Can GIS Models Predict Habitat Use of Reintroduced Bighorn Sheep?

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ABSTRACT

Habitat-use models for wildlife reintroductions are important management tools. Such predictive models can save managers time and money by ensuring animals are released into suitable habitats. We tested predictive winter and lambing habitat-use models constructed by Whiting et al. (2004) for Rocky Mountain bighorn sheep (*Ovis canadensis canadensis*) on Mount Nebo, Utah. We used ArcGIS 9.2 to determine the number of bighorn sightings within predicted habitats. Additionally, we documented which variables were violated for bighorn sightings outside of modeled habitats. Our results showed that bighorns used predicted slopes, elevations, and vegetation cover types only 40% to 60% of the time during both seasons. Furthermore, only 14% of winter sightings (n = 70) and 18% of lambing sightings (n = 55) were within habitats predicted by Whiting et al. (2004). Finally, we offer suggestions to improve both models, which will aid in the restoration and conservation of bighorns in Utah.

INTRODUCTION

Bighorn sheep (*Ovis canadensis*) are native to Utah and inhabited nearly every mountain range in the state prior to European settlement (Dalton and Spillett 1971). However, these animals were nearly extirpated from Utah by the 1930s, because of competition with domestic livestock, disease, habitat alterations, and human disturbance (Smith et al. 1988). Since 1966, the Utah Division of Wildlife Resources has aggressively reintroduced Rocky Mountain bighorns (*O. c. canadensis*) to Utah with limited success (Smith et al. 1988). Over the past 42 years, only 4 of 17 reintroduced bighorn populations in Utah have been successful (Shannon et al. in review). Reasons for poor reintroduction success are 1) inadequate quantities of available habitat, 2) competition with ungulates, 3) contact with domestic sheep and goats, 4) improper juxtaposition of key habitat components, 5) a lack of one or more critical seasonal ranges, and 6) excessive harassment by humans (Smith et al. 1990).

A common concern of wildlife managers regarding bighorn reintroductions is that animals are moved from one location to another without first assessing the quality and quantity of habitat in the release area (Valdez and Krausman 1999). Bighorn sheep are habitat specialists (Geist 1971, Shackleton et al. 1999), and generally use mountainous areas consisting of steep slopes, rock outcroppings, and precipitous terrain (Smith et al. 1990). Bighorns also prefer open areas with low-growing vegetation and high visibility to detect predators (Risenhoover and Bailey 1985).

Habitat models that predict areas used by reintroduced animals are important management tools (Whiting et al. 2004). Such predictive models can save wildlife managers time and money by ensuring animals are released into areas with suitable

habitat, which increases the probability of a successful reintroduction. Little is known, however, regarding the accuracy of habitat models for bighorns. Whiting et al. (2004) constructed two habitat models that quantified available winter and lambing habitat on Mount Timpanogos, Utah. They then extrapolated these models to Mount Nebo, Utah, to predict areas that bighorns would use after reintroduction. Our objective was to test the accuracy of their models by quantifying habitat use of reintroduced bighorns on Mount Nebo, Utah, during winter and lambing seasons.

STUDY AREA

Mount Timpanogos (40°10´N, 111°30´W) is located in the Uinta National Forest near Provo, Utah (Fig. 1). Elevations range from 1,388 to 3,582 m. This mountain, which is part of the Wasatch Mount Range, is oriented north to south and is experiencing urban encroachment from the west (Whiting et al. 2008). Dominant cover types described by the United States Forest Service (2002) in this area included: mahogany/oak (MOAK), mountain mahogany/bitter brush (MMBB), oak (OAK), oak/maple (OKMP), rocky outcrop (OUTC), perennial grass (PERG), pinyon/juniper (PJ), scree (SCRE), spruce/fir with a crown density of 15-59% (SF15), spruce/fir with a crown density of 60-100% (SF60), snowberry (SNBE), big sagebrush (VAS), mountain brush (BRSH), grass/forb complex (GRFB), oak/pinyon-juniper (OKPJ), sagebrush (SAGE), and white-fir (WF).

Since 2000, 82 bighorn sheep have been released on Mount Timpanogos, and 32 bighorns have been released in nearby Rock Canyon. In January 2008, 92 animals inhabited these 2 areas. Bighorns from Mount Timpanogos and Rock Canyon interacted and therefore were considered a metapopulation. In this paper, we referred to both populations as the Mount Timpanogos herd.

