

## Use of Digital Elevation Data to Predict Bighorn Sheep Habitat at Badlands National Park

**TERESA J. ZIMMERMAN**,<sup>1</sup> Department of Wildlife and Fisheries Sciences, South Dakota State University, Brookings, SD 57007, USA

**JONATHON A. JENKS**, Department of Wildlife and Fisheries Sciences, South Dakota State University, Brookings, SD 57007, USA

**ROBERT W. KLAVER**, United States Geological Survey, Center for Earth Resources Observation and Science, Sioux Falls, SD 57198 USA

**DAVID M. LESLIE, JR.**, United States Geological Survey, Oklahoma Cooperative Fish and Wildlife Research Unit, Department of Zoology, Oklahoma State University, Stillwater, OK 74078, USA

**EDDIE L. CHILDERS**, Badlands National Park, National Park Service, Interior, SD 57750, USA

**Abstract:** Originally, Audubon's (a.k.a., Badlands) bighorn (*Ovis canadensis auduboni* now *O. c. canadensis*) was described as a subspecies of Rocky Mountain bighorn sheep inhabiting the Badlands of western South Dakota, USA. By 1925, the last bighorn sheep from the White River Badlands in southwestern South Dakota was harvested. To restore this native ungulate to its former range, 20 Rocky Mountain bighorn sheep (*O. c. canadensis*) were introduced to Badlands National Park (BADL) from Pikes Peak, Colorado, in 1964. In 1995, bighorn sheep habitat in the greater BADL area was evaluated using Digital Elevation Model (DEM) data using 30- and 90-m<sup>2</sup> resolution, and biomass estimates for the badlands of North Dakota. Suitable habitat was identified in 802 km<sup>2</sup> of the 5,322 km<sup>2</sup> at BADL and it was estimated that BADL could sustain 400 to 600 bighorn sheep. Escape terrain was the dominant variable affecting the extent of bighorn sheep habitat, as other components were not limiting. Due to the ruggedness and steepness of the highly erodable clay badlands, we reevaluated bighorn sheep habitat at BADL using 10-m<sup>2</sup> DEM data. Our model identified 1,938.8 km<sup>2</sup> of suitable habitat in the greater badlands ecosystem, 2.5X more than the previous estimate based on the coarser resolution. These data will be used to identify areas of suitable habitat for other bighorn sheep reintroductions at BADL and to reevaluate carrying capacity estimates in the greater badlands ecosystem.

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**Key words:** Audubon's bighorn, Badlands National Park, Digital Elevation Model, habitat, *Ovis canadensis auduboni*, Rocky Mountain bighorn sheep.

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<sup>1</sup> Corresponding author e-mail: [teresa.zimmerman@sdstate.edu](mailto:teresa.zimmerman@sdstate.edu)

Originally, Audubon's (a.k.a. subspecies of Rocky Mountain bighorn Badlands) bighorn (*Ovis canadensis* sheep (*O. c. canadensis*) inhabiting the *auduboni* now *O. c. canadensis* [Wehausen badlands of the Yellowstone and Missouri and Ramey 2000]) was described as a rivers in eastern Montana, eastern

Wyoming, western North and South Dakota, and northwestern Nebraska (Valdez and Krausmann 1999). By 1925, this subspecies was extirpated throughout its range in South Dakota. Management policy states that the National Park Service will maintain as parts of the natural ecosystems of parks all native flora and fauna and will strive to restore extirpated native plant and animal species to parks (if) the population can be self-perpetuating (U. S. Department of the Interior, National Park Service 2000). Therefore, to restore this native ungulate to its former range, 20 Rocky Mountain bighorn sheep were introduced from Pikes Peak, Colorado to a 60.7-ha enclosure in Badlands National Park (BADL) in 1964 (Ramey et al. 2000).

In 1967, a *Pasteurella* outbreak reduced the number of captive sheep to 14 (2 adult rams, 2 adult ewes, 4 yearling ewes, 3 ram lambs, and 3 ewe lambs) (Ramey et al. 2000), and these were released into the wild. In 1981, 8 sheep from the North Unit of BADL colonized the South Unit, initiating a second subpopulation. In 1982, a second *Pasteurella* and/or bluetongue epizootic reduced the North Unit population to 50 to 60 animals. By 1988, the 2 subpopulations reached 140 individuals (Singer and Gudorf 1999) but a third disease epizootic reduced the total BADL population to about 60 animals by 1996. At this time, 12 ewes and 4 rams from the Pinnacles area in the western part of the North Unit were translocated to the Cedar Pass area in the eastern part of the North Unit of the Park.

Based on the estimated effective population size and analysis of molecular genetic data, the bighorn sheep population at BADL had been through a population bottleneck at founding (Ramey et al. 2000). A mixed-sex augmentation of more than 30 bighorns from an outbred native

population of Rocky Mountain bighorn sheep was recommended to restore genetic diversity and provide short- and long-term contributions to the BADL population (Ramey et al. 2000). These authors further recommended that the introduced bighorn sheep should augment the current population and add a new subpopulation to the existing 3 in BADL. Supplemental populations of more than 5 sheep were recommended to provide increased group vigilance and a lower per capita risk of predation resulting in higher individual survival rates (Mooring et al. 2004), although a minimum of 20 translocated individuals also have been recommended (Douglas and Leslie 1999). Therefore, in conjunction with the South Dakota Game, Fish and Parks, and the New Mexico Game and Fish, 23 sheep (10 adult ewes, 2 yearling ewes, 5 ewe lambs, and 6 ram lambs) captured from Wheeler Peak, New Mexico were transported and released at BADL in September 2004.

To aid restoration of bighorn sheep throughout their historical range habitat in the greater BADL area was evaluated. Using the parameters and model for evaluating bighorn sheep habitat developed by Smith et al. (1991) and refined by Johnson and Swift (1995), Sweanor et al. (1995) estimated that BADL could maintain 400 to 600 bighorn sheep. Digital elevation models (DEM) with 30- and 90-m<sup>2</sup> resolutions were used to determine escape terrain slope, buffer, and aspect. Forage biomass estimates were unavailable for BADL, so estimates for the badlands of North Dakota were used to estimate forage production in BADL (Sweanor et al. 1995). In addition, water availability was not evaluated. A total of 802 km<sup>2</sup> of the 5,322 km<sup>2</sup> study area was suitable bighorn sheep habitat and 3,012 km<sup>2</sup>, 1,410 km<sup>2</sup>, and 503 km<sup>2</sup> for summer, winter, and lambing range, respectively,

was available (Sweanor et al. 1995). Escape terrain was the dominant variable affecting the amount of suitable habitat because other components such as horizontal visibility, water availability, natural barriers, and human-use areas were not limiting.

Due to the ruggedness and steepness of the highly erodable clay badlands (Weedon 1999), using a finer resolution was deemed useful in identifying specific habitat requirements of bighorn sheep. Therefore, our study objective was to map suitable by applying the model developed by Sweanor et al. (1995) using 10-m<sup>2</sup> DEM data.

### Study area

The study area encompassed 5,322 km<sup>2</sup> located in Pennington, Shannon, and Jackson counties in southwestern South Dakota (Sweanor et al. 1995). It included Badlands National Park and adjacent lands in the Buffalo Gap National Grasslands and Pine Ridge Indian Reservation, interspersed with private land. Areas located within the White River badlands consist of very fine, unconsolidated clay with thin beds of sandstone or isolated concretions (Weedon 1999). Sharp gradients in altitude occur throughout 700 to 1,000 m (Sweanor et al. 1995). Topography of the badlands is the coincidence of elevation, rainfall, carving action of streams, and substrate, resulting in slumps, natural bridges, arches, sod tables, toadstools, and isolated flat remnants of the higher plains (Weedon 1999). Vegetated slumps along with mixed-grass prairie sod tables occur in close proximity to steep badland terrain and are important feeding areas for bighorn sheep (Gamo et al. 1993). Temperature ranges from -41 C to 47 C, and annual precipitation averages 41 cm (Weedon 1999).

The badlands encompass true short-grass prairie, midgrass prairie, and bunch grass types with plant species including western wheatgrass (*Pascopyrum smithii*), green needlegrass (*Nassella viridula*), blue grama (*Bouteloua gracilis*), and needle and thread grass (*Hesperostipa comata*), fringed sage (*Artemisia frigida*), prairie junegrass (*Koeleria macrantha*), little bluestem (*Schizachyrium scoparium*), green sagewort (*A. ludoviciana*), purple coneflower (*Echinacea angustifolia*), and buffalo grass (*Buchloe dactyloides*) (Weedon 1999). Patches of Rocky Mountain juniper (*Juniperus scopulorum*) and eastern red cedar (*J. virginiana*) occur in upper protected draws and slopes (Weedon 1999). Other species such as plains cottonwood (*Populus deltoides*), peach-leaved willow (*Salix amygdaloides*), box elder (*Acer negundo*), green ash (*Fraxinus pennsylvanica*), and American elm (*Ulmus americana*) occur in the deciduous complex along the White River (Weedon 1999). Although 42% of BADL is covered by prairie grasslands, over 46% is clay formations on which vegetation is sparse or absent (Von Loh et al. 1999).

### Methods

The habitat model used by Sweanor et al. (1995) eliminated areas which do not fit the identified criteria for bighorn sheep habitat. The model identified escape terrain (ET), buffer (BT), horizontal visibility (HV), water sources (WS), natural barriers (NB), human-use areas (HU), man-made barriers (MB), and domestic livestock (DL) as important characteristics affecting habitat suitability of bighorn sheep. The criteria for these parameters were:

ET = include land areas with slope >27° but <85°

- BT* = include land areas within 300 m of ET and land areas  $\leq 1000$  m wide bounded on at least 2 sides by ET
- HV* = remove areas with visibility  $< 55\%$
- WS* = remove land areas  $> 3.2$  km from water sources
- NB* = remove land areas with rivers  $> 56.6$  m<sup>3</sup>/second, visibility  $< 30\%$  that are 100 m wide, and cliffs  $> 85^\circ$  slope
- HU* = remove areas covered by human development
- MB* = remove areas inaccessible due to man-made barriers including major highways, wildlife-proof fencing, aqueducts, and major canals
- DL* = remove areas within 16 km of domestic sheep use.

Area of suitable bighorn sheep habitat was calculated using as  $ET + BT - HV - WS - HU - MB - DL$ .

In the model used by Sweanor et al. (1995) openness of habitat was adequate throughout the study area; therefore, HV was not a limiting factor. Water sources were insufficiently documented; thus, incorporating the WS parameter inaccurately reduced the estimate of suitable bighorn sheep habitat. No natural landscapes were considered barriers; therefore, NB was excluded from the model. Man-made areas (4.8 km<sup>2</sup>) occupied by highways and roads (not considered a barrier), and group-campsites, visitor-information centers, and scenic overlooks were removed from the total estimate of suitable habitat. Areas within 16 km of domestic sheep also were not applicable. Therefore, ET and BT were the only parameters that limited bighorn sheep in the greater badlands ecosystem (Sweanor et al. 1995). Using geographic information system with 10-m<sup>2</sup> DEM data, we reevaluated ET and buffer BT in the greater badlands ecosystem study area.

## Results and Discussion

Using 10-m<sup>2</sup> DEM data, we determined that 1,938.8 km<sup>2</sup> (or 37.1 %) was suitable bighorn sheep habitat. Using the finer resolution, we predicted nearly 2.5 times more bighorn sheep habitat than Sweanor et al. (1995). Similarly, in comparing habitat available to desert bighorn sheep (*O. c. mexicana*), average land surface ruggedness derived from 30-m data was greater than that derived from 100-m elevation data because the finer resolution detected smaller changes in elevation data (Devine et al. 2000). Locations of female desert bighorns also had greater average land surface ruggedness in 30-m compared to 100-m elevation data. Johnson and Swift (2000) tested the effect of using finer elevation data at Mesa Verde, Colorado and identified 629 km<sup>2</sup> and 401 km<sup>2</sup> of core bighorn sheep habitat using 1:24,000 and 1:250,000 scale data, respectively (i.e. predicting more habitat with a finer resolution). They concluded that analyses conducted at different scales leads to variable results and can have critical implications to management decisions for bighorn sheep restoration.

Because the bighorn sheep population in BADL never exceeded 140 individuals, biologists have questioned the 400 to 600 animal carrying capacity estimate of Sweanor et al. (1995). Some studies grossly overestimate true carrying capacity of bighorn sheep (DeYoung et al. 2000). Determining true carrying capacity of a population is critical to survival because the closer to carrying capacity, the more severely the population can be affected by climatic vicissitudes (e.g., drought) (Macnab 1985). Although we predicted 2.5 times more available escape terrain with our model than Sweanor et al. (1995), based on vegetation coverage we suggest that forage availability in close proximity

to escape terrain is probably a limiting factor for population growth at BADL. As recommended by Ramey et al. (2000), our data will assist BADL biologists in the conservation and management of lands identified as critical habitat in promoting restoration of this prairie bighorn sheep population.

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