Bienn. Symp. North. Wild Sheep
and Goat Counc. 8:256-263.

PRELIMINARY TESTS OF A MOUNTAIN SHEEP HABITAT MODEL USING A GEOGRAPHIC INFORMATION SYSTEM

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Abstract: Since 1850, 45 populations of mountain sheep (*Ovis canadensis* ssp.) have become locally extinct in California. Conservation efforts for this species emphasize restoration of these extirpated populations. Although models that assess potential relocation sites exist for mountain sheep, none have been adequately tested. We used the overlay capabilities and proximity functions of a vector-based geographic information system, and aerial telemetry data from a reintroduced population of desert-dwelling mountain sheep, to test the significance of vegetation, topography, and availability of water as predictors of mountain sheep presence. Statistical results indicate that, while these variables are important, their use in the model evaluated was not predictive. For instance, while slope was a significant variable, and the steepest slope categories were selected by mountain sheep, all other categories of slope were avoided, even though the model suggested moderate use in some categories.

In the decades following the California gold rush, a rapid loss of mountain sheep populations occurred (Wehausen et al. 1987). Unregulated market hunting and grazing of domestic livestock are implicated in this decline, as are certain diseases that are associated with livestock, particularly with domestic sheep (Buechner 1960). Despite legal protection of the species by the California legislature in 1873, populations failed to increase in size, or to recolonize vacant habitats. Moreover, the extirpation of mountain sheep populations continued; 45 of 104 mountain sheep populations thought to exist prior to 1850 are extinct in California (Wehausen et al. 1987). Although management efforts may have resulted in some population increases, little natural recolonization has occurred. Mountain sheep conservation strategies currently emphasize

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3 approaches: (1) isolation from domestic sheep (Desert Bighorn Council 1990); (2) habitat improvement, primarily through the construction of artificial watering devices (Bleich and Pauli 1990); and (3) the establishment of this species on formerly occupied ranges (Bleich et al. 1990b).

Several habitat evaluation procedures have been developed for desert-dwelling mountain sheep (Ferrier and Bradley 1970, Merritt 1974, Hansen 1980, Wilson et al. 1980, Holl 1982, Armentrout and Brigham 1988, Cunningham 1989, Wakeling and Miller 1990), but they have not been adequately tested. Of those currently available, the model developed by Hansen (1980) is the most widely-used. However, given the expense and complexity of mountain sheep translocation projects (Bleich 1990, Bleich et al. 1991), it seems prudent to evaluate that model further, in an effort to enhance the success of future translocations (Smith et al. 1991).

Hansen's (1980) procedure rates the suitability of mountain sheep habitat on 7 factors: natural vegetation, topography, precipitation, evaporation, water availability, existing mountain sheep use, and human impacts. Individual sections (1 mi^2) of habitat are rated, using a point system, based on these factors, and a total score is calculated. Sections having the highest numerical scores are deemed the most important, or most suitable, for mountain sheep. Sections with moderate, or low, scores are considered to be of lesser value to mountain sheep.

A geographic information system (GIS) is a computer tool that can be used to rapidly analyze and model the types of spatial data necessary for informed decisions on wildlife management options (Johnson 1990, Nicholson and Bowyer In Press). Indeed, several authors have used the overlay capabilities and spatial analysis functions of a GIS to evaluate habitat, and wildlife use of habitat (Donovan et al. 1987, Broschart et al. 1989, Pereira and Itami 1991, and others). Several parameters in the Hansen Model lend themselves well to GIS analyses; therefore, we used a vector-based GIS to test predictions of the model with respect to topography, vegetation, and water availability.

We thank D. Pearson of the Southern California Edison Company (SCE) for providing digital data used in the GIS analyses, R. W. Anthes, M. W. Berbach, L. Heitz, M. J. Kie and J. Santana for providing telemetry data, J. G. Kie for access to digitizing hardware, and Environmental Systems Research Institute (ESRI) for providing training in the use of ARC/INFO. GIS analyses were funded by the Environmental Data Center, University of Rhode Island, and the Fitzpatrick Institute of African Ornithology, University of Capetown. Funding for data acquisition and manuscript preparation was provided by the Boone and Crockett Club, California Association of Professional Scientists, California Department of Fish and Game (CDFG), Foundation for North American Wild Sheep, National Rifle Association, M. P. Northam, Sacramento and San Diego Chapters of Safari Club International, Society for the Conservation of Bighorn Sheep, and the Graduate School, University of Alaska Fairbanks. This is a contribution from the CDFG Bighorn Sheep Management Program.

STUDY AREA

The Sheephole Mountains are a relatively precipitous, low elevation mountain range located in the southern Mojave Desert, San Bernardino County, California. The mountain chain follows a northwest - southeast orientation and reaches a maximum elevation of 1,406 m (Pauli and Bleich 1991). Soils predominantly are of granitic origin (Weaver and Mensch 1971). Daytime maxima frequently exceed 38 C during the summer, but temperatures $\leq$ 0 C are not uncommon in winter (Freiwald 1984). Precipitation averages 7 cm annually, and occurs mostly during winter from Pacific weather fronts; summer storms are infrequent, unpredictable and highly localized (Weaver and Mensch 1971). Vegetation in the study area is predominantly creosote bush (*Larrea tridentata*) scrub, with higher elevation slopes supporting *Ephedra* spp. and *Yucca* spp.

The study area was defined by the extreme southwest and northeast distribution of mountain sheep in the Sheephole Mountains, as determined from aerial telemetry data. The study area is 12.4 km from east to west, 10.5 km from north to south, and is 132 km^2 in size. Historically, mountain sheep occurred in the Sheephole Mountains, but they were nearly extirpated during the recent past. Mountain sheep were translocated to the range during 1984 (n = 11) and 1985 (n = 16) (Bleich et al. 1990*a*).

SOURCES OF DATA

From 1984-86, 401 aerial telemetry fixes were obtained from 11 adult, female, mountain sheep. Bimonthly flights were conducted as described by Krausman et al. (1984), and the estimated locations of mountain sheep were plotted on 15' United States Geological Survey (USGS) topographic maps during each flight. These locations were digitized, and projected into Universal Transverse Mercator coordinates (Monmonier and Schnell 1988).

We extracted vegetation data from an Integrated Terrain Unit Map (Dangermond et al. 1982) supplied by SCE. Categories of vegetation were then reclassified as either "low desert shrub" or "middle desert shrub" (Hansen 1980:326, Table 1).

We used the ARC/INFO TIN Module (ESRI, Redlands, Calif.) to derive a slope map from commercially available USGS 3-arc-second Digital Elevation Models (Carter 1988). Because Hansen (1980) described slope in relative terms, such as flat or steep, we adapted the criteria of Armentrout and Brigham (1988) to quantify 5 of Hansen's slope descriptors: level (0% slope), undulating (>0-8% slope), rolling hills (>8-100% slope), and steep (>100% slope) (Table 2). For some analyses of slope selections, we also separated rolling hills into two categories (>8-30% and >30-100%).

Using the criteria of Hansen (1980:325), the slope map adapted from Armentrout and Brigham (1988), and a map of dry stream courses, we created a terrain model that incorporated 3 topographic parameters. This model considers slope, as well as the juxtaposition of steep terrain to slope classes, and the brokenness of terrain. Thus, we were able to simulate six terrain categories that Hansen included in his model.

Table 1. Mountain sheep use of Hansen's (1980) vegetation types in the Sheephole Mountains, San Bernardino County, California, 1984-1986. Sheep use of vegetation was significantly different from availability ($\underline{X}^2$ = 20.2, $\underline{P}$ < 0.001, 1 df).

Vegetation type	Available hectares	Sheep locations
Low Desert Shrub	2,108	31
Middle Desert Shrub	11,110	370

No naturally-occurring permanent water sources occur in the Sheephole Mountains (Weaver and Mensch 1971, Pauli and Bleich 1991). The location of the only artificial water source was plotted on a 15' USGS topographic map, and digitized into the GIS.

