# Restoration of Bighorn Sheep Metapopulations In and Near 15 National Parks: Conservation of a Severely Fragmented Species

## Volume II: Synopsis of Research Findings

Open File Report 99-105

In cooperation with Natural Resources Ecology Lab, Colorado State University

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# Restoration of Bighorn Sheep Metapopulations In and Near 15 National Parks: Conservation of a Severely Fragmented Species

## Volume II: Synopses of Research Findings

By

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## FOREWARD

In 1991, the National Park Service (NPS) initiated a series of research studies to support an effort to restore bighorn sheep (*Ovis canadensis*) into 15 national parks in the Intermountain West and Colorado Plateau areas (Fig. 1). The Biological Resources Division of the U.S. Geological Survey provided scientific advice and research coordination for the NPS restoration (Fig. 2).

The research studies were conducted by scientists from the Biological Resources Division of the USGS (formerly NBS) (11 research studies), university-based scientists (Univ. of Wyoming - 2 studies, University of Colorado - 1, Colorado State University - 2, University of California, White Mountain Center - 1, Northern Arizona University - 1, Montana State University - 1) and by state agency veterinarians: Drs. Beth Williams of Wyoming, Mike Miller of Colorado, and Terry Spraker of Colorado State University. Only the highlights of these research studies are presented below. Full research reports are available in Volume III of this series.

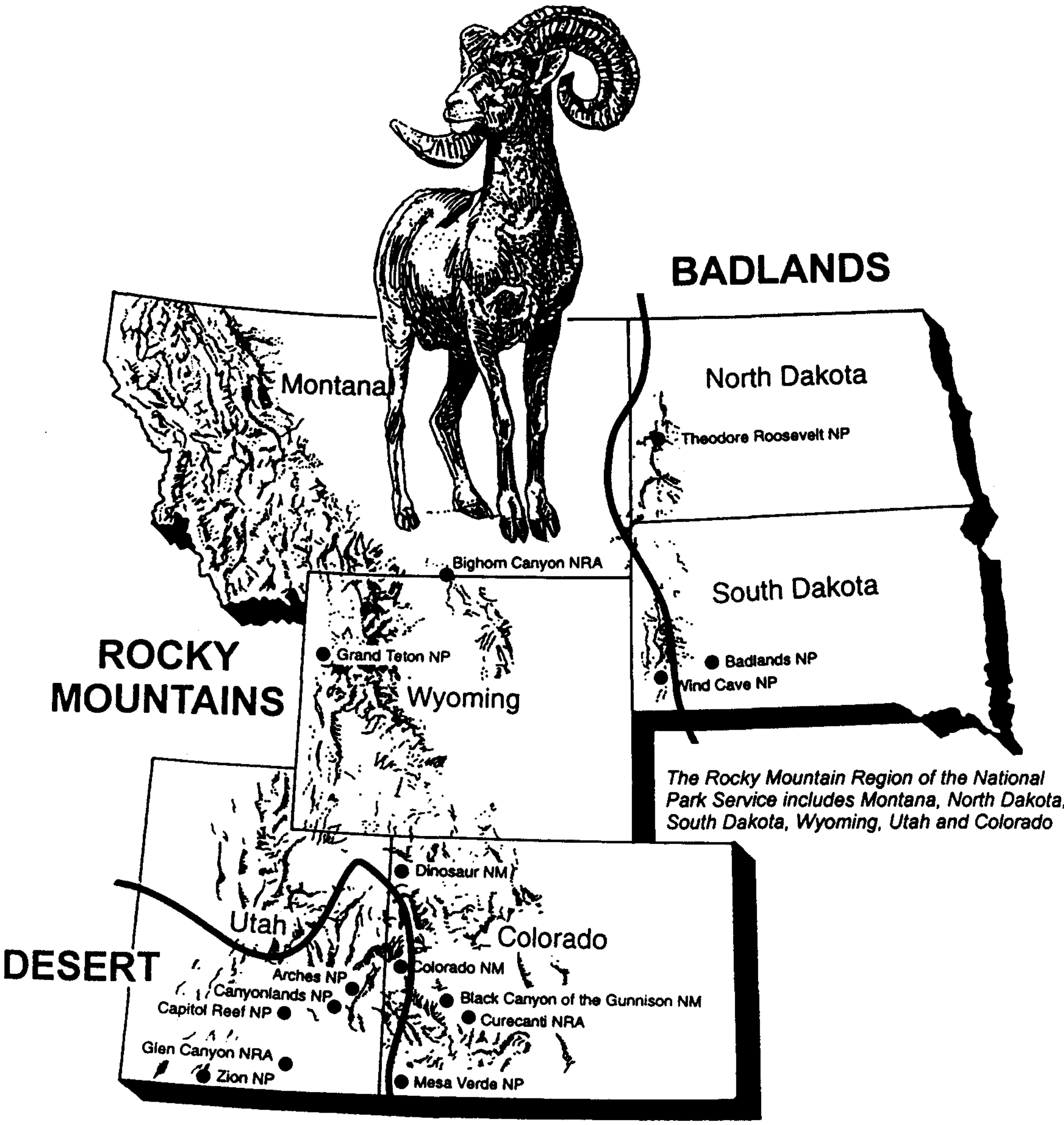


Fig. 1. National parks in the six-state area where bighorn sheep habitat assessments and/or restorations were conducted.