Mount Nebo (40°14´N, 111°39´W) is also located in the Uinta National Forest (Fig. 1), approximately 60 km south of Mount Timpanogos (Whiting et al. 2008). Elevations are slightly higher than Mount Timpanogos, ranging from 1,501 m to 3,636 m. Dominant cover types are similar to those on Mount Timpanogos (USFS 2002).

Since 2004, 43 bighorn sheep have been reintroduced on Mount Nebo. In 2008, the population estimate for this herd was 35 animals. Furthermore, bighorns on Mount Nebo were isolated from other populations of bighorn sheep.

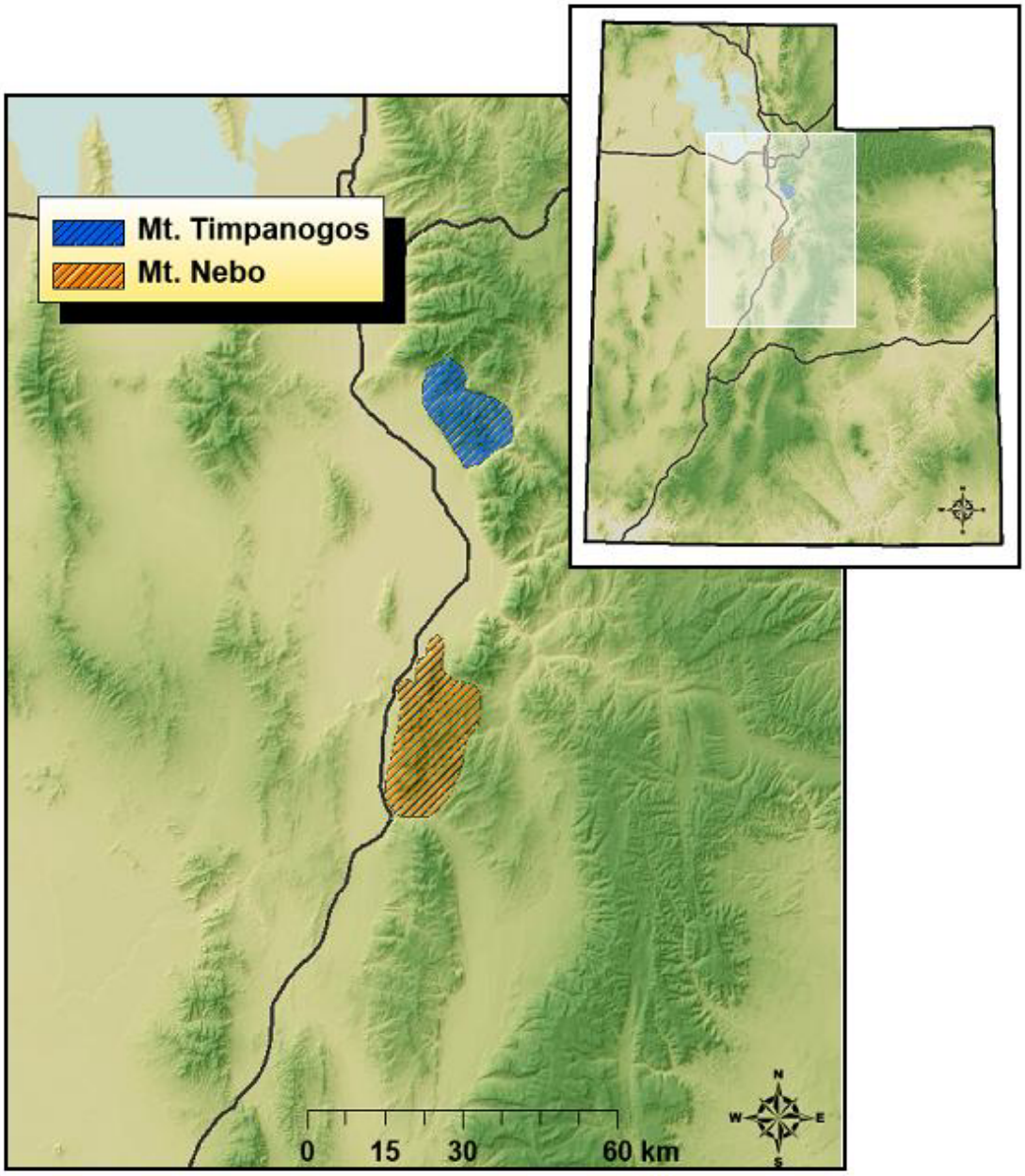


Figure 1. Mount Timpanogos and Mount Nebo in north-central Utah.