ANALYTICAL METHODS

All spatial data mentioned above were inventoried and analyzed with ARC/INFO. We evaluated whether mountain sheep used habitat in a manner consistent with predictions based on Hansen's (1980) model. We used the method of Neu et al. (1974) to calculate whether use of vegetation and terrain differed statistically from expected values, based on availability.

The Hansen Model effectively is raster-based, and the cells are 1 mi^2. In the Model, the value of each cell is rated, in part, on the presence or absence of water; however, if we simply examined the study area for presence of water, our results would be of little value. Because we used a vector-based GIS, we were able to calculate the distance of each sheep location to the point source of water in the Sheephole Mountains.

We tested the hypothesis that mountain sheep distribute themselves randomly with respect to the availability of water by comparing the distribution of sheep locations in 11 classes of distance to water (each 1 km in width) with the distribution of an equal number of randomly generated points. Because the water source was located in steep terrain, we corrected for possible interactions between slope class and distance to water by eliminating "flat" areas from analyses. Frequencies were compared using the Bonferroni procedure (Neter et al. 1985).

RESULTS AND DISCUSSION

Mountain sheep in the Sheephole Mountains selected middle desert vegetation (Table 1). This was consistent with the prediction of Hansen (1980). Although the Hansen Model includes a total of 8 vegetation types, only two were present in the study area. The predictive power of the Model remains to be tested with respect to the six other vegetation types recognized by Hansen (1980).

Table 2. Mountain sheep use of five slope classes in the Sheephole Mountains, San Bernardino County, California, 1984-1986. Mountain sheep were not distributed in proportion to the availability of slope classes ($\underline{X}^2$ = 542, $\underline{P}$ < 0.001, 4 df).

Slope class(%)	Available hectares	Sheep locations
0	336	5
0.01-8.00	6,599	21
8.01-30.0	3,237	97
30.01-100.0	3,040	276
>100.0	9	2

Mountain sheep selected steep terrain and avoided flat areas; this is consistent with the expectations of the Model (Table 2). However, sheep also avoided moderate slopes (>8-30%), and this is contrary to the Hansen Model. We suggest additional tests, in a number of mountain ranges, before conclusions can be reached regarding the predictive power of terrain classes in the Hansen Model.

Table 3. Mountain sheep use of 6 terrain classes (Hansen 1980) in the Sheephole Mountains, San Bernardino County, California, 1984-1986. Mountain sheep were not distributed in proportion to the availability of terrain classes ($\underline{X}^2$ = 622, $\underline{P}$ < 0.001, 5 df).

Terrain class	Available hectares	Sheep locations
Level, >1.6 km from rocky or steep terrain	6,366	11
Level, <1.6 km from rocky or steep terrain	569	15
Rolling hills >1.6 km from rocky or steep terrain	1,963	13
Rolling hills <1.6 km from rocky or steep terrain	4,313	361
Rocky and steep, w/o washes, slopes >100%	5	1
Rocky and steep, cut by washes, slopes >100%	4	0

When we quantified Hansen's (1980) slope categories by adapting the criteria of Armentrout and Brigham (1988), we discovered an apparent typographical error in their paper that eliminated a major slope category (>30-60%). We call this to the attention of the reader because this slope class was strongly selected by the animals in our study, and is of clear importance to mountain sheep (Table 3).

Mountain sheep distributed themselves significantly closer to water than would be expected if they behaved randomly with respect to proximity to water ($\underline{X}^2 = 765$, $\underline{P} < 0.001$, 10 df). This result was unchanged when slope interactions were eliminated ($\underline{X}^2 = 302$, $\underline{P} < 0.001$, 10 df).

These results, although preliminary in nature, indicate that the Hansen Model has value in evaluating sites that are being considered for the reintroduction of desert-dwelling mountain sheep. However, further multivariate GIS analyses are necessary before firm conclusions can be reached.

GIS technology was used to test this model in an effort to bring the potential value of this analytical tool to the attention of wild sheep managers. This is the first application of a GIS to the management of mountain sheep, and it proved to be extremely valuable. However, managers are cautioned that the accuracy of the results of their analyses will be a function of the quality of the original data that they use to develop their application (August In Press, Lunetta et al. 1991).

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