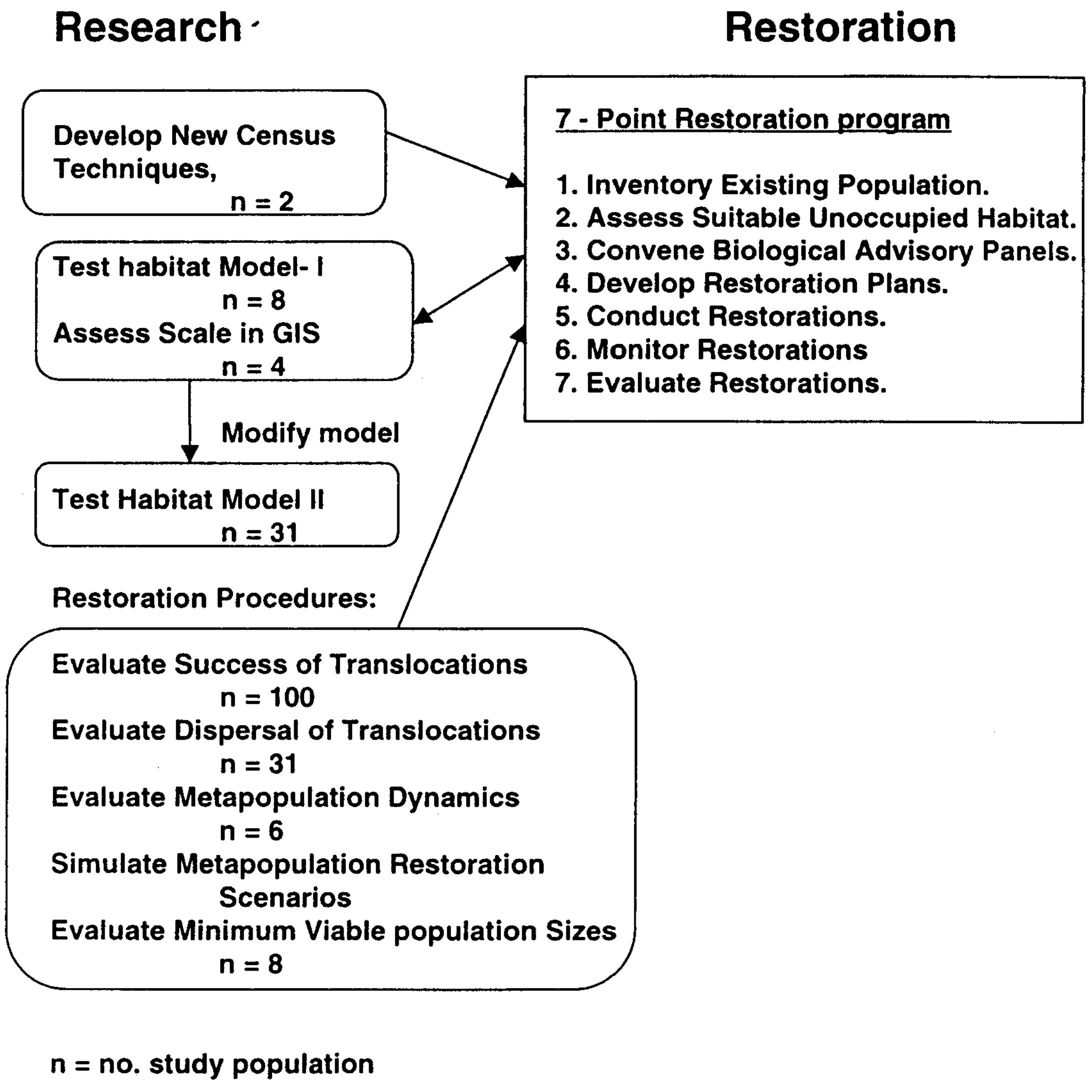


Fig. 2. The interrelationship between research described in this report and the 7-point program followed in the national parks to restore bighorn sheep.

# A. CENSUS OF POPULATIONS

## DEVELOPMENT OF SIGHTABILITY MODELS FOR THE CENSUS OF BIGHORN SHEEP IN BADLANDS AND CANYONLANDS NATIONAL PARKS, PROGRESS REPORT 1992-95

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The National Park Service requires more accurate census techniques for bighorn sheep. Based upon input received from park units during the planning stage in 1991 and 1992 the Idaho sightability model (Unsworth et al. 1994, Bodie et al. 1995) was selected for development in Badlands and Canyonlands National Parks. These parks needed a technique that could detect a 15%-20% decline in numbers of bighorn sheep in a source population. That figure was selected as a warning signal to defer any further removals of animals for translocation purposes. Development of an accurate census technique was considered a prerequisite for any removals of animals for restoration purposes in Badlands and Canyonlands National Parks.

The populations were divided into counting units based on topographic barriers such as cliff lines, riverbanks, watershed boundaries, and any other feature distinguishable from the air. The Badlands population was divided into five count units, all of which were surveyed. The Canyonlands population was divided into 26 count units. A random sample of units occurring in three density strata (high, medium and low) was surveyed. The survey crew consisted of two observers and the pilot. The count units were flown systematically at 80 kmph (50 mph) at 0.5 km contour intervals. The observers in the helicopter recorded a variety of sighting variables for each group of bighorns observed.

The first step in the development of the census method was to determine what factors affected sightability of bighorn sheep. Ground crews located and hiked to a sample of groups and observed these animals during the course of the helicopter census. The sighting conditions of each group were recorded by the ground crew as the helicopter passed, as well as the animals' behavioral responses to the helicopter and whether or not the helicopter detected the group. The sightability data from groups seen or missed during the helicopter survey were the variables used to develop the sightability model. The sightability model itself is a multiple logistic regression model with the dependent dichotomous variable being the groups seen or missed by the helicopter crew. The goal was to obtain 70-100 data points in each of the park study areas prior to final model development. A data point in this case was each opportunity to see or miss a marked group of bighorn sheep.

The second step in the census application was to calculate a corrected estimate of the population. Once the logistic regression model was completed and finalized with 70-100 data points, an aerial count of a stratified random sample of the count units of the population was conducted. The regression model of visibility factors was applied to the groups seen in a count unit to calculate a correction estimate of the animals missed in each count unit. These corrected estimates were then accumulated in each stratum to provide a corrected estimate for the entire population. A confidence interval on the estimate was calculated based on methods described by Samuel et al. (1987).

Model development to date includes 62 data points in Badlands National Park and 43 data points in Canyonlands National Park. The helicopter crews spotted 65% of the marked groups in Badlands National Park and 70% of the groups in Canyonlands National Park. In the Badlands regression model, vegetation cover and topographic position were significant variables. Vegetation cover alone provided the model with the best fit based on model selection criteria (AIC criteria, Akaike 1973). In the Canyonlands model, activity of bighorns and topographic position were both significant and produced the model with the best fit.