METHODS

Winter and Lambing Habitat Models

In 2004, Whiting et al. constructed winter and lambing habitat models for Mount Nebo using sightings of reintroduced bighorn sheep on Mount Timpanogos. They collected 306 winter locations and 244 lambing locations from 2001 to 2003. Winter was defined as November through April, and lambing season was defined as 1 May to 30 June. They recorded habitat use for 4 variables: elevation, slope, aspect, and cover type (Table 1).

Elevation was treated as a continuous variable, whereas slope, aspect, and cover type were considered categorical variables. For elevation, they included all locations within 2 standard deviations of the mean elevation used during each season. For categorical variables, only those categories with at least 5% frequency were included in the models (Table 1.). Their models predicted 1,102 ha of winter habitat and 3,310 ha of lambing habitat on Mount Nebo (Whiting et al. 2004).

Table 1. Winter and lambing habitat models developed by Whiting et al. (2004) for bighorn sheep on Mount Nebo, Utah.

	Habitat Models	
Variable	Lambing	Winter
Elevation	1628-2380 m	1612-2196 m
Slope	26.1-39.2°	21.6-34.7°
Aspect	All aspects except NE and E	SE, S, SW, W, and NW
Cover Types	MOAK, OAK, OUTC, PERG PJ, SCRE, SF-15	MMBB, OAK, OUTC, OKMP, PERG, PJ, SNBE

Model Assessment

The reintroduction of bighorn sheep to Mount Nebo in December 2004 provided an opportunity to assess the accuracy of habitat models developed by Whiting et al. (2004). We reconstructed winter and lambing habitat models (Whiting et al. 2004) for the Mount Nebo study area using ArcGIS 9.2 (ESRI, Redlands, CA). Similar to Whiting et al. (2004), we located and observed bighorns with transmitting collars using radio receivers, binoculars, and spotting scopes. Winter range locations of all bighorns were collected from 1 November to 30 April and lambing range locations of ewes and lambs from 1 May to 30 June. We then overlaid bighorn locations on predicted winter and lambing habitats to obtain the percentage of locations that fell within each model. To account for inherent errors associated with mapping locations, we created “distance to model” layers for observations outside of modeled habitats using Euclidean Distance tool in Spatial Analyst. This allowed us to assess how far observations occurred from modeled habitat. Additionally, for each bighorn location we ascribed a value for elevation, slope, aspect, and cover type. We used a 10 m Digital Elevation Model (DEM) obtained from the United States Geological Survey to acquire elevation values. We also used the 10 m DEM to create slope and aspect layers using Spatial Analyst in ArcGIS 9.2 (ESRI, Redlands, CA). Finally, we overlaid bighorn locations on a cover type layer obtained from the United States Forest Service (2002) to ascertain which vegetation types were utilized by bighorns.

To determine potential causes of model inaccuracy, we tested for differences in habitat use variables between bighorn locations on Mount Timpanogos and on Mount Nebo. We performed all statistical analyses in NCSS 2007 (NCSS, Kaysville, UT). For continuous variables (slope and elevation), we used the Aspin-Welch unequal-variance test or the Wilcoxon rank-sum test. We initially transformed the data; however, variables still lacked normality and had unequal variances. We tested for differences in aspect, which was a categorical variable, by using a Chi-square test. Finally, because of inadequate sample sizes, we did not test for differences in cover types.

RESULTS

Winter Habitat Model

During winter from 2005 to 2007, we observed bighorn sheep on Mount Nebo on 70 occasions. Only 14% (n = 10) of bighorn locations fell within the winter habitat model developed by Whiting et al. (2004; Fig. 2). For locations that fell outside the model (n = 60), the median distance to modeled habitat was 205.6 m (Fig. 3). When a 100 m buffer was applied to winter habitat, model accuracy increased to 42.9%. No difference in slope use (P = 0.391, df = 69) existed between bighorns on Mount Timpanogos and Mount Nebo. Bighorns on Mount Nebo, however, used elevations that were 268 m higher than those used by bighorns on Mount Timpanogos (P < 0.001, df = 1). Aspect use also varied between areas, and bighorns on Mount Nebo used south aspects more than expected (P = 0.017, df = 3). Our sample size was too small to test for differences in cover types used by bighorns, although it appeared these animals used different cover types between study areas (Fig. 4). Overall, the winter model accurately predicted the use of slope 50% of the time, aspect 97% of the time, elevation 56% of the time, and cover types 59% of the time on Mount Nebo (Fig. 5).

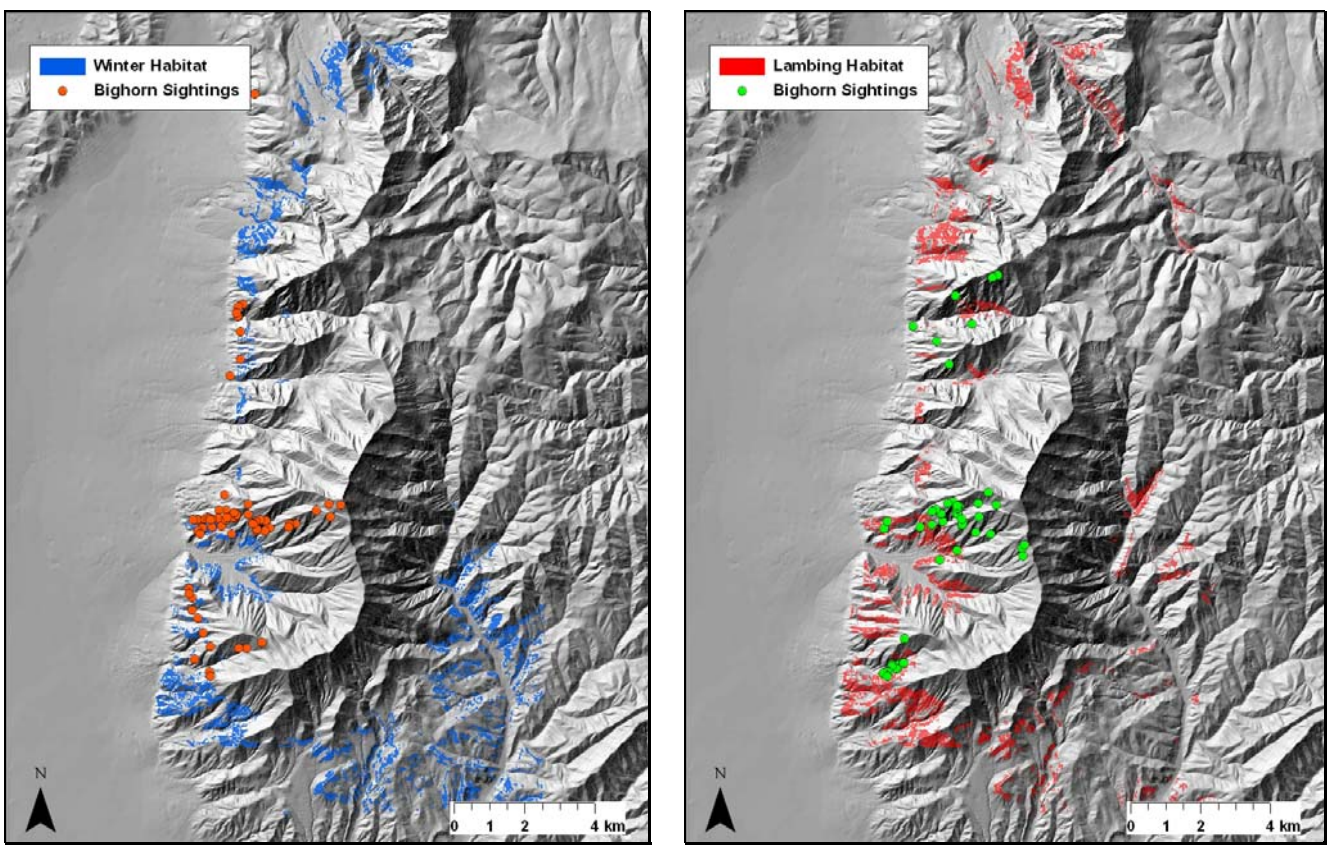
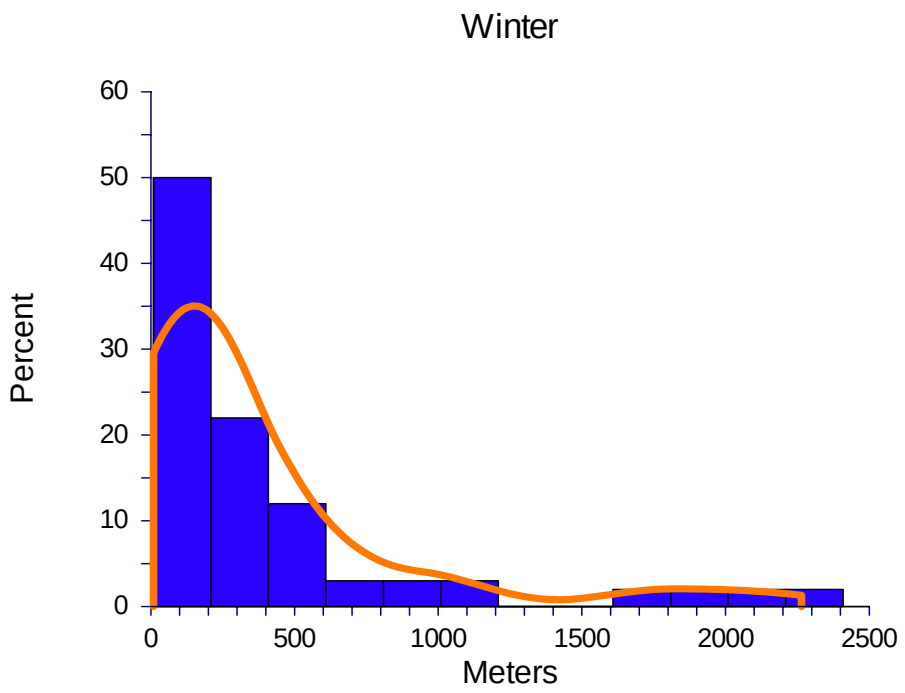


Figure 2. Winter and lambing habitat models (blue and red polygons) constructed by Whiting et al. (2004) for Mount Nebo, Utah. Sightings of reintroduced bighorn sheep (circles) from 2005 to 2007 overlay predicted habitats.



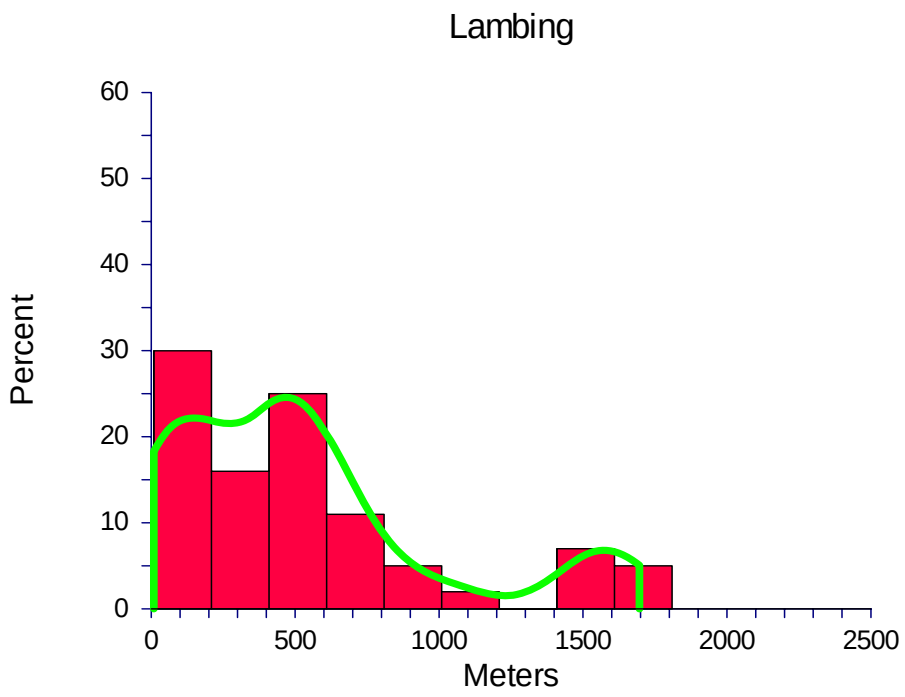
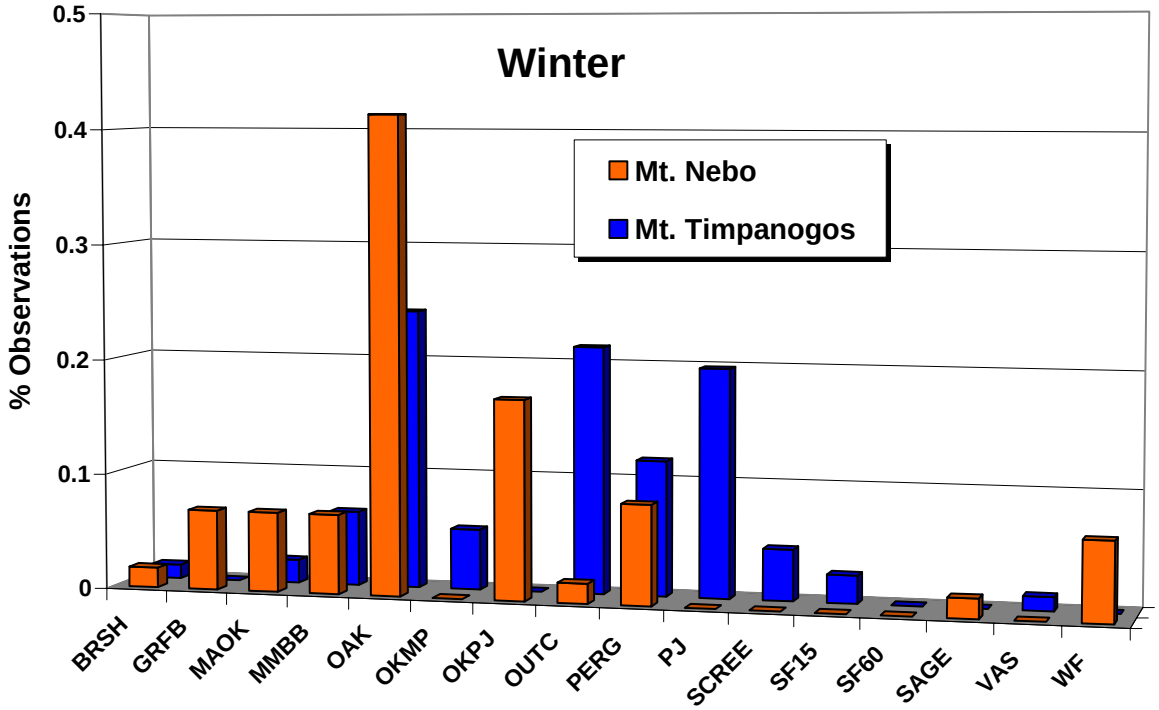


Figure 3. Distance of bighorn locations to predicted winter and lambing habitats on Mount Nebo, Utah.



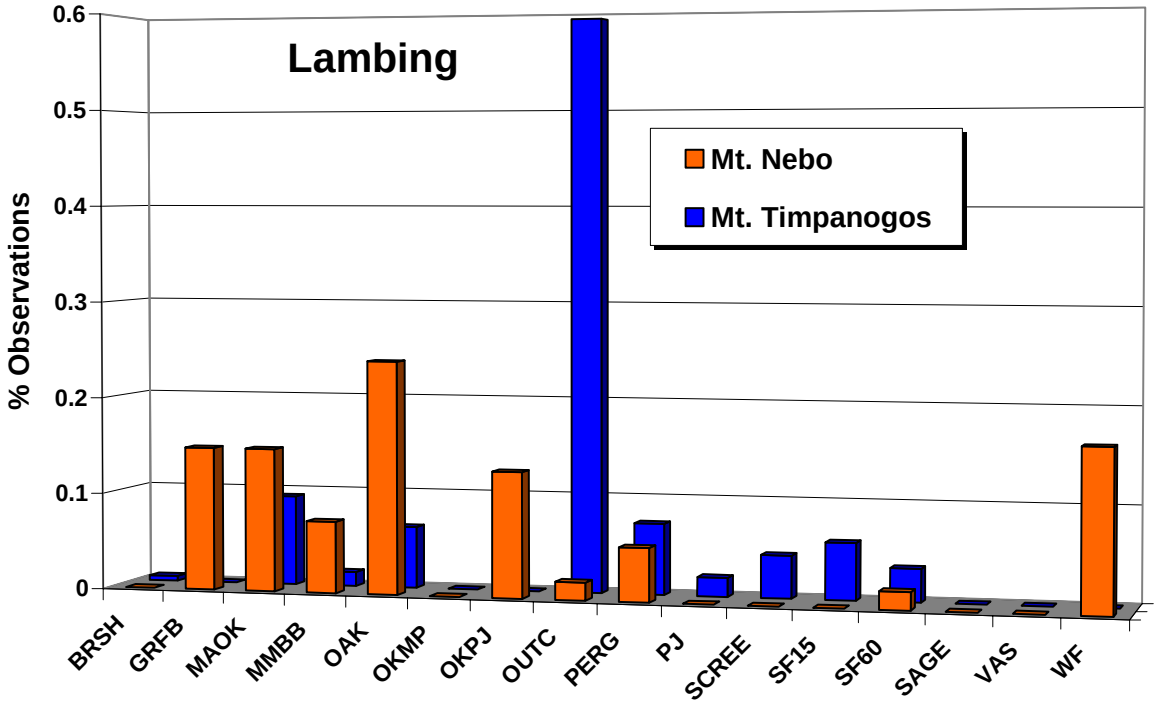


Figure 4. Cover types used by bighorns during winter and lambing seasons on Mount Timpanogos (blue) and Mount Nebo (orange). Bighorns on Mount Timpanogos used considerably more rock outcrops (OUTC) and pinyon-juniper (PJ), whereas bighorns on Mount Nebo used more grass/forb (GRFB), oak (OAK), oak/pinyon-juniper (OKPJ), and white fir (WF) areas.

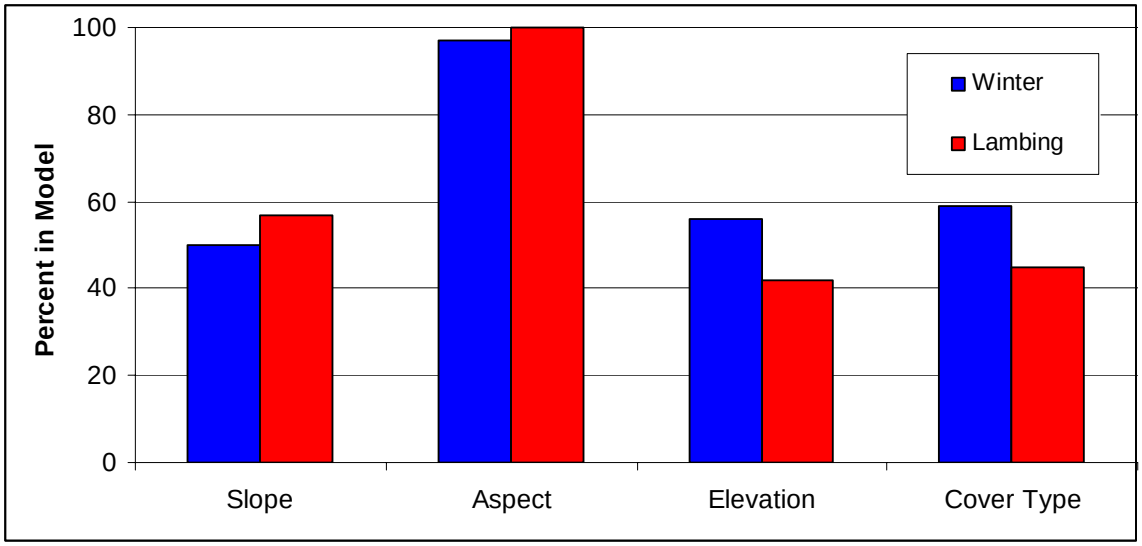


Figure 5. Percent of variables that fit the winter and lambing habitat models. Bighorns on Mount Nebo used higher elevations, steeper slopes, and different cover types than the models predicted by Whiting et al. (2004).

Lambing Habitat Model

During lambing season from 2005 to 2007, we observed bighorns on 55 occasions. Only 18% (n = 10) of bighorn observations fell within the lambing habitat model (Fig. 2). For locations outside of the model (n = 45), the median distance to modeled habitat was 445.7 m (Fig. 3). With a 100 m buffer applied to modeled habitat, model accuracy increased to 36.4%. Slope use ($P < 0.001$, df = 1) and elevation use ($P < 0.001$, df = 1) varied between study areas. Bighorns on Mount Nebo used higher elevations than bighorns on Mount Timpanogos (median difference = 493 m). Although there was a significant difference in slope use, the median difference was only 2.7 degrees, which may not be biologically meaningful. Aspect use did not differ between study areas ($P = 0.526$, df = 3). We did not test for differences in cover type, although bighorns apparently used different cover types on Mount Nebo than on Mount Timpanogos (Fig. 4). Overall, the lambing model accurately predicted the use of slope 57% of the time, aspect 100% of the time, elevation 42% of the time, and cover types 45% of the time on Mount Nebo (Fig. 5).

DISCUSSION

Since 1923, only 41% of bighorn reintroductions in the Western United States and Canada were successful (Singer et al. 2000). Successful reintroductions are highly correlated with the quantity and quality of available bighorn habitat, particularly lambing areas (Zeigenfuss et al. 2000). Although several habitat models using GIS have been constructed and implemented over the past 2 decades, these models seldom used actual bighorn locations and were rarely tested (Johnson and Swift 2000).

When we compared locations of bighorn sheep to habitat modeled by Whiting et al. (2004), we found distinct differences. Bighorns occurred in modeled habitat 18% of the time during lambing and 14% of the time during winter. Even with an addition of a 100 m buffer, model accuracy was increased to only 36% during lambing and 43%

during winter. This level of accuracy is well below the standard of 75% (Schamberger and O'Neil 1986).

The low accuracy of the models developed by Whiting et al. (2004) was in large part due to differences in habitats used by bighorns between study areas. During winter, bighorns used higher elevations and more southerly aspects on Mount Nebo. Moreover, during lambing season, bighorns used higher elevations and steeper slopes than predicted. Cover type use also appeared to be different, which was likely due to differences in availability between the 2 study areas.

Differences in habitat use between bighorns on Mount Timpanogos and Mount Nebo may be attributed to the habitats these animals used in their source herds. For instance, from 2000 to 2002, bighorns from Alberta, Utah, and Sula, Montana were translocated to Mount Timpanogos. From 2004 to 2007, bighorns from Augusta, Montana were reintroduced to Mount Nebo. These animals may have used different slopes, aspects, elevations, and cover types before being translocated to Utah. We did not test for these differences; although, this may explain a portion of the variation in the habitat use of bighorns between the 2 study areas. Further research is warranted regarding habitat use of bighorns before and after being translocated.

In addition to differences in habitat use, these models were poor fits possibly because 1) the variables slope and elevation were too restrictive, 2) aspect was a surrogate variable for the amount of solar radiation an area receives, and 3) the models failed to include variables that were biologically meaningful for bighorn habitat use such as vegetation structure and landscape ruggedness. For instance, bighorn sheep throughout North America have been observed using elevations ranging from 78 m below sea level to 4267 m (Krausman and Bowyer 2003). Therefore, elevation use may not be a variable robust enough to extrapolate from one area to another, and we recommend excluding it from the models.

Furthermore, slope use was too restrictive in the models created by Whiting et al. (2004), particularly during lambing season. Bighorns seclude themselves in steep, precipitous terrain (ie. escape terrain) during the birthing season to avoid predators and protect neonates (Bleich et al. 1997). Escape terrain is often described as rock outcroppings or slopes from 27° to 85° (Smith et al. 1990). Therefore, we recommend loosening the upper parameters of slope use from 34.7° during winter and 39.2° during lambing to 85° for both seasons.

Aspect contributed little to the models because 62.5% to 75% of all possible aspects were included in the models. We argue that measuring which aspects bighorns use is less meaningful than measuring the solar radiation an area receives. A solar radiation calculation is available in Spatial Analyst, which ascribes a pixel value of watt hours/m^2 (ESRI, Redlands, CA). It is likely that bighorns select aspects based on the amount of solar radiation a given area receives. We recommend replacing aspect with a solar radiation index because it is a better indicator of why bighorns select areas and can be measured as a continuous variable.

Because bighorns prefer open areas with low vegetation and high visibility for predator detection (Risenhoover and Bailey 1985), the overall structure of vegetation likely has more biological significance to bighorns than the particular species of vegetation present. This is evident by bighorns using from 4 to 19 vegetation types a year depending on location and availability (Shackleton et al. 1999). Olson et al. (in review)

showed that the density of vegetation (> 1 m) could more accurately predict habitat use of bighorn sheep than cover type. Feature Analyst is a tool in ArcGIS 9.2 that can classify canopy cover from an aerial photograph. We recommend using Feature Analyst to classify tall brush and tree cover >1 m tall, and label these areas as unsuitable bighorn habitat.

Landscape ruggedness is also a component of escape terrain for bighorn sheep and is biologically important in the habitats they use (Bangs et al. 2005, Sappington et al. 2007). It has been quantified in bighorn habitat-use studies using the Land Surface Ruggedness Index (LSRI) and the Terrain Ruggedness Index (TRI) (Bleich et al. 1997, Turner et al. 2004). Additionally, the Vector Ruggedness Measure (VRM) has recently been developed and has been shown to be an important variable in the habitat-use of female bighorn sheep (Bangs et al. 2005, Sappington et al. 2007). Ruggedness was never addressed by Whiting et al. (2004), but may have increased the predictive ability of their winter and lambing habitat models (Olson et al. in review).

Two major goals of the Utah Bighorn Sheep Statewide Management Plan (2008) are 1) to increase bighorn sheep populations statewide by 50% over the next 5 years and 2) to use GIS to identify areas suitable for bighorns and translocate animals to these locations to establish new populations. By evaluating and correcting existing models constructed specifically for habitat in Utah, we can objectively identify the best habitats in the state for future bighorn sheep reintroductions, assist in increasing bighorn populations statewide, and increase the efficacy of restoring this unique mountain ungulate to former ranges.

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