range in northern California (Wieczorek, 2002). The topography of each study plot was characterized by rugged mountain ranges, south-facing U shaped canyons, high elevation ridge lines, and an abundance of snow-melt springs and lakes to supply water and nutrient rich wet meadow plant communities to a bighorn sheep herd (USGS Global Visualization Viewer, 2014; Johnson et al., 2005; Wehausen, 2013). The elevation boundaries of the study plots varied from a maximum elevation of 3,109 meters (m) to 975 m. Bighorn sheep feed on a large variety of plant species as seasonal nutrients become available depending on annual precipitation and location of a home range (Wehausen & Hansen, 1988;Wehausen, 1999). Wehausen and Hansen (1988) suggest that the timing of rainfall for the Sierra Nevada Mount Baxter herd in Inyo county is very important for bighorn sheep diet as the first rain storms initiate the growth of cold tolerant plant species.. These cold tolerant plant species influence a high nutrient diet, which enhances the reproductive success for an entire bighorn sheep herd (Wehausen, 2013). The importance of precipitation and diet quality could also apply to this study area as cold tolerant, sub-alpine forage quality can have a direct relationship on a herd’s long term survival and reproductive success.

Climate of the study area is characterized by warm summers, calm and mild springs, and cold winters. Snow storms in the northern Sierra Nevada are influenced by north Pacific storms and are characterized by heavy precipitation through the months of October through April with the highest snow depth averages recorded in March (Johnson, Bleich, & Stephenson, 2005;Wehausen, 1980; Central Sierra Snow Laboratroy, 2013). Average winter temperatures range between -8° C to 6°C in the month of December, and the summer temperatures range between 5 °C to 27 °C in the month of July (The Weather Channel, 2014). Most of the storms drift from the Pacific and become trapped above the western crest line causing a rain shadow, which is responsible for greater precipitation and canopy cover on the west slope and a dryer desert ecosystem on the east(Johnson et al., 2005;Wehausen, 1980).

The main plant communities within the study plots include the following: Great Basin sagebrush scrub, foothill woodland, pinjon-juniper woodland, subalpine woodlands, mixed chaparral, mixed conifer, montane hardwood and alpine meadow (Van Wagtendonk & Fites-Kaufman, 1997). The low elevations 305 m to 914 m are characterized by sage scrub, gooseberry, lodgepole pines and mixed firs, valley oaks, toyon and mixed manzanita (Olson & Sawyer, 2012; Van Wagtendonk & Fites-Kaufman, 1997; US Forest Service, 2012). The mid elevations 914 m to 2,134 m vegetation consists of ponderosa and a mixture of conifer forest, montane conifer, Douglas, red and white firs, eastern shrubs and mixed manzanita (Olson & Sawyer, 2012;US Forest Service, 2012). From 2,135 m to 2,743 m, in the subalpine zone, extensive dominant stand patches of lodgepole pines and red fir forest occur. The maximum subalpine zone extends between 2,744 m to 3,109 m and consists of lodepole pine, mountain hemlock forest, pinyon- juniper woodlands, sup-alpine meadows and sparse bare rock forage (Johnson et al., 2005). Canopy cover and horizontal visibility is an important summer habitat variable to consider in northern California, as plant succession and lack of fires have resulted in an increase in vegetation densities over the past century. Bighorn sheep prefer steep rocky terrain that is visually open with canopy cover that is no greater than 40% (Smith et al., 1991;O'brien, 1997). By having visually opened steep terrain, bighorn sheep can spot predators from a distance and use their adaptations to out run these predators on top of precipitous mountain peaks (Wehausen, 2013).

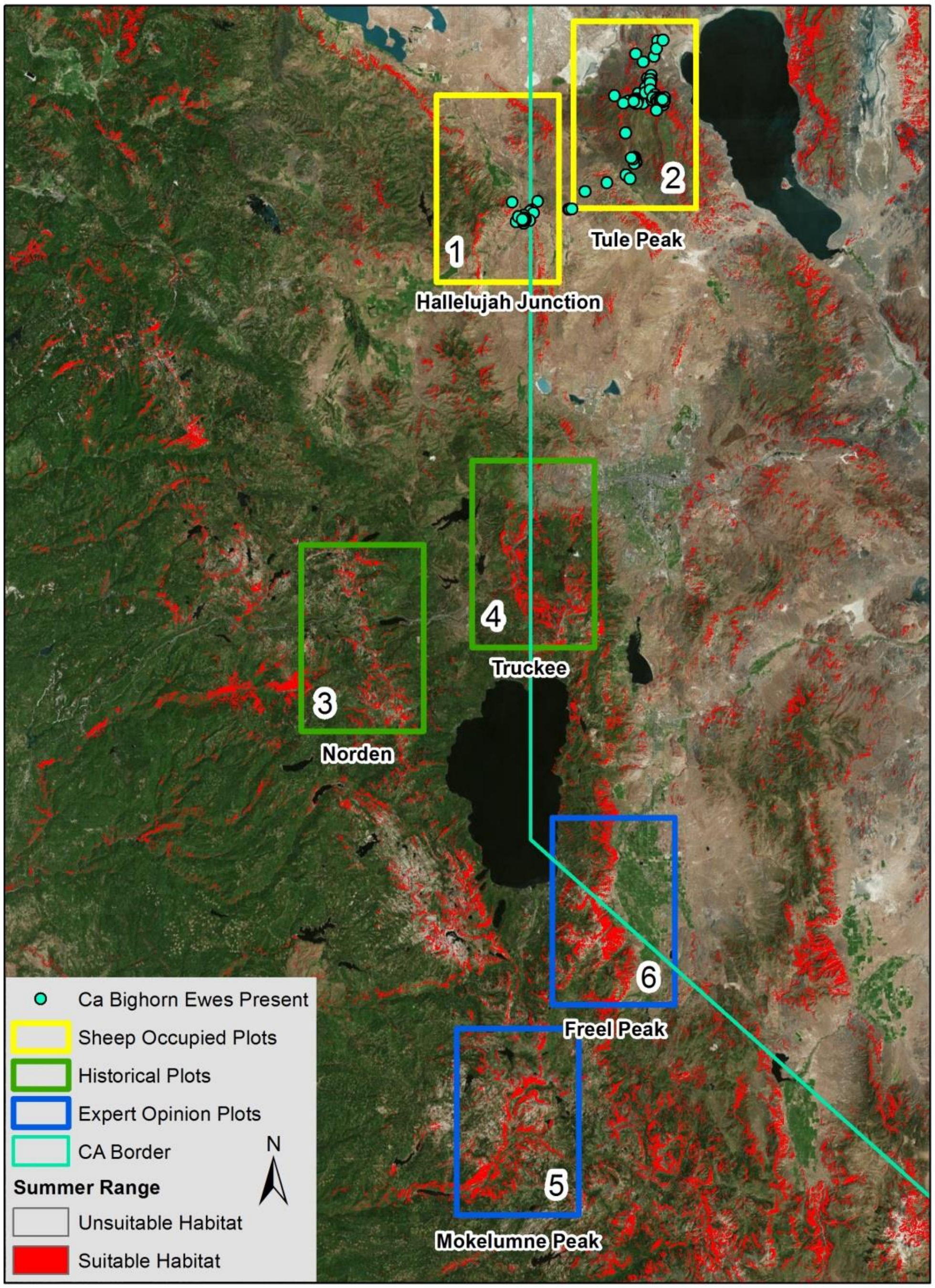


Figure 1: Study area and plots 1- 6 broken down into three categories: sheep occupied, historical and expert opinion plot

## Methods

The summer and winter habitat models for this study were produced using ESRI ArcGIS 10.1 software. Constructed of five individual layers, the GIS summer and winter models utilize several habitat variables to identify the quantity of suitable habitat for bighorn sheep (Table 1). The habitat variables used include escape terrain (Layer 1), escape terrain and open canopy terrain (Layer 2), and snow cover depths and the aspect of south facing slopes (Layers 3 and 4, respectively). Each GIS model was then calculated in square kilometers ($km^2$) to find out how much optimal habitat in summer and winter range was available for each of the study plot locations (Layer 5). The amount of available habitat identified in Layer 5 was then compared to a researched bighorn sheep home range density to calculate whether each study plot provided enough suitable summer and winter habitat to support a minimum viable population (MVP) of 100 to 125 sheep.

### *GIS model layers*

Table 1: The GIS habitat suitability model is constructed of 5 individual layers, which evaluates seasonal habitat criteria for a bighorn sheep's summer and winter home range. .

| Model Layer | Definition | Season |
|---|---|---|
| 1 | Suitable Escape Terrain buffered by 300 m | Summer |
| 2 | Optimal Escape Terrain and Canopy Cover buffered by 300 m | Summer |
| 3 | Winter Range with No Snow & Potentially No Snow Areas | Winter |
| 4 | Optimal Winter Range with No Snow, Potentially No Snow Areas and Southern Aspects | Winter |
| 5 | Optimal Summer and Winter Ranges for Each Study Plot | Summer & Winter |

### *Summer habitat modeling*

For summer habitat, the optimal escape terrain modeling was based primarily on slope data derived from a 30-meter resolution digital elevation model (DEM) that was downloaded from the USGS National Map Viewer. The critical habitat variables identified for the GIS summer range model are optimal escape terrain and canopy cover visibility (Smith et al., 1991; Singer, Gudorf, & Bleich, 2000). Layer 1 of the habitat models consisted of a DEM layer, which is a georeferenced raster data file made up of a matrix of pixels, each having its own elevation values (Gilad et al., 2013). Layer 2 consisted of a downloaded 2011 USGS National Land Cover data set and Digital Elevation data set that entails a matrix of pixels, each having canopy cover density, vegetation type and elevation. This layer of the summer model identified the canopy cover visibility of each plot by using the tree density attribute within the USGS vegetation layer.

The two summer habitat layers detailed in Table 2 were superimposed in ArcGIS 10.1 on the study areas to calculate how much suitable habitat existed in each plot. Specific habitat variables defined in Table 2 were measured in square kilometers ($km^2$) for each plot by using the Spatial Analyst functionality of ArcGIS 10.1. Additionally, the evaluated suitable habitat found in $km^2$ for each study plot was then compared to a density of 7.7 animals/$km^2$, and thus the area required to support an MVP of 100 -125 animals was calculated (Smith et al., 1991; Montana Fish & Wildlife, 2010).

The model flow used for summer range was also undertaken for the winter range. Winter range modeling is explained in a separate section.

*Layer 1: Suitable escape terrain buffered by 300 meters*

Escape terrain for bighorn sheep is defined as any area of 27 ° -85 ° slope, also referred to as optimal escape terrain (Smith et al., 1991; Hansen, 1980; Gilad et al, 2013). Suitable escape terrain was determined primarily by slope information derived from a 30m-resolution DEM downloaded from the National Elevation Dataset (NED). Areas with optimal escape slopes of 27° -85 ° were then buffered by a 300 m distance and referred to as potential escape terrain (Table 2). This DEM layer that characterized optimal and potential escape terrain was the first data layer in this bighorn sheep feasibility study.

*Layer 2: Optimal Escape Terrain and Canopy Cover buffered by 300 m*

The second layer used in the feasibility study found areas with rocky slopes of 27 °-85 ° and areas relatively barren of vegetation. Bighorn sheep require steep open habitat with high visibility to evade predators seen at distance (Johnson et al., 2005; Wehausen, 2013). Bighorn sheep have been observed to avoid thick, closed canopies of vegetation. Therefore, suitable escape terrain with less than 40% forest cover (also referred to as area with less canopy cover) was calculated and buffered by a 300 m distance to each plot (Table 3). Horizontal visibility and steep escape terrain is an important habitat variable to be considered in Northern California as plant succession and lack of fires has resulted in an increase in vegetation densities, which did not exist over 140 years ago (Bighorn Sheep Advisory Group, 1991). These critical habitat variables were used in Layer 2 to analyze the availability of steep, open slopes and calculate the area of suitable summer habitat present for a bighorn sheep herd.

Table 2: An overview of the summer range habitat parameters and the definitions of the variables used to define Layer 1 and Layer 2 of the GIS habitat suitability model.

| **Summer Range: Habitat Parameters** | **Definition** | **Buffer Areas with 300 m** | **Source** |
|---|---|---|---|
| | | | |
| **Layer 1: Escape Terrain** | 27° ≤slope ≤85° | 27° ≤slope ≤85° with 300 m | Smith et al. 1991; Singer et al. 2000; McKinney et al. 2003 |
| | | | |
| **Layer 2: Escape Terrain & Canopy Cover** | 27° ≤slope ≤85° & <40 % Veg Cover | 27° ≤slope ≤85° & <40 % Veg Cover with 300 m | Smith et al. 1991 ; Schirokauer 1996 |
| | - | - | |

### *Winter habitat model overview*

Thematic Mapping Landsat 5 imagery of 2003 and 2011 data were used to evaluate the presence and absence of snow deposition across six study plots selected for this feasibility study. The winter habitat model was derived from gathering GIS data from archived Landsat 5 imagery using the USGS Global Visualization Viewer (Glovis) on the USGS Earth Resource Observation and Science Center (EROS) website. Landsat 5 grid scenes were downloaded instead of Landsat 7 grids because Landsat 5 supplied imagery with the highest quality of data that did not have image gaps. For each 2003 and 2011 scene downloaded, a version of the Normalized Difference Snow Index (NDVI) was created using a ratio equation of the difference in wavelength-bands 3 and 5 for each date respectively. The NDVI equation for reflectance values was taken from a Montana winter range research paper, and the equation [(3-5)/(3+5)] was applied to all six of the winter range study plots (Dicus, 1999). The NDVI equation was then used to delineate areas covered by snow and areas where snow was absent in both Thematic Mapping images for 2003 and 2011 data.

Researchers modeling bighorn sheep winter range have identified that suitable winter range habitats must be relatively snow free with snow depths of less than 25 centimeters (cm) (Smith et al., 1991). The Thematic Mapping imagery for the year 2003 was chosen because it represents the average snowfall (in centimeters) and snowpack depths out of 135 years of data cited from the Central Sierra Snow Laboratory in Soda Springs, CA (Central Sierra Snow Laboratroy, 2013) . The year 2011 was chosen because it represents the highest snowfall (cm) and snowpack depths (cm) within the past 42 years recorded for the area (Central Sierra Snow Laboratroy, 2013). By comparing the average snow cover year in 2003 to the highest snow cover year in 2011, scientists can reasonably predict the amount of suitable snow-free habitat available for bighorn sheep to utilize in the coldest and highest snow cover years.

Because cloud cover blocks the satellite view of the earth’s surface, cloud free days were chosen for clarity for both 2003 and 2011 TM images. The 2003 and 2011 images were selected from a set of downloaded data and the best ones with no cloud cover were chosen. Additionally, the Central Sierra Snow Laboratory data demonstrated that the highest snow cover months in the northern Sierra occur in March. The clearest data closest to the month of March were used to calculate the highest snow cover values for a given year. The GIS analysis found relatively cloud free data in 2003 for scenes path/row 4432 on February 09 and Path/Row 4433 on March 29. For

2011 data, the scenes found with the most clarity were Path/Row 4332 January 14 and Path/Row 4333 April 4. Three of these data images are not taken directly from the month of March because cloud cover was extremely dense throughout Match in 2003 and 2011.

The NDVI image from 2003 was superimposed and compared to the NDVI image from 2011 using image algebra in ArcGIS. A value of zero (0) was then assigned to all areas with no snow present in both 2003 and 2011 data layers. A value of one (1) was assigned to all areas were snow was present in only one year, either 2003 or 2011 data; this layer was referred to as potential snow-free areas.  Lastly, a snow bound value of two (2) was allocated to each grid cell to indicate the presence of snow during both dates of 2003 and 2011; this value was referred to as unsuitable habitat in Table 3.

*Layer 3: winter range with no snow and potentially no snow areas in 2003 and 2011*

Layer 3 of the GIS model identified suitable winter range habitat for bighorn sheep where no snow and potentially no snow areas can be found in 2003 and 2011 data images. Current winter habitat research in Utah shows that bighorn sheep abandon areas that exceed 25 cm (11 inches) of snow pack (Montana Fish & Wildlife, 2010). Therefore, a raster calculator analysis was used to quantify the total square kilometers ($km^2$) of no snow (value 0) and potentially no snow (value 1) areas in each of the six plots.

*Layer 4: optimal winter range with no snow, potentially no snow areas and southern aspects*

Layer 4 of the GIS model took the suitable winter range analysis one step further by identifying area in layer 3 with optimal no snow and potentially no snow areas with south facing aspects of 135°–225° (Gudorf, Sweanor, & J, 1996). Suitable winter range has been classified as areas of little to no snow cover and where southern wind-swept peaks are located (Montana Fish & Wildlife, 2010; S. Torres, CDFW, personal communication, April, 2014). Sierra Nevada bighorn sheep (*Ovis canadensis sierrae*) in Inyo County, California have been found to survive the harshest of winters by either selecting high elevation or low elevation terrain with patches of vegetation on south or east facing wind-swept peaks (Alex Few, CDFW, Personnel communications, December 2013). This suggests that bighorn sheep will use several winter strategies in relation to elevation migration to find the most nutrient rich and snow free habitat to survive the coldest winter months. Layer 4 is classified in Table 3 as optimal winter habitat. The optimal winter habitat was calculated by performing a raster analysis to find all critical variables where the values in both 2003 and 2011 images contained no snow (value 0) and potentially no snow (value 1) and southern aspects of 135°–225° (Smith et al., 1991; Dicus, 1999). By selecting all these variables, the optimal winter range habitat was identified in each study plot and given a value of one (1) in each grid cell. Finally Layer 4 was summed to find the total area in $km^2$ of optimal winter habitat per study plot. The sum of the optimal habitat in Layer 4 for each plot was then compared to a winter bighorn sheep density in order to determine if each study plot contained enough optimal winter habitat to support a MVP of bighorn sheep.

Table 3: The 2003 and 2011 winter habitat model calculates the amount of opportunistic habitat that has value zero (0) no snow in both 2003 and 2011 data and value one (1) no snow in either 2003 or 2011 with south facing aspects of 135°–225°.

| **Winter Range: Habitat Parameters** | **Definition** | **GIS Values** | **Equation** |
|---|---|---|---|
| | | | |
| **Layer 3: No Snow and Potentially No Snow in 2003 & 2011** | The sum of each plot in $km^2$ of no snow in both 2003 and 2011 & No snow in either 2003 or 2011 data | No snow = 0<br>Potentially No Snow = 1<br>Snow Present =2 | Layer 3 = SUM(Winter= 0 & Winter = 1) |
| | | | |
| **Layer 4: Optimal No Snow Areas and Aspects** | The sum of each plot in $km^2$of layer 3 and aspects of 135°–225°. | Optimal Habitat = 1 (Snow free and Southern Aspect) | Layer 4 = SUM(Layer3 & Aspects >135& Aspects<225) |
| | | | |

*Layer 5: optimal summer and winter range for each plot*

Layer 5 of the GIS model calculated how much suitable summer and winter habitat in $km^2$ was available in each plot from Layers 2 and 4 respectively. We classified plot 2 as a reference plot for comparison to the other plots as it contained the only bighorn sheep GPS presence data available. A ratio of summer over winter habitat [S/W] was calculated to compare suitable habitat in plot 2 to the rest of the six plots in the study area. The plots with the lowest ratio difference, in reference to plot 2, were ranked from 1 as the most suitable to 6 as the most risky plots for a reintroduction effort. The amount of available habitat identified in Layer 5 was then compared to a researched bighorn sheep density to calculate whether each plot provided sufficient suitable summer and winter habitat to support a MVP of 100 - 125 sheep.

*Plot proximity to the nearest domestic sheep allotment*

After evaluating which plots in the study area ranked the highest in suitable habitat, we determined which of these occupied or unoccupied areas are exposed to domestic sheep. In this study, we evaluated the distance from the study plots to the nearest active domestic sheep allotments. The distance measurements were calculated by using the ArcGIS proximity toolset, which measured the distance from the centroid of the summer suitable escape and canopy cover variables in Layer 2 to the nearest active sheep or goat allotment.

After the distance was found of each plot to the nearest allotment, we added a significant threshold buffer that extended 23 km (14.3 miles) from any domestic sheep allotment (Zeigenfuss, Singer, & Gudorf, 2000; Bureau of Land Management, 1992). A 23 km buffer was used as the studies significant indicator of risk as Zeigenfuss et al (2000) found in his bighorn sheep transplants studies that the most successful bighorn transplants were an average of 23 km from domestic sheep (Montana Fish & Wildlife, 2010; Zeigenfuss et al., 2000). Identifying plots and allotments that are less than 23 km distance to domestic sheep has provided this feasibility study a spatial aid to diagnose the riskiest plots and identify active domestic allotments that should be phased out before a reintroduction of bighorn sheep can take place.

## Results

### *Summer range: suitable habitat for desert sheep in the northern Sierra Nevada*

The summer GIS model demonstrates in Layer 2 that plots 5 and 6 south of Lake Tahoe (Fig.1) have more steep escape terrain and open canopy cover than those north of Lake Tahoe plots 1, 2, 3 and 4 (Table 4). The summer GIS model analyzed one critical habitat characteristic in Layer 1 and evaluated two independent habitat variables in Layer 2. Of all critical habitat variables examined, Layer 2 was the best model predictor for suitable summer habitat, as it analyzed two variables that allow scientists to compute the amount of optimal and suitable habitat found in each plot for bighorn sheep (Table 4).

Layer 1 of the summer GIS model distinguished plot 5 as having the largest quantity of optimal escape terrain for bighorn sheep, totaling 93 $km^2$ of optimal escape terrain (slopes of 27° – 85°) and 427.4 $km^2$ of suitable escape terrain (slopes of 27°-85° buffered by 300 m) (Fig. 2). Layer 2 analyzed two critical habitat variables, identifying areas with steep, precipitous escape terrain and open canopy cover that is less than 40% cover. Plot 5 was classified as the plot with the largest amount of optimal escape terrain and low canopy cover habitat totaling, 77.5 $km^2$, and the largest amount of suitable escape terrain with a 300 m buffer, totaling 419.5 $km^2$ of habitat (Fig. 3).

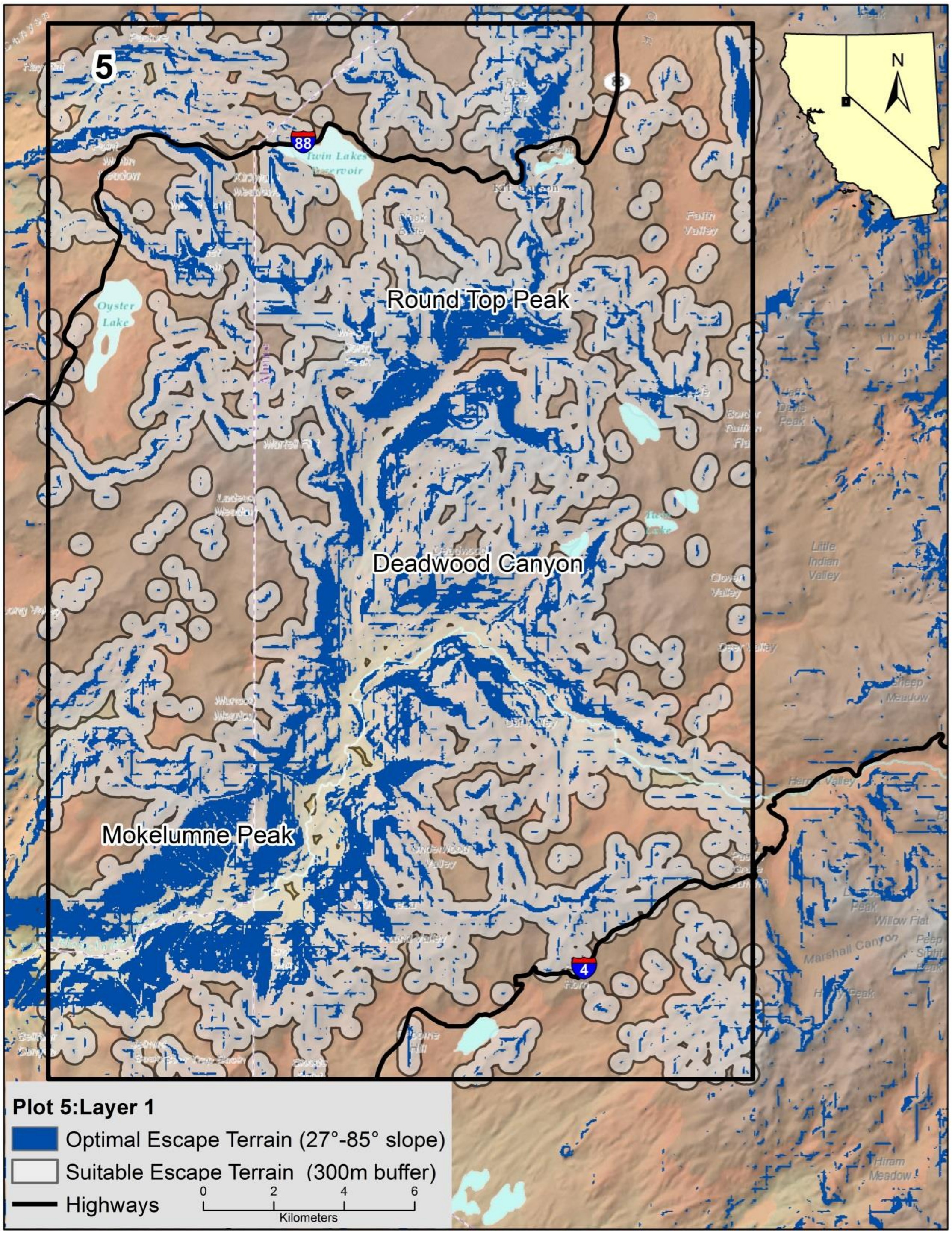


Figure 2: In Layer 1 of the summer suitability model, plot 5 contains the largest amount of optimal and suitable escape terrain defined by critical slope variables in table 2

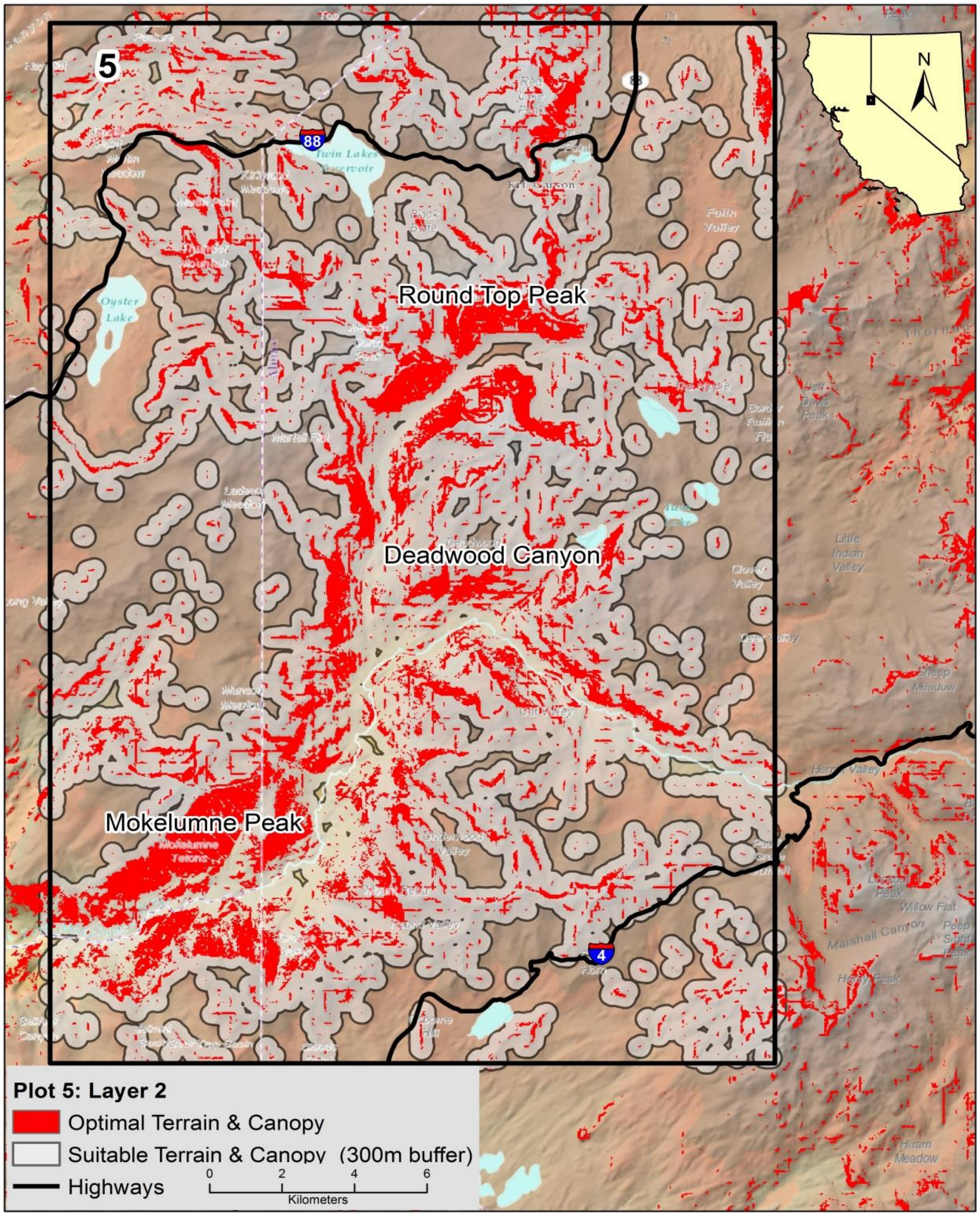


Figure 3: Layer 2 of the summer habitat suitability model identifies plot 5 as having the largest amount of optimal escape terrain and areas that are less than 40% canopy cover. These two critical habitat variables aid in predicting a spatial summer home range area for a reintroduced bighorn sheep herd.

Table 4: Optimal and suitable plot areas (km$^2$) satisfying summer range criteria for a bighorn sheep herd in the northern Sierra Nevada.

| **Plots** | **Layer 1:** (km$^2$) | | **Layer 2:** (km$^2$) | |
|---|---|---|---|---|
| # | Optimal Escape Terrain | Suitable Escape Terrain with 300 m Buffer | Optimal Escape Terrain & Canopy Cover | Suitable Escape Terrain & Canopy Cover with 300 m Buffer |
| 1 | 41.22 | 298.9 | 35.8 | 292.4 |
| 2 | 46.2 | 311.4 | 46.2 | 311.4 |
| 3 | 64.1 | 416.51 | 43.2 | 375.9 |
| 4 | 73.1 | 386 | 65.6 | 374.8 |
| 5 | 93 | 427.4 | 77.5 | 419.5 |
| 6 | 84 | 298.1 | 73.9 | 294.6 |

### *Winter range: suitable habitat for desert sheep in the northern Sierra Nevada*

Of all the critical habitat variables examined for winter range, Layer 4 was the best model predictor for winter range as it analyzed two critical habitat variables that included no snow areas and south facing aspects (Table 5). Layer 3 of the winter range feasibility study found plot 1 to contain the largest amount of no snow and potentially no snow areas totaling 464.4 km$^2$ of winter habitat (Fig. 4). When applying the southern aspects attribute (125°-225°) in Layer 4, plot 2 emerged as the largest plot, with a total of 132.8 km$^2$ of optimal no snow areas and south facing aspects (Fig.5).

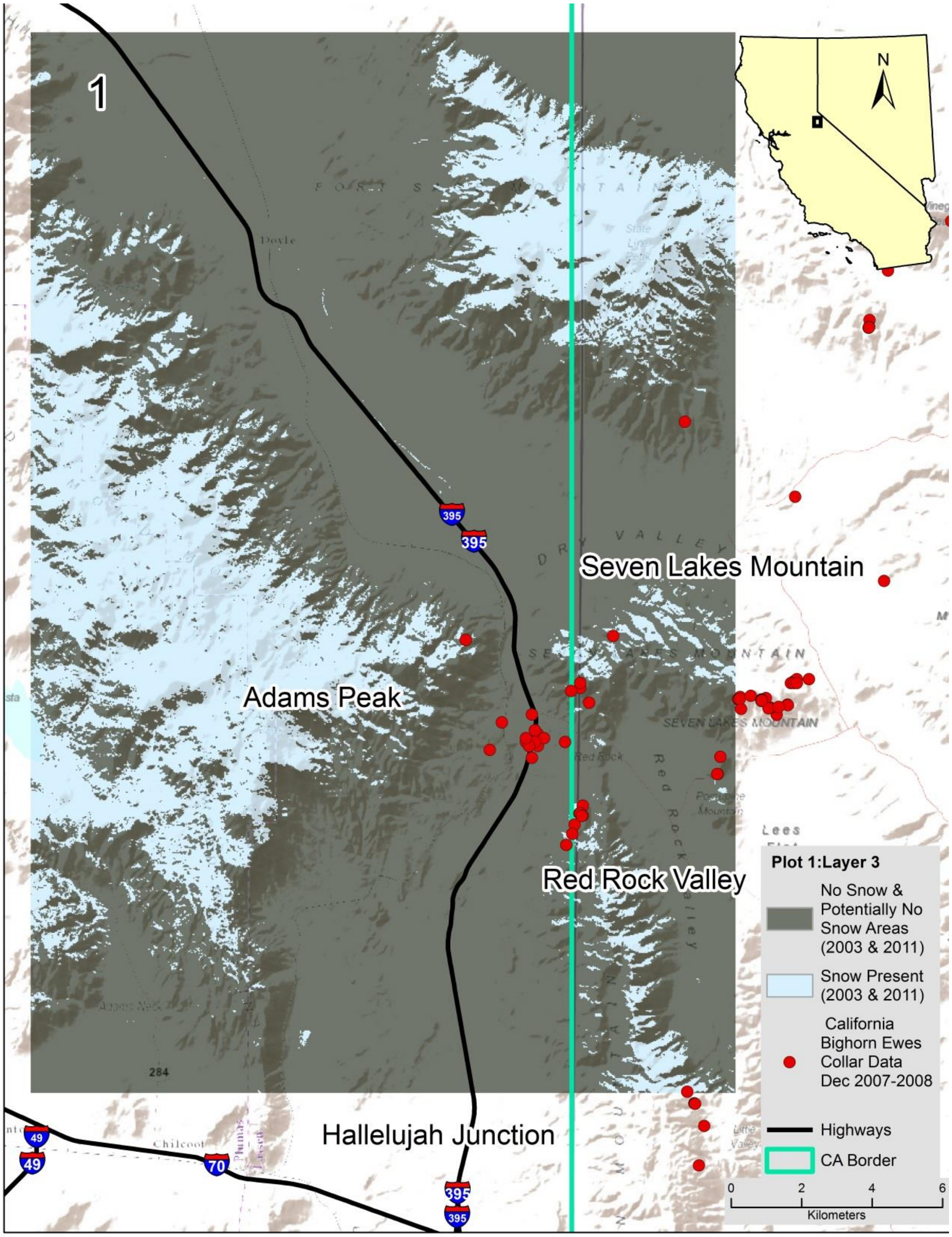


Figure 4: Plot 1, in Layer 3, of the winter suitability contains the largest amount of no snow and potentially no snow area.

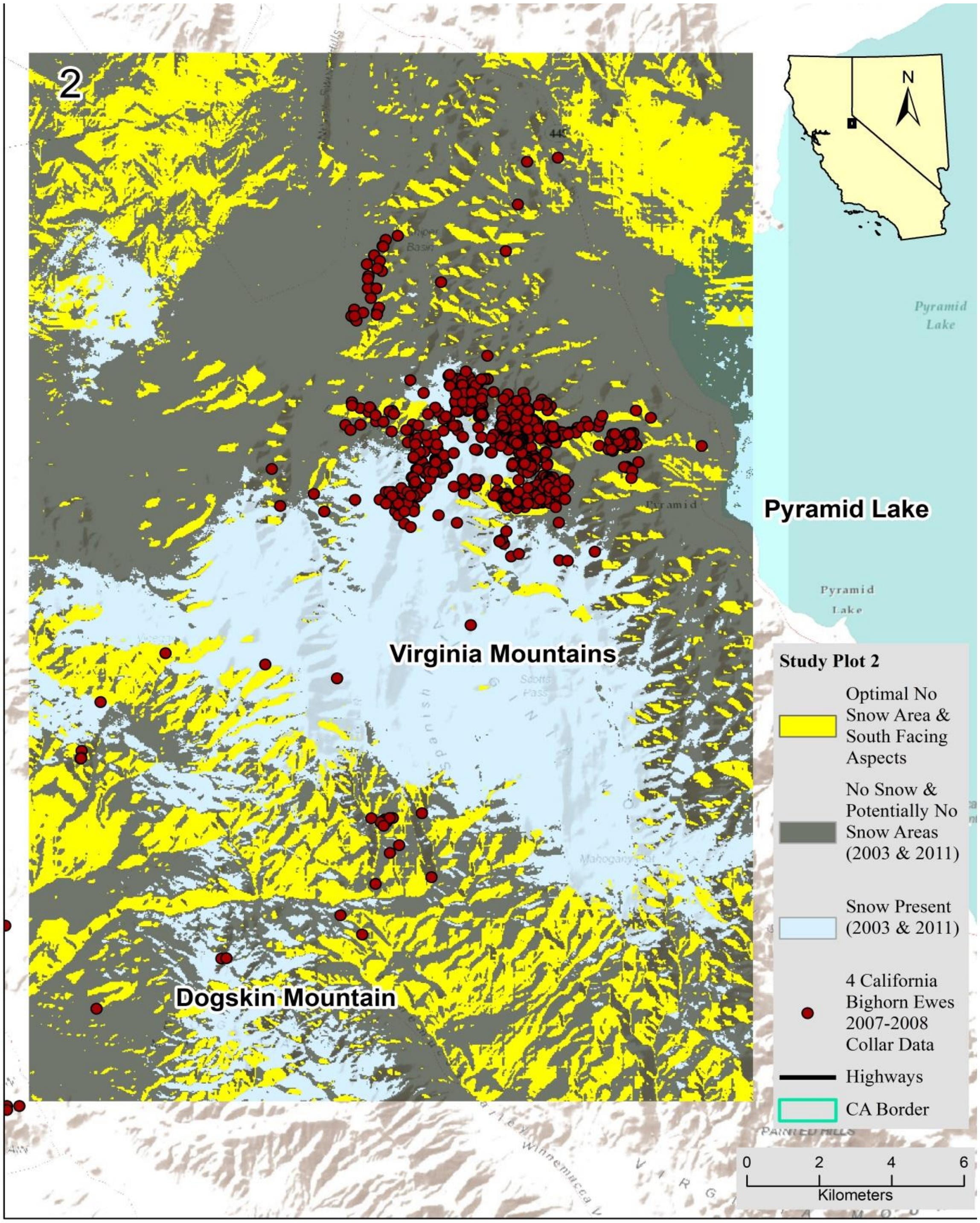


Figure 5: Plot 2, in Layer 4, of the winter suitability model contains the largest amount of no snow and potentially no snow areas with southern aspects

Table 5: Layer 3 and Layer 4 plot areas ($km^2$) satisfying winter range criteria for a bighorn sheep herd in the northern Sierra Nevada

| **Plots** | | **Layer 3:** ($km^2$) | **Layer 4:** ($km^2$) |
|---|---|---|---|
| # | No Snow in Both 2003 + 2011 | No Snow and Potentially No Snow Areas in 2003 + 2011 | Optimal No Snow Areas and Aspects |
| 1 | 313.1 | 464.4 | 115.37 |
| 2 | 298 | 446 | 132.8 |
| 3 | 0.4 | 81.5 | 49.8 |
| 4 | 133.1 | 331.2 | 97.34 |
| 5 | 10 | 68.9 | 34 |
| 6 | 313.1 | 398.1 | 67.4 |

*Layer 5: ranking of summer and winter range habitat*

The six study plots have been compared and ranked to illustrate which of the six plots contain the most amount of habitat per range. The plots with the largest amount of summer habitat consistently contained the lowest amount of winter habitat (Fig.6). A ratio rank from 1 to 6, 1 being the lowest and most suitable rank, was used to evaluate the greatest suitability and risk of each study plot for a reintroduction effort (Fig 7.) As a result, study plot 2 ranked the lowest with a ratio of 2.3 and a score of 1. Conversely, plot 5 had the highest ratio of 12.3 and a high score of 6, which indicates plot 5 as the riskiest plot for a relocation effort.

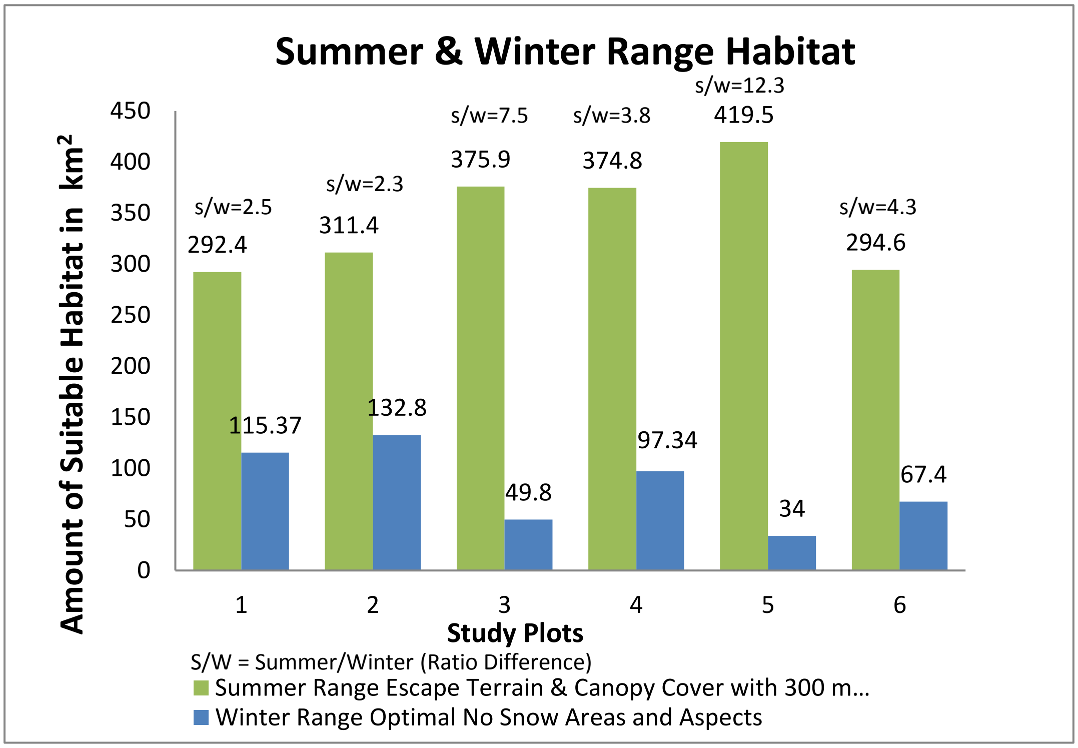


Figure 6: Total quantity of summer and winter range habitat for each study plot calculated in km2. The inverse relationship between a larger summer range and a smaller winter range can be observed among most of the study plots. The ratio difference of summer divided by winter range [S/W] was calculated to assist in comparing ratios of ranges to plot 2, which is occupied by sheep

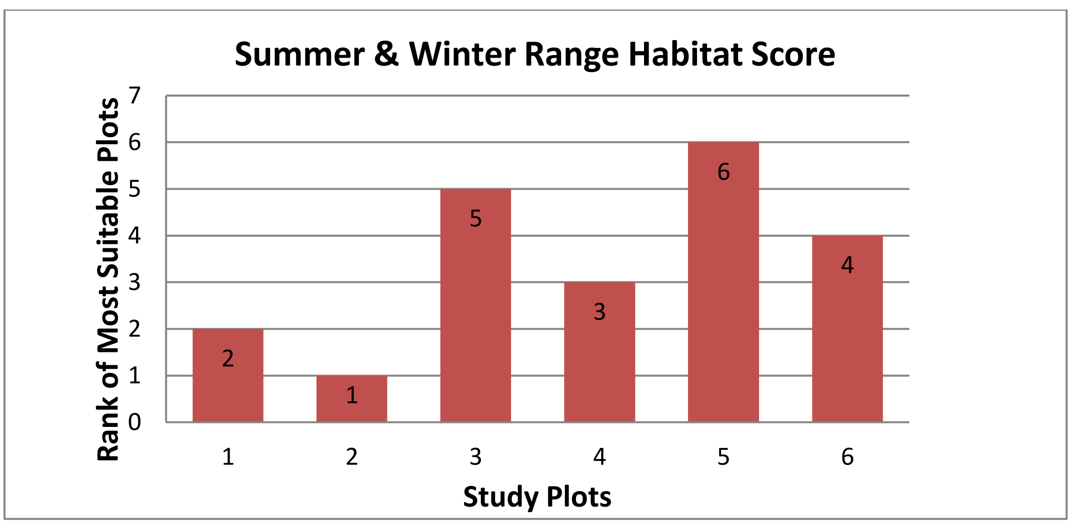


Figure 7: Habitat suitability scores rank both summer and winter range habitat using the ratio difference values of [S/W] to determine the feasibility rank of each plot for a reintroduction effort of bighorn sheep.

### *The proximity of plots to domestic sheep*

US Forest Service (USFS) and Bureau of Land Management (BLM) active domestic sheep allotments were identified by current GIS shapefiles supplied by USFS and Nevada Department of Fish and Wildlife (NDOW). The primary risk of a bighorn sheep reintroduction effort is the proximity of the transplanted herd to the nearest domestic sheep or goat allotment. Identifying areas of federal grazing allotments provide scientists with the initial risk assessment data needed to evaluate distances and other risks (Fig.8). When applying proximity analysis in ArcGIS, plot 4 was classified as the riskiest plot because it was the closest to domestic sheep with a distance of 5.5 $km^2$ (Table 5). Conversely, plot 2 and 6 were considered the furthest away from an active domestic sheep allotment with distances of 26.9 km and 23.3 km (Table 6).

Table 6: Proximity values were calculated from the centroid of the study plot to the nearest domestic sheep allotment

| **Plot** | **Proximity to active domestic sheep allotments in Kilometers** |
|---:|---:|
| 1 | 17.8 |
| 2 | 26.9 |
| 3 | 12.2 |
| 4 | 5.5 |
| 5 | 16.9 |
| 6 | 23.3 |

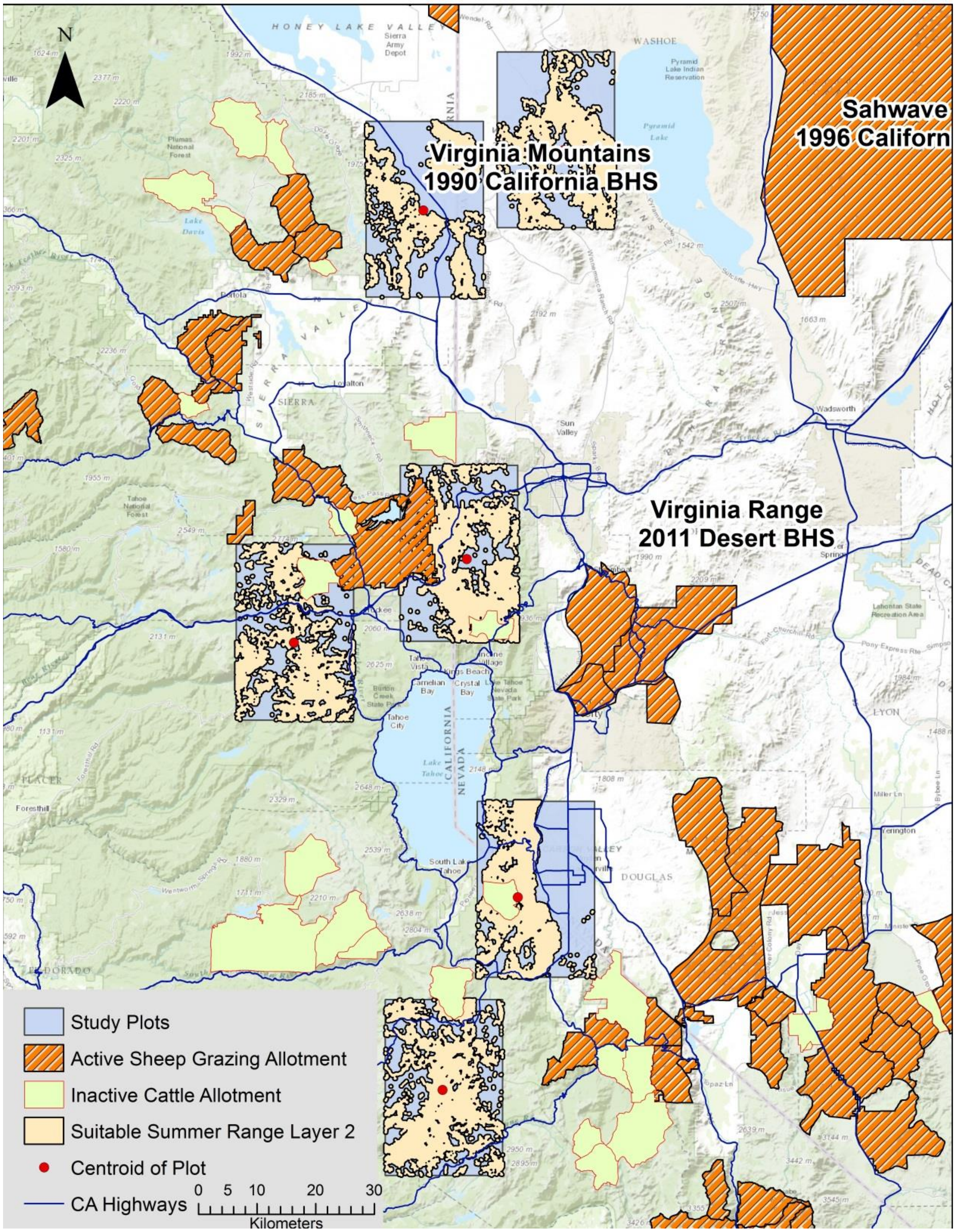


Figure 8: Distribution of domestic sheep allotments on USFS and BLM managed land in Northern California.

## Discussion

Ewes and rams have been tracked crossing the borders of Nevada into Red Rock Valley, California suggesting that northern California could have potential habitat for bighorn sheep persistence. However, reintroduction of a species into its historic or potential range is a costly effort with a high risk of failure and the ability to create an imbalance in the ecosystem present. As a result a habitat feasibility study was necessary to evaluate whether the northern Sierra Nevada mountain range contained enough suitable summer and winter range habitat to support a viable population of bighorn sheep.

Six study plots were evaluated in the northern Sierra Nevada, and suitable summer habitat was found in all six plots to exceed the minimum area required to support a viable population of bighorn sheep (15- 17 $km^2$ for 100 – 125 sheep) (Singer et al., 2000;Smith et al., 1991; Gilad et al., 2013). The White Mountain desert bighorn sheep data was analyzed from Inyo County, but accurate total sheep densities could not be derived from the inconsistent minimum ewe counts data available for the White Mountain herd, which is located 48 km northeast of Bishop, California. With similar escape terrain and precipitation levels, we used the researched density figures from Utah's data of California bighorn sheep, which was surveyed at 7.7 bighorns per $km^2$, suggested by Smith et al (1991), to calculate 15- 17 $km^2$ of summer habitat needed to support a MVP of 100 - 125 bighorn sheep (Montana Fish & Wildlife, 2010;Smith et al., 1991). As 7.7 bighorns per $km^2$ may be a high density for the northern Sierra Nevada, we took into account an average range of summer habitat densities from other studies. Zeigenfuss et al. (2000), using a modified version of the Smith model, averaged bighorn densities for a variety of study sites and found that Rocky Mountain habitat had a differing average density of 1.47 bighorn/ $km^2$, which took 85 $km^2$ of suitable habitat to support a MVP of 100 -125 sheep (Montana Fish Wildlife & Parks, 2010). Using a range of density figures with similar escape terrain and habitat, we have found that all six study plots exceed 15 – 85 $km^2$ of suitable summer habitat with the lowest suitable area totaling 292.4 $km^2$ in plot 1 of Layer 2 (Table 4).

### ***Habitat quantity***

In summary, all six plots exceeded the 15-17 $km^2$ of year-round habitat needed to support an MVP of 100-125 bighorn sheep (Table 4). This is a significant finding as preferred habitat for bighorn sheep is primarily on steep escape terrain that is visually open, which allows bighorn sheep to easily detect and evade predators (Wehausen, 2013).

Winter range was defined as all escape terrain that receives less than 25 cm of snow pack (Smith et al., 1991). Smith found, when averaging bighorn sheep densities across a number of western winter ranges, that sheep density does not exceed 20 sheep per km $^2$(Montana Fish Wildlife & Parks, 2010; Smith et al., 1991). Wehausen (1983) also reported winter densities averaging 20 bighorn sheep per $km^2$ for the Sierra Nevada Mt. Baxter herd. These two sources support our decision to use the winter range sheep density of 20 $km^2$ to calculate the required winter habitat in the GIS habitat model. As a result, five out of six plots surpassed 6.25 $km^2$ of absolute snow-free winter habitat in 2003 and 2011 (Table 5), which strongly suggests the majority of plots could support bighorn sheep in the harshest of winters. Likewise on an average snow year, in Layer 4, all six plots have been found to exceed 6.25 $km^2$ of snow-free habitat with south facing aspect. This is a significant finding as many biologist believed that the winter range habitat for bighorn sheep would be a limiting factor in the northern Sierra Nevada mountains as high snow fall would decrease the quantity of available nutrients for a herd. Even though snow-free areas are present, seasonal forage quality needs to be further evaluated to identify the quality of winter range for a herd's survival.

The only plot that did not exceed the allotted 6.25 $km^2$ of snow-free habitat was plot 3. The data showed that in an extreme snow year such as 2011, plot 3 would only contained .4 $km^2$ of absolute snow-free habitat, but on an average year it would contain 81.5 .4 $km^2$ . Therefore, plot 3 was eliminated as a feasible reintroduction plot because it did not contain enough summer and winter home range habitat to support a long term MVP of 100- 125 bighorn sheep.

Furthermore, the results in all six study plots presented three distinct patterns of data, which can assist wildlife biologists in interpreting and ranking plots from the most suitable to most risky for a possible relocation effort. The three patterns that emerged in the results data included: (1) An inverse relationship was observed between the total sum of summer vs winter habitat recorded in the plots studied (Fig.5). (2) The smallest ratio difference of [S/W] was found in plot 1 and 2, which ultimately had bighorn sheep present. (3) Increasingly larger ratio differences of [S/W] were observed in plots moving west from the Nevada-California border.

The first pattern (Fig 5) indicates that an inverse relationship exists in the amount of summer habitat and winter habitat available for the plots studied. For example in plot 5, the summer habitat was quantified as having the largest sum out of all six plots, while the winter habitat was recorded as the lowest of all plots. This pattern reveals that the southernmost plots below Tahoe (Fig.1) have an abundance of steep and open summer escape terrain, but a much more limiting winter range. The inverse relationship in habitat identifies these plots as having the greatest geographic extremes, which could potentially suggest a higher risk for a relocation effort.

The second pattern demonstrates that the plots with the smallest ratios between summer and winter habitat ranges [S/W] were also the plots with the initial sheep presence data. These were plots 1 and 2 (Fig.5). When comparing range ratios, plot 2, on the California-Nevada border, was identified as the best suitable home range with the smallest difference between available summer and winter habitat. This result tends to support the summer and winter models produced and the scoring method used. Since there is a successful reintroduced herd of California bighorn sheep near this area of the California border, we can use plot 2 as a known reference plot to compare the [S/W] ratio of summer and winter habitat to other plot. However, though plot 2 can be used as a reference plot, it is important to note that even the most suitable and least suitable plots in this feasibility study have all reached their significant threshold of density, meaning each plot could theoretically sustain a viable population of 100 -125 sheep.

The third pattern observed was that the [S/W] ratios (Fig 5.) become larger as the plots move west from the Nevada and California border (Fig. 1). The pattern suggests that the plots nearest to the Nevada border have the least geographic extremes and habitat variance based on the resource requirement of summer and winter habitat selected. Therefore, this pattern could be due to a combination of factors such as the location of the plot or an increase in precipitation moving west over the crest of the Sierra Nevada mountains.

Interestingly, plot 1 and plot 4 were the lowest scoring plots after comparing their summer and winter range ratios to plot 2, the reference plot. Plot 1 is significant as a California bighorn sheep population consisting of both ewes and rams were tracked and observed crossing Highway 395 from Nevada into suitable habitat in California through the months of December and January of 2007 and 2009 respectively. This signifies that this plot could contain a high quality of winter range habitat, which sheep are seeking to occupy.

Additionally, female bighorn sheep are observed to be more reluctant to move across large distances without escape terrain (Geist, 1971; Wehausen, 2013). Therefore, the natural dispersal of ewes from plot 2 to plot 1 in California could suggest an action of natural re-colonization. The dispersal of ewes could mean that the northern Sierra Nevada may have enough suitable habitats to maintain a genetically viable metapopulation of sheep.

### *The highest scoring plots*

Plot 1 should be considered as one of the top plots for a natural recolonization effort of California bighorn sheep. Because plot 1 has high habitat suitability and female ewes present, it should be further studied and protected to enhance the possibilities of a natural colonization effort into northern California. The model data can be used to initiate further conversation between USFS and BLM about the possibilities of phasing out nearby domestic sheep or goat allotments to protect migratory bighorn sheep appearing near Red Rock Road and Hallelujah Junction, California.

Plot 4 should also be considered as one of the top plots for a reintroduction effort as it contains a low summer to winter range ratio and is also recognized as a plot with historical occupancy (Fig.1). In this plot, there are several unobstructed corridors from suitable winter range to suitable summer range assuming the sheep would winter on the east side of the Sierra Nevada mountains near Martis Peak or Juniper Hill. A disadvantage to this plot is that highway 80 runs through the Truckee River Canyon separating important migratory corridors from the north to the southern end of the plot. Without wildlife corridors or fencing, a reintroduction into this area could increase vehicle collision or create an island of sheep. Lastly, the suitable summer habitat in this plot extends mostly into Nevada, which initially could create a migratory herd moving along the upper Tahoe Rim Trail into Relay Peak and out of California.

### *Domestic sheep proximity and risk*

After evaluating areas that contribute to suitable habitat in the northern Sierra Nevada, we evaluated which study plots are most exposed to domestic sheep. Each threat needs to be looked at from the standpoint of unique populations and individual locations, which we have applied to the overall evaluation (Wehausen, 1999).

One of the biggest concerns in relocating bighorn sheep in California and along the borders of Nevada is the potential contact between domestic sheep and wild bighorn sheep. Domestic sheep or goat grazing creates the greatest threat for a reintroduced bighorn sheep population due to the potential transmission of microbes that cause respiratory disease, such as pneumonia, which has been proven to lead to fatal sheep die off records (Wehausen, 2013).

We have learned from the past reintroductions that transplants are the most successful when bighorn sheep and domestic sheep are spatially separated with a buffer in order to minimize the possibilities of contact. There has been considerable research on the significant threshold distances and the recommendation for how far a transplant site should be away from an active domestic sheep herd. For this study, we used Zeigenfuss, et. al. (2000) which looked at a number of successful and unsuccessful transplants and found that the most successful bighorn sheep transplants were on average 23 km away from domestic sheep (Montana Fish Wildlife & Parks, 2010;). Even though the distance of 23 km was incorporated in this feasibility study, wandering rams occasionally have been documented through GPS collars to travel as far as 40 to 50 km to different mountain ranges in search of potential mates (Ben Gonzales, CDFW, personal communication, July, 2014). From this feasibility study, plot 2 and 6 were the only plots that were further than 23 km away from an active USFS or BLM domestic sheep allotment. Therefore, current proximity to domestic sheep is a limiting factor in successfully reintroducing a bighorn sheep herd into the northern Sierra Nevada mountain range. Federal grazing allotments shown in Fig. 8 will need to be discussed and phased out before a reintroduction plan continues.

In summary, plots 2 and 6 are the only plots that can be recommended for a successful reintroduction effort at this time. Both sites contain enough suitable habitat in the summer and winter range, and they are also further than 23 km from active sheep allotments.

### *Habitat characteristics not included*

Several habitat characteristics were not included in this habitat feasibility study: they are water sources, connectivity of habitat, quality of forage available, proximity of site to adjacent land ownership and mountain lion predation.

*Water sources.* Perennial and consistent surface water is available in the northern Sierra Nevada due to high precipitation and snow melt off in the spring. Therefore, like the Sierra Nevada bighorn sheep herd located in Inyo County, the competition for surface water in the north Sierra Nevada would not be a limiting resource as bighorn sheep could obtain enough drinking water from perennial streams or the moisture within their forage (John Wehausen, personal communication, November, 2013). Thus, no criteria in the summer model were used to define areas that could supply perennial water for bighorn sheep in this study area.

*Connectivity of habitat.* A habitat connectivity component should be considered when evaluating possible study plot areas for a reintroduction effort of bighorn sheep. Habitat patches and range connectivity vary greatly in California with the diverse geography and the increase in urbanization. Wehausen and Bleich state that the ability of bighorn sheep to migrate between population patches is essential for increased gene flow, genetic diversity, and the long term sustainability of a population (Wehausen, 2013). However, metapopulation connectivity can be a double edge sword. Disease and predators are also likely to disperse through habitat corridors putting sheep population at greater risk than isolated herds (Ca Department Fish and Wildlife, 1986; Singer et al., 2000). Additional research in phase II of this study could assess the connective corridors of each plot in relation to a least-cost pathway between plots. With 10-15 collared sheep in phase II of the study, additional genetic samples could be evaluated to determine gene flow and the migration pathways of a bighorn herd.

*Quality of forage.* This study mapped the high elevation snow free patches in winter months but did not evaluate the quality of alpine shrubs or forage resources available for bighorn sheep in each of the plots. Wehausen has suggested that the alpine plant communities present on wind swept peaks in the winter can be lacking as a nutrient rich foraging resource (John Wehausen, personal communication, November, 2014). This is due to the wind wicking away the needed moisture to support quality vegetation growth (Wehausen, 1999). Therefore, before any potential relocation site is picked, the winter patches found on the models need to be surveyed on the ground to evaluate forage availability and quality of nutrients in order to secure a herd's long-term survival.

*Proximity of plot to adjacent private land ownership.* Adjacent land ownership and private land is a significant factor that can contribute to the spread of disease and the survival of a translocated herd. This factor was left out of this study due to insufficient data available from California

Department of Agriculture for active private grazing of livestock. It is known that plots 1 through 4 have more private land ownership than plots 5 and 6. More information will need to be collected on adjacent land ownership and private grazing parcels before a translocation effort is performed.

*Mountain lion predation.* The final factor that was not included in this study was the native predation of mountain lions *(Puma concolor)* on bighorn sheep. No studies were available to characterize whether there was a high or unstable density of mountain lions within the overall study area. However in this study area, plots do overlap with deer herds, which is a preferred species for mountain lions. High canopy cover and deer presence can further suggest that mountain lions, coyotes, bears and other predators will be present around the study area. While the northern Sierra Nevada ecosystem contains predators, we should keep in mind that more than 300 other wildlife species will be available for prey other than bighorn sheep. Nevertheless, research has shown isolated populations of bighorn sheep can be widely depressed from mountain lion predation, which can limit population growth and decrease genetic diversity (Wehausen, 2013). For example, some mountain lions have learned to specialize in hunting bighorn sheep (US Fish and Wildlife Service, 2007). When this occurs, mountain lions have been removed with depredation permits when they are considered a threat to the recovery of the Sierra Nevada bighorn sheep herd, which is listed as a state and federally endangered species. Even though removing predators is not a long-term conservation objective, careful consideration should be given before releasing a herd into unfamiliar territory with a high deer population.

## Conclusion

The northern Sierra Nevada mountains were historically believed to be inhabited by migrating bighorn sheep over 140 years ago. Reintroduction of bighorn sheep into Northern California would restore a native species, increase the habitat quality for the surrounding ecosystem and meet the mission of CDFW and the management policy for bighorn sheep set forth in section 4900 of the Fish and Game Code (California Department Fish and Wildlife, 2014). This feasibility study demonstrated that the northern Sierra Nevada's have a sufficient amount of suitable habitat in each of the six plots evaluated and could support a viable population of 100-125 bighorn sheep. This is significant as many scientists previously thought that the amount of open, steep terrain was limited and could not support a viable carrying capacity of bighorn sheep.

Consequently, the limiting factor that emerged in this study was identifying plots with a proximity threshold greater than 23 km away from an active domestic sheep allotment. Plots 2 and 6 are the only plots that exceed a distance of 23 km away from an active allotment and have sufficient suitable habitat.

We recommend that the results of the study be submitted to USFS and BLM in order to form a California Bighorn Sheep Technical Working Group (CBST) for phase II of the re-introduction plan. This working group could collaborate in ongoing efforts to decrease the risk associated with domestic sheep or phase out federal grazing allotments for domestic sheep or goats near the plots selected for a re-introduction effort.

We recommend that the working group put a high priority in studying and monitoring the potential natural recolonization event of California bighorn sheep crossing over the Nevada-California border from plot 2 into plot 1 (Fig.1). The Nevada Department of Wildlife's collared 6 ewes in 2007-2008 in the Virginia Range. The collared ewes were tracked for the first year utilizing the bordering habitat of Red Rock Valley, CA and areas east of Adams Peak. A GPS collared study in this area would be essential to evaluate whether additional recolonization is currently occurring or if this herd is only migrating seasonally into California's borders.

The second priority should be designing a phase II re-introduction study for plots 4, 6 and 5. These plots were the most suitable plots scored for an experimental phase II reintroduction of 10-15 collared bighorn sheep with the final goal of a larger translocation of 30 sheep if confirmed successful. Within the phase II reintroduction plan, the CBST working group would need to collaborate to phase out or decrease the risk of nearby active domestic sheep allotments and evaluate the winter sub-alpine forage quality at the site selected for a potential reintroduction.

Our management recommendations for phase II of the study need to be evaluated through the California Department of Fish and Wildlife reintroduction and translocation assessment process as follows:

### *Short Term Management Actions Needed for Phase II of the Next Study:*

1. Establish a multidisciplinary California Bighorn Sheep Technical Working Group (CBSTW) comprising US Forest Service, Bureau of Land Management, California Department of Food and Agriculture (CDFA), Nevada Department of Fish and Wildlife

and California Department of Fish and Wildlife to foster open communication and support for advocating phase II of The Status and Relocation of Bighorn Sheep into the northern Sierra Nevada Mountain Range. This group will open communication about public and private domestic sheep allotments and will work towards phasing out active domestic sheep allotments that are within 23 km of the selected plots for reintroduction.

2. Perform an additional 3-5 day alpine shrubs and forage quality survey with a botanist to evaluate the main plant communities and the quality of the sub- alpine shrubs that are most consumed by desert bighorn sheep. This survey will take into account the quantity, quality and location of these forage resources and document whether there is enough nutrient rich vegetation available for a herds survival in winter and summer range.
3. Distribute the Status and Reintroduction of Desert Bighorn Sheep Feasibility study internally to CDFW unit biologists and the bighorn sheep coordinator in order to gather recommendations and support to construct phase II of the collaring and reintroduction of desert bighorn sheep study.

***Long-Term Management:***

1. Ensure the long-term conservation of future bighorn sheep by evaluating the study plots' fragmentation of optimal habitat and the plots range of connectivity to other potential reintroduction sites. This should be studied to ensure future migratory corridors are present to allow a natural colonization event to occur or the establishment of two or more large, self-sustaining populations that are isolated from other populations in the southern Sierra Nevada.
2. Transplant and equip up to 10 – 15 bighorn sheep with GPS collars in one or two of the selected plots evaluated in the Status and Transplant of Bighorn Sheep Feasibility Study for a pilot study. This pilot study would collect data on habitat use, home range, migration patterns and survival rate. If pilot study data shows that a population of 10 -15 bighorn sheep can successfully reproduce and survive, a transplant of 30 additional bighorn sheep would augment this initial population with the intent of creating a completed transplanted bighorn sheep herd.
3. Mountain lion predation and density figures are unknown for the study area as limited scientific studies have been conducted. Deer densities and other predator/prey relationships should be identified in release sites. Careful consideration should be given

when releasing transplanted bighorn sheep into unfamiliar habitat with no knowledge and experience with predators and lack of herd structure (Gilad et al., 2013). The scientist connected with phase II of the Translocation of Bighorn Sheep project can work closely with the newly founded CDFW Mountain Lion Resource Assessment Program to monitor mountain lions and calculate a population density in the area of the planed translocation site.

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