These preliminary models provided provisional estimates of 347, 385, 394 and 395 bighorn sheep for the Island Sky-Potash population of Canyonlands National Park, and estimates of 195, 106, 113, 137, and 144 sheep for Badlands National Park for the study years. The Canyonlands estimates did not differ significantly between years ($P>0.45$), indicating a stable population. The Badlands estimates were reasonably consistent except for the September 1992 survey ($n=195$). The high estimate was the product of a few large ewe groups (>20) being observed in the five count units surveyed. The estimate would likely be lower if more count units had been surveyed. The authors stress that these census estimates are provisional only. The work conducted to date suggests that sighting conditions vary between Badlands and Canyonlands study sites, and in turn, both of these study sites differ in sighting conditions from the Owyhee Canyon area of Idaho where the bighorn model was originally developed (Bodie et al. 1995). The authors recommend that model development continue until a minimum of 80 data points have been gathered for each study area. At that time the models should be considered final, at least until such time as any major change in sighting conditions occurs in a study area. A major change in sighting conditions might be a drastic alteration in behavior of bighorns in response to the helicopter or a large burn in a forested area. No major change in sighting conditions is projected.

# B. CONSERVATION BIOLOGY AND FACTORS RELATING TO SUCCESS OF TRANSLOCATIONS

## SIMULATING DESERT BIGHORN SHEEP POPULATIONS TO SUPPORT MANAGEMENT DECISIONS: EFFECTS OF PATCH SIZE, SPATIAL STRUCTURE, AND DISEASE

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Efforts to restore bighorn sheep populations in the western United States have achieved mixed success. Areas that once could have supported a single large population are now dissected by roads, subdivisions, or other developments, resulting in habitat that will now support only a number of smaller, isolated populations. In addition, diseases associated with domestic livestock have caused catastrophic epidemics that threaten the persistence of bighorn sheep populations. A consequence of these changes is the need to identify habitat and population characteristics that favor long-term persistence of bighorn sheep populations and that can help guide efforts to identify suitable sites for restoration. To meet these needs, we simulated bighorn sheep dynamics in landscapes that consisted of a single patch of habitat or that consisted of patches that could support bighorn sheep populations linked by dispersal (a metapopulation structure). We examined population persistence in response to (1) total patch size, (2) single versus multiple patches, (3) frequency of disease infection, and (4) habitat improvements.

We developed an individual-based model to simulate the dynamics of desert bighorn sheep. Our model explicitly simulated the sex, age, location, and disease status of each individual in the population, and used age and sex-specific rates (probabilities) for fecundity and mortality. Stochastic demographic effects that are important in small populations were incorporated in the model as well as process-level variation. Disease effects were included in the model by reducing survival, recruitment, and dispersal for up to 5 years subsequent to infection. We simulated bighorn sheep that occupied a landscape consisting of patches of suitable habitat separated by areas that could be traversed by sheep, but which did not support any animals. We simulated populations introduced into landscapes composed of a single patch with an area of 35-500 $km^2$ and we simulated introductions in landscapes composed of up to three discrete same-sized patches. To evaluate effects of habitat spatial structure, we compared simulations in which the total patch area was the same but the number of patches differed. For each set of parameters, we conducted 1000 simulations that each lasted 200 years.

Simulated bighorn populations located in single small patches of suitable habitat of 35-75 $km^2$ in size exhibited high rates of extinction (75-15%) even in the absence of disease. In contrast, few populations introduced into larger patches (>100 $km^2$) perished during the 200 years of simulation. Disease had an overwhelming effect on simulated bighorn sheep populations, and a single introduction of disease resulted in a dramatic increase in the likelihood of extinction in populations inhabiting patches of 125 $km^2$ or less. When repeated infections were simulated, populations in even the largest patch examined (500 $km^2$) were subject to extinction over a 200-year period. In the absence of disease, simulated bighorn sheep populations had greater persistence rates in a single large patch than in two or three smaller patches of the same total area. When patch sizes were larger (>225 $km^2$ total area), persistence was very high (>95%) in all spatial arrangements of single or multiple patches (one, two or three patches). In the presence of disease, bighorn populations inhabiting a single large patch had higher rates of persistence than those in 2 or 3-patch systems. In our simulations, habitat improvements were unlikely to significantly increase persistence rates unless they dramatically increased the ability of the habitat to support bighorn sheep.

## TRANSLOCATION AS A TOOL FOR RESTORING POPULATIONS OF BIGHORN SHEEP, *OVIS CANADENSIS,* INTO HISTORIC RANGE

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Bighorn sheep are estimated to currently number only a fraction of their historic

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numbers (Buechner 1960, Wishart 1978). Restoration of bighorn sheep through purposeful reintroductions or translocations has occurred throughout many of the western states since about the 1940s. Some of these translocation programs have been highly successful. For example, the state of Colorado has managed to approximately triple its populations of the species during the two-decade period of the 1970s and 1980s, largely through an aggressive translocation program (Bailey 1990). But while Colorado's program was successful, a shotgun approach to management that included aggressive translocation (44 translocations were conducted), population reductions through removals, mixing of genetic stocks, artificial feeding, and baiting and treating with antibiotics, resulted in no clear cut evidence as to which management strategies were best supported (Bailey 1990). Other translocation programs have been considerably less successful. A total of four out of eight translocations of Rocky Mountain bighorn sheep into the northern one-third of Utah resulted in extirpated populations (Smith et al. 1988). Only 46 (53%) of 87 translocations conducted in the western states were rated as successful by Leslie (1980).

The purpose of this investigation was to analyze the factors promoting success for all translocations onto all public lands that had occurred in the six-state Intermountain Region of the National Park System. These six states included Wyoming, Montana, Colorado, Utah, South Dakota, and North Dakota. Our objectives were to determine, through correlative analyses, which restoration practices were most likely to result in successful, increasing new populations of bighorn sheep.

A total of 100 prior translocations that were conducted in the six-state area were analyzed. There were 21±1 years of information per translocation. Questionnaires were sent to the management agencies involved in the translocations, including the six respective state wildlife agencies, the Bureau of Land Management, the U.S. Forest Service, and the National Park Service. The effects of a variety of practices (i.e. independent variables) on the success of translocations were analyzed, including: founder size, number of augmentations, size of source population, type of founder (indigenous or dilution source), migratory tendency in the released population, distance to the nearest other bighorn population, distance to domestic sheep, presence or absence of cattle, and whether or not the population was hunted. The relative success of the translocation was evaluated through the following factors (dependent variables) using logistic regression: population trend (extirpated, increasing, stable, decreasing), the rate of population increase or lambda ($\lambda$), and the population size category in 1994. We classed the populations as: unsuccessful = remnant, 1-29, or extirpated; modest success = 30-99; successful = 100-350.

Thirty (30%) of the translocations were unsuccessful (n=13 were extirpated and n=17 were remnant), 29 were only modestly successful (30-99), and 41 were successful

(100-350 animals). Success was negatively correlated to presence of domestic sheep on the same range or less than six km away. Cattle grazing on the same range also negatively influenced success. Migratory tendency in the translocated group promoted success. The genetic diversity hypothesis was partially supported. Use of indigenous versus dilution stocks doubled the rate of success, but the mixing of source stocks (both practices increase genetic heterozygosity) did not.

## DISPERSAL AND COLONIZATION RATES OF UNOCCUPIED PATCHES BY MOUNTAIN SHEEP: THE ROLE OF DISEASE, CORRIDOR FEATURES, AND PATCH SIZES

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Due to a widespread decline in population and consequent attempts at population restoration, currently more than one-half of extant populations of bighorn sheep are the result of purposeful translocations. Many of these translocated populations are sedentary, yet most indigenous populations that have been studied have been strongly migratory. Sedentariness in translocated bighorns has a number of negative population consequences. Dispersal is rarely observed in these sedentary bighorn sheep, and even more rarely observed is the colonization of new patches of habitat by both sexes with successful reproduction.

The purpose of this paper was to document any dispersal and colonizations from 31 released populations of bighorn sheep, and to correlate any dispersals with growth rates, disease history, patch size, and founder characteristics in the release population and patch. A second purpose was to correlate dispersals to the water, highway, dense cover, and terrain barriers in the intervening habitats.

Of the 31 released populations, 18 (55%) grew steadily at an average rate of 17% increase per year, but only nine of these populations numbered >100 by 1994. Another 12 (39%) grew initially, but then declined to extirpation or remnant status. Disease was the likely causative factor in the decline of four of these populations, very restricted area of habitat (defined as <30 $km^2$ of habitat) in another two, and a combination of disease and limited habitat in another five of the declines. Contacts with domestic sheep were known in three of the declines and suspected in another two of the declines. Size of habitat patch was very important. The growing populations had been released into patches of 490 $km^2$ on the average, while the declining populations had been released into an average of 60 $km^2$ of habitat. Only one (3%) population rebounded from a decline.

Dispersal rates of healthy populations were nearly double those of diseased populations. Successful colonizations of new patches were positively correlated with four factors: higher population growth rates, greater number of years since release, larger population sizes, and a migratory tendency in the initial released population. Populations that were growing at a rate of 20% per year or greater were more likely to colonize new patches. Fewer water barriers, more open vegetation, and more rugged, broken terrain were all correlated with successful colonizations.

The authors concluded that dispersal rates and colonizations in bighorn sheep can be increased by releasing bighorns into a number of adjacent patches with intervening habitat containing rugged, low substrate and few water or human development barriers. Dispersal rates are also higher when the founder group comes from mixed sources and when the founder group is larger.

## ASSESSING DECISIONS ON RESTORATION OF METAPOPULATIONS OF BIGHORN SHEEP: IMPLICATIONS OF DISEASE, PATCHES, AND DISPERSAL RATES

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Biologists are increasingly confronted with the need to conserve populations that are fragmented, subject to catastrophes, and that inhabit highly variable environments. Bighorn sheep (*Ovis canadensis*) epitomize this situation. Bighorn sheep once occupied most of the mountainous and steep terrain in the western United States, but they are now restricted to discrete populations. Bighorn sheep suffer from habitat loss and fragmentation, insularity, and large-scale epizootics that can result in death rates of 75% over a 1-3 year period. Most extant populations of bighorn sheep in the western United States originated from a translocation, but more than half of all restoration attempts were unsuccessful.

To support decisions on restoration and management of bighorn sheep in the Badlands National Park - Lakota Sioux Tribal Reservation ecosystem we simulated the population dynamics of native sheep subjected to various changes that represented potential management actions and rates of disease-causing infection. To so do, we developed an individual-based model that simulated the birth, movement, and death of each animal in a population on a yearly time schedule. We assumed that the modeled population was isolated from all other populations, but the population consisted of a set of local populations connected by dispersal and colonization. The landscape was composed of patches that could support a local population and a background matrix through which animals moved, but in which a population could not persist. This spatial structure was represented by parameters for the size, quality, and annual variation in the quality of each patch, and the distance between the patches. To evaluate the relative merits of different management actions, we simulated bighorn sheep population dynamics using data from the spatial arrangement of habitat patches in the Badlands ecosystem. We evaluated the sensitivity of the model to demographic parameters with and without simulated epizootics. We varied rates of recruitment, mortality, and colonization in the model. We examined the consequences of disease scenarios that represented mild, moderate, and severe epidemics, and we explored the interaction of disease frequency and intensity with other treatments. We simulated diseases varying in severity from mild (about 12% mortality) to severe (about 67% mortality) and varying in frequency from once to occurring at regular intervals or with a given probability each year.

In the absence of disease, 200-year extinction rates were uniformly low and were insensitive to changes in colonization rates or area of suitable habitat. A single infection in conjunction with changes in area or colonization rate resulted in extinction rates of up to 40%, and large changes in average population size (up to 10-fold changes with a change in area; 4-fold with changes in colonization rate). Simulations with multiple infections, which are probably most realistic, generally resulted in extinction rates that exceeded 20% over a 200 year period. Our results provide strong support for efforts directed toward reducing the frequency or severity of disease rather than using limited resources for acquiring new habitat or enhancing corridors between existing habitat patches. Although

**theory predicts that enhanced movements may exacerbate effects of disease, increased colonization rates resulted in relatively small but consistent increases in persistence and average population size for all combinations of parameters we examined.**

## C. DISEASES AND IMPLICATIONS FOR CONSERVATION

### INVESTIGATIONS OF INFECTIOUS KERATOCONJUNCTIVITIS (PINKEYE) IN MULE DEER

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Infectious keratoconjunctivitis (IKC) in free-ranging ruminants was investigated from August 1994 through August 1996. An outbreak in mule deer (*Odocoileus hemionus*) in Zion National Park, Utah, occurred in fall and winter 1992-1993 and 1993-1994. Cases were again seen in fall and winter 1995-1996. Park officials were concerned for the deer herd and the possibility of IKC being transmitted to the reintroduced desert bighorn sheep (*Ovis canadensis nelsoni*) in Zion National Park. To aid in determining the etiology of IKC in wild ruminants, IKC cases in moose (*Alces alces*) and mule deer from Wyoming were also examined.

Given that *Maraxella* spp., *Chlamydia* sp., and *Mycoplasma* spp. have been implicated in IKC outbreaks in domestic and wild ruminants, conjunctival swabs were taken from affected and normal individuals to test for these pathogens. Twenty live deer from Zion National Park were sampled in January 1995 and 24 were sampled in January 1996. Infectious keratoconjunctivitis was not observed in animals sampled in 1995, but three individuals had clinical signs in 1996. Pathogenic bacteria were not isolated from these individuals, but *Moraxella ovis*, which has been shown to cause IKC in sheep and goats, was isolated from two clinically normal deer.

In December 1995, 12 bighorn sheep were captured in Zion National Park and samples of the eyes were taken for pathogenic bacteria. Infectious keratoconjunctivitis was not observed in these individuals and no pathogenic bacteria were isolated.

In order to differentiate pathogenic bacteria from normal flora, 226 adult male mule deer were sampled from hunter check stations in Utah and Wyoming in October 1994 and October 1995. All bacteria isolated in 1994 were identified to species while only potentially pathogenic species were so identified in 1995. Bacteria isolated from hunter-killed deer were compared to those from live deer. Most of the isolates were environmental contaminants or normal flora of the conjunctival sac. Potentially pathogenic bacteria were *M. ovis* isolated from the two clinically normal live deer in Zion National Park in 1996 and *M. bovis*, the bacterium implicated in bovine IKC, was isolated from one live deer in 1995 and one hunter-killed deer in 1994. *Chlamydia* spp. and *Mycoplasma* spp. were not detected in any samples collected.

Blood was also drawn from the deer captured in Zion National Park to test for antibodies against various viral and bacterial pathogens. Antibodies against epizootic hemorrhagic disease virus, bluetongue virus, bovine respiratory syncytial virus, parainfluenza 3 virus, and *Chlamydia* sp. were detected in multiple samples. Deer did not show signs of respiratory disease or hemorrhagic disease, suggesting that the diseases were not affecting the deer but that they had been exposed to the viruses or closely related viruses previously. In addition, antibodies against *Chlamydia* sp. were not detected in serum from deer with clinical signs of IKC in 1996, suggesting that *Chlamydia* sp. was not the primary cause of IKC in the deer herd.

During fall and winter 1995-1996, three cases of IKC in mule deer and three in moose were examined at the Wyoming State Veterinary Laboratory, Laramie, Wyoming. Samples were delivered to the laboratory from five counties in western Wyoming. Animals were sampled for potential pathogens, and *M. ovis* was isolated from two moose and two mule deer. Next, experimental infection of healthy mule deer fawns with an *M. ovis* isolate obtained from an adult male mule deer with IKC was attempted. The left conjunctival sac of three fawns was inoculated with 0.5 ml of a $6.0 \times 10^8$ suspension of *M. ovis* in sterile saline. One fawn was used as a control and received only sterile saline. Clinical IKC was not observed in any deer during the trial and *M. ovis* was not recovered. As a result, *M. ovis* does not appear to be a primary pathogen of mule deer. It is possible that *Mycoplasma* sp. or *Chlamydia* sp. were present, but were not detected by our methods. In addition, several environmental factors, such as dust and ultraviolet light, often play a role in IKC with *Moraxella* spp. We did not expose experimental animals to environmental or mechanical insult.

An experimental infection of domestic sheep used as surrogates for bighorn sheep was also attempted. An *M. bovis* isolate obtained from a mule deer fawn at Sybille Wildlife Research Facility, Wheatland, Wyoming with clinical IKC was used as the inoculum. Sheep did not show clinical signs of IKC and the bacterium was not isolated. Again, animals were not exposed to environmental conditions thought to add in IKC.

Conclusions:

1. *Moraxella ovis* appears to contribute to IKC in free-ranging ruminants, perhaps under certain environmental conditions or synergistically with *Mycoplasma* sp., or *Chlamydia* sp.

2. It appears unlikely that *M. ovis* IKC from deer would affect the bighorn herd in Zion National Park. Infectious keratoconjunctivitis was not observed in the twelve bighorns examined in the Park. In addition, reported cases of IKC in bighorn were attributed to *Chlamydia* sp.

3. We were unable to reproduce IKC in mule deer or domestic sheep under experimental conditions.

4. Serologic tests did not detect evidence of exposure to livestock pathogens likely to have significant impacts on the Zion National Park mule deer herd, though they have been exposed to several potential pathogens.

## THE ROLE OF INFECTIOUS DISEASES ON FECUNDITY, SURVIVORSHIP, AND DISPERSAL IN RECOVERING POPULATIONS OF BIGHORN SHEEP

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More than two-thirds of the existing populations of bighorn sheep in the western U.S. occur in small, isolated populations of less than 100 animals. Apparently, only an aggressive translocation program will restore bighorn sheep to their formerly large distribution, but only about one-half of translocations result in successful, increasing populations (Leslie 1980).

One purpose of this study was to investigate the population dynamics and rates of increase of several healthy and several diseased populations of bighorn sheep. A second objective of this study was to gather preliminary serological and diagnostic data, including pregnancy rates, from select herds in NPS units, especially herds with recent histories of infectious disease outbreaks and/or poor recruitment. A third objective was to develop approaches for evaluating bighorn herd health as a component of future bighorn restoration programs in the park units. Survey herds included Badlands National Park (North and South Unit herds), Dinosaur National Monument-Green River corridor area (Beaver Creek herd), Canyonlands National Park area (Island Sky, Needles, Lockhardt, and South San Juan herds), and Zion National Park.

A total of 143 bighorn sheep were captured by net gunning or drop net from eight desert and four Rocky Mountain bighorn herds. Blood, nasal, pharyngeal, and fecal samples were collected from each animal. The samples were screened for a wide variety of parasitic, bacterial and viral infectious agents.

*Pasteurella spp.*, the single most significant potential pathogen, was isolated from 90% of the bighorns cultured. Prevalence ranged from 67%-100% in each herd sampled. *Moraxella sp.*, another potential pathogen, was isolated from three of five desert bighorns and was the likely contributor to death in one desert ram from Canyonlands. The Rocky Mountain bighorn herds showed greater exposure to PI-3 virus and the desert bighorn herds showed greater exposure to bluetongue virus.

Results from this preliminary survey indicate a variety of potentially serious infectious agents in all the park herds. In many cases, sample sizes were too small to reliably estimate prevalence. Bighorns infected with a particular pathogen should not be used as source stock. Mixing of bighorn herds should be avoided due to the potential for introducing novel pathogens. Additional samplings should focus on lambs and yearlings since the younger animals will better reflect the most recent pathogen activity.

Two active epizootics were observed during this study: one at Beaver Creek, just outside Dinosaur National Monument; and one in the Needles-San Juan area of southeast Utah.

The precise causative agent for the desert bighorn declines in the Needles district of Canyonlands National Park was not established. *Pasteurella spp.* titers did not differ between the healthy Island Sky and the diseased Needles populations, but PI-3 and bluetongue exposures were higher in Needles. While these two agents could be contributing to chronic lamb mortality in Needles, several pathogens acting in concert may also explain the epizootic.

The die-off in the Beaver Creek, Dinosaur area population was likely caused by *P. haemolytica*, serotypes 3 and 4, contacted during the dispersal and later return of a radioed ram to the population (Williams et al. 1994). Ironically, the ram that was suspected of carrying the pathogen survived the epizootic, but roughly one-third of the population died during the first winter.

The major difference between healthy and diseased populations was the reduced survivorship of lambs through the summer period in the diseased populations. Survival of older animals and pregnancy rates did not differ between the two populations, at least following the initial epizootic. In the year of the epizootic, annual survival was 0.62 in Beaver Creek, but this survivorship had increased to 0.85 by the second and subsequent years post-epizootic. Annual survival of rams (0.94) exceeded that of adult ewes (0.89).

## D. GENETIC AND MORPHOMETRIC CONSIDERATIONS IN RESTORATION

### MORPHOMETRIC ANALYSIS OF SKULL AND HORN VARIATION IN THE NORTHERN REGIONS OF *OVIS CANADENSIS*

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Taxonomy is important to conservation because of its role in identifying unique biological forms, as well as in the selection of the best sources to use in restoration attempts. This research consisted of the development and analysis of a new morphometric data set for bighorn sheep (*Ovis canadensis*) from the Great Basin desert north to British Columbia and Alberta, and east to the species boundary east of the Rocky Mountains. Traditional taxonomy has long recognized four subspecies in this region: the Nelson bighorn (*O. c. nelsoni*) in the Great Basin, the California bighorn (*O. c. californiana*) west of the Rocky Mountains from the southern Sierra Nevada north to British Columbia, the Rocky Mountain bighorn (*O. c. canadensis*) along the Rocky Mountain chain, and the Audubon bighorn (*O. c. auduboni*) east of the Rocky Mountains. However, recent reanalysis of the data on which this taxonomy was based and an analysis of mitochondrial DNA variation have not supported much of this taxonomy. This study was undertaken to provide a second data set to complement recent mitochondrial DNA data.

We used univariate and multivariate statistical methods to examine the geographic variation in skull and horn characters of bighorn sheep, to test traditional taxonomic designations as hypotheses, and to look for previously unrecognized variation. We considered that subspecies should represent major subdivisions of the gene pool diversity within species where such subdivisions can be supported by the concordant patterns of multiple genetically based traits. This criterion requires that subspecies be "distinguishable" and that they have an evolutionary basis.

We found substantially more morphometric variation in skull and horn size and shape west of the Rocky Mountains than within the Rocky Mountains. Our results did not support the recognition of Audubon's bighorn as a separate subspecies from Rocky Mountain bighorn sheep. California bighorn from Washington and British Columbia were similarly not distinguishable from Rocky Mountain bighorn, but differed notably from populations in the Sierra Nevada Mountains of California considered part of that subspecies. Bighorn from the Sierra Nevada also were found to be distinguishable from those of the adjacent Great Basin desert region. Extirpated populations from northeastern California, Oregon, southwestern Idaho, and northern Nevada, also considered to be California bighorn, shared with Nelson bighorn from the Great Basin desert a horn related character that distinguishes them from Rocky Mountain bighorn.

Our morphometric results were concordant in geographic patterns with available molecular data from mitochondrial DNA. Consequently, we synonymize *O. c. auduboni* with *O. c. canadensis*. We also assign extant and extinct populations of *O. c. californiana* from British Columbia and Washington to *O. c. canadensis*. Finally, we assign extinct populations of *O. c. californiana* from Oregon, southeastern Idaho, northern Nevada, and northeastern California to the Great Basin desert form of *O. c. nelsoni*, recognizing that some transition to Rocky Mountain bighorn probably occurred along this northern boundary, as is evident for native bighorn from the Salmon River. This leaves *O. c. californiana* only in the central and southern Sierra Nevada, which makes it one of the most endangered mammalian taxa in North America.

## FURTHER MORPHOMETRIC ANALYSES OF MOUNTAIN SHEEP IN SOUTHWESTERN UNITED STATES AND MEXICO: A REPORT TO COOPERATORS

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This research extends our previous cranial morphometric analyses of southwestern bighorn sheep into the region of transition between southwestern deserts and the Rocky Mountains. Specific questions addressed were the affinities of specimens from the Utah Canyonlands region and El Malpais National Monument relative to questions of reintroduction stock. These questions were addressed in a larger geographic analysis encompassing the Sonoran, Mojave, Great Basin, and Chihuahuan Deserts and Colorado Rockies. Our database totaled about 600 skulls measured primarily from the Southwest and southern Rockies. Nevertheless, additional specimens are still needed from various locations within the region reported on here. Both univariate and multivariate statistical analyses were used to address questions of morphometric patterns and affinities.

Our results support a distinction between the Rocky Mountains and the deserts as a whole. Although sampling and analyses of the Sonoran Desert are not complete, variation among desert bighorn as a whole appears to divide them morphometrically into two latitudinal bands: (1) a southern warm desert band extending from the Mojave Desert across the Sonoran Desert of Arizona and Sonora to the Chihuahuan Desert of New Mexico and Chihuahua; and (2) a cold desert band beginning around the southern end of Death Valley in California and extending east across all but very southern Nevada and all of the canyon country of Utah, the northern limit of which has not yet been investigated. There are indications of some differences between the ends of both of these east-west bands, which would be expected in terms of isolation by distance, as well as habitat transition.

A transition between warm and cold desert affinities would be expected along the Colorado River. We found a Mojave Desert affinity for bighorn sheep along the Colorado River in the Lake Mead area of southern Nevada and a strong Great Basin affinity for sheep from the Canyonlands region of Utah. The Grand Canyon area already exhibited considerable Great Basin characteristics, but was interpreted to be a transition region. Consequently, it is most probable that native sheep in southwestern Utah were of the Great Basin race. The transition between these two desert sheep types appears to occur between 36° and 37° N. latitude, which is also about where a shift in lambing period pattern occurs (Bunnell 1982, Thompson and Turner 1982). However, this should not be viewed as a distinct line of demarcation, nor should these cold and warm desert types be viewed as distinct taxa at this time. We suggest that they be viewed as geographic races that intergrade from one to the other, and may prove to be part of a larger geographic pattern as yet uncovered.

Specimens from lava caves of El Malpais National Monument in northwestern New Mexico indicated more desert than Rocky Mountain affinity, but results were not entirely clear-cut. Within the desert, there appeared to be more of an affinity to the Sonoran rather than Chihuahuan Desert. However, there was some suggestion of a Utah alliance as well. The native sheep there probably were intergrades between the warm deserts of Arizona and New Mexico and the cold desert of Utah, but may have had some Rocky Mountain influence as well.

# COMPARATIVE ANALYSIS OF ALLOZYME AND MICROSATELLITE DNA VARIATION IN MOUNTAIN SHEEP (*OVIS CANADENSIS*) POPULATIONS: IMPLICATIONS FOR CONSERVATION

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The distribution of genetic variation within and among native and transplanted populations of bighorn sheep was analyzed using allozyme and microsatellite DNA data from Buskirk and Johnson (1995). Similar levels of genetic variation were found in transplanted and native herds, and there was no support for the hypothesis that reintroduced populations have a lower heterozygosity than native bighorn populations. It appears that allozyme variation is being maintained in populations by balancing selection (heterozygote advantage).

The analysis of genetic variation among populations indicates that there appears to be negligible differentiation between the Needles population and the Canyonlands Island in the Sky population. Reintroductions east of the Colorado River should therefore involve desert bighorn sheep from Canyonlands to restore a genetically similar population. The results reported here support the separation of cold desert bighorn sheep (Canyonlands) from Rocky Mountain bighorn sheep (Colorado), although the low $F_{ST}$ values for allozymes and microsatellites relative to the fixed mtDNA differences suggest some historic male-mediated gene flow among these regions.

# E. HABITAT SUITABILITY MODELS FOR RESTORATION PLANNING

## A TEST OF A HABITAT EVALUATION PROCEDURE FOR ROCKY MOUNTAIN BIGHORN SHEEP

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Geographic information systems (GIS) provide a valuable tool for making land management decisions on broad geographic scales. However, results from GIS analyses are highly dependent upon data scale (Lam and Quattrochi 1992, Bian and Walsh 1993, Bian 1997). Digital maps are comprised of pixels that are each assigned a value. For continuous data the pixel value is based on an average. For categorical data the pixel value is based on the condition represented by the majority of the area within the pixel. Small-scale data provide less accurate representations than larger scale data, because small-scale maps are based on information with poorer resolution, resulting in loss of detail (Lam and Quattrochi 1992, Goodchild and Quattrochi 1997). It is often important to determine the size of an area meeting given criteria. A GIS representation of an area meeting a given criterion may under or over estimate the size of the area, depending on how the criterion value compares to the average or majority value within each pixel.

Smith et al. (1991) developed a habitat evaluation procedure for Rocky Mountain bighorn sheep (*Ovis canadensis canadensis*) designed to use GIS to assist biologists and managers in evaluating occupied or proposed ranges for bighorn population restoration. We used GIS to test the predictive reliability of this procedure (Johnson 1995). In the process it became clear that results were highly dependent upon the scale of data used for the analysis. However, the authors of the model did not address data scale. To evaluate the effect of data scale on the analysis we compared results using data at two different scales for an 1800 $km^2$ area in and around Mesa Verde National Park and a 600 $km^2$ area within Dinosaur National Monument.

The bighorn habitat model developed by Smith et al. (1991) uses core habitat, defined as areas of escape terrain (slopes$\geq$27 degrees) along with an adjacent buffer zone, as the basis for the analysis. We determined the amount of core habitat in Mesa Verde National Park and Dinosaur National Monument using both 1:24,000 scale (U.S.

Geological Survey digital elevation model) and 1:250,000 scale (Defense Mapping Agency digital elevation model) elevation data. We detected different amounts of core habitat using data at two different scales in both study areas. In the area in and around Mesa Verde, we detected 629 $km^2$ of core habitat using 1:24,000 scale elevation data, but only 401 $km^2$ of core habitat using 1:250,000 scale elevation data. In Dinosaur, we detected 550 $km^2$ of core habitat using 1:24,000 scale elevation data, but only 303 $km^2$ of core habitat using 1:250,000 scale elevation data.

Using GIS analyses to determine the true size of an area meeting given criteria is difficult, largely because results from GIS analyses are data scale dependent (Davis et al. 1991, Cao and Lam 1997). While analyses conducted using 1:250,000 data average information over 90 m pixels, analyses conducted using 1:24,000 data average information over 30 m pixels. In our analysis, we could not detect rock outcrops that may serve as bighorn escape terrain if they occurred within a pixel with average slope less than 27 degrees. We found that small patches of suitable escape terrain were more likely to be omitted in analyses using 1:250,000 scale data than those using 1:24,000 scale data.

Our results from comparisons at Mesa Verde National Park and Dinosaur National Monument demonstrated that the same analysis repeated using data at different scales yielded a 36-45% difference in the amount of available habitat. Variable results based on analyses conducted at different scales could have critical implications to management decisions regarding the wisdom of attempting to restore bighorn populations. It is crucial that data scale be considered when making land management decisions based on GIS analyses.

## A SUMMARY OF BIGHORN SHEEP HABITAT PATTERNS IN BADLANDS NATIONAL PARK

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Historically, bighorn sheep (*Ovis canadensis*) have occupied larger geographic ranges than they do now (Buechner 1960, Geist 1971). Among areas where sheep have been extirpated are the western Great Plains. The subspecies that occupied this area (*O. c. audouboni*) was eradicated earlier this century. Recent efforts have reintroduced bighorn sheep from the Rocky Mountains (Benzon 1990) into some of the Audubon's bighorn sheep historic range; namely Badlands National Park, and Theodore Roosevelt National Park. Badlands National Park presented a unique opportunity to study seasonal habitat characteristics of a self-sustaining low-elevation non-mountainous prairie bighorn sheep herd. The objectives of this study were to quantify habitat associations of bighorn sheep in the North and South Units of the park and to further determine North Unit bighorn ewe seasonal preferences for four habitat characteristics: topographic position, cover type, distance to escape terrain, and slope.

Radio-collared bighorn sheep were monitored from June 1992 to September 1994 in both the North and South Units of Badlands National Park. Due to the lack of vegetation information at the time of this study, the question of habitat availability could not be addressed thus limiting the type of analyses that could be used. Data collected were summarized to present information regarding the habitat association for bighorn sheep. Home ranges were determined for Badlands bighorn sheep using minimum convex polygons. Seasonal differences in topographic position, cover type, slope, and distance to escape terrain were further analyzed for North Unit ewes.

Both North Unit ewes and rams, on average, had larger home ranges than their counterparts in the South Unit of the park. The larger home ranges displayed by North Unit sheep may have been due to the fact that their range lies within the Sage Creek Wilderness area. This area is free of roads and has minimal human disturbance. In contrast, several roads access the South Unit and livestock grazing also occurs there. Bighorn sheep in both units were most often observed on grassy areas such as sod buttes and slumps. Grassy areas on sod buttes provide abundant forage and allow for an almost unrestricted field of view for sheep. Sheep were often observed feeding in these areas. Other commonly observed cover types were non-vegetated or bare areas, which offer an unobstructed line of sight for sheep. North Unit ewe groups selected different topographic positions, cover types, distance to escape terrain, and slope according to the season. They were found in areas of early green-up during spring and switched to steep rugged areas during the lambing season. Summer and fall habitats were more variable while winter habitats tended to offer more protection from the elements.

# UNIQUE ASPECTS OF THE ECOLOGY OF BIGHORN SHEEP OCCUPYING A CLAY HILLS-PRAIRIE ENVIRONMENT IN BADLANDS NATIONAL PARK

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Due to a dramatic decline in the population levels of bighorn sheep in the late 1800s and early 1900s, recent reintroduction efforts have been made in order to restore the populations of bighorn sheep to historic levels. However, the stochastic occurrences of disease and inherently low dispersal rates have prevented bighorn sheep populations from increasing to previous census levels. In order to monitor and better manage the bighorn sheep population in Badlands National Park, a research plan was developed to investigate the influence of several variables known to affect bighorn sheep mortality: the presence of lungworm larvae as indicated by fecal samples; bighorn sheep diet preference and the availability of preferred foods; the effect of fire on forage quality and abundance; and the influence of seasonality on the Badlands National Park microhabitat.

Fresh bighorn sheep fecal piles were collected and analyzed for number of lungworm larvae per gram, and the presence or absence and relative incidence of lungworm larvae across different seasons were compared between the North and South Unit samples. These data on annual lungworm infection levels were then used to test for a relationship to annual precipitation. Additional fecal samples were collected and frozen for later analysis on bighorn sheep diet. These samples were microhistologically analyzed to estimate dietary selection. All plant genera found at a frequency of 10% or more in the samples were analyzed using a multi-response permutation procedure, which tested for differences in dietary composition between the North and South Units.

The effect of fire on forage quality was assessed by establishing several sites for burning. One-third of each site was burned in 1992 and 1993 and the remaining third was left as a control. Plots were established for the collection of plant clippings before burning and throughout the year after burning. Clippings were used to estimate biomass and identify species. Data collected for five known forage plant species (*Agropyron smithii, Bouteloua gracilis, Carex elocharis, Carex filifolia*, and *Stipa comata*) included: dry weight, percent nitrogen, percent protein, and dry matter digestibility. In order to assess habitat type, collared ewes were randomly encountered and data collected on their location. Seasonal habitat selection was determined according to topographic position, cover type, distance to escape terrain, and slope.

Results show that lungworm larvae levels were higher in the North Unit than in the South Unit, which may be explained by a higher bighorn population density in the North Unit. Variation in annual precipitation rates did not produce a significant seasonal variation in lungworm infestation. The diets of bighorn sheep in the North and South Units were similar in their plant diversity, but were dominated by different plant genera. This is probably due to natural microhabitat variation between the two units, but only after a vegetation map is created and plant abundance is sampled will the dietary preferences of the two units be accurately known. We documented few positive effects due to burning. The nutritional advantages were the short-term increased nitrogen concentration in the most common bighorn forage species (*A. smithii*), and increased digestibility in the second most utilized forage genus (*Stipa spp.*).

Ewes were shown to prefer specific topographic positions, cover types, distance to escape terrain, and slope according to season. In the spring, ewes were most often found on elevated sod buttes where foraging efficiency is expected to be high. During lambing season, ewe groups were located in extremely remote midslope and peak/ridge areas, possibly in order to escape harsh sun and high temperatures in these shadier regions. Ewe position did not change significantly in the summer, probably because ewes with lambs were maintaining maternal ranges while other ewes moved into summer habitats. During the period of rut, ewes were the farthest from escape terrain. This enabled ewe groups to spend more time in grass cover habitats. During winter, ewe groups were most often observed foraging on elevated sod buttes where wind minimized snow accumulation. In addition, ewes were frequently found on badland slumps where juniper cover provided some protection from the wind and access to nearby grassy forage.

The bighorn sheep of Badlands National Park occupy a prairie-grassland environment, much different than the montane environment inhabited by most well studied bighorn herds. Therefore, data collected during this study provide invaluable preliminary indicators for bighorn sheep health and management plans. The higher relative incidence of lungworm larvae in the North Unit may imply a higher infection rate, but these data need to be interpreted with discretion due to the possibility for alternate conclusions (Festa-Bianchet 1991). Differences in the dietary content between the two units indicate an urgent need for a vegetation map of the area so that the influence of forage availability can be evaluated. The effects of burning in our study were found to be minimal, contrary to the results of similar studies in Rocky Mountain habitats. Finally, our results emphasize the varying seasonal requirements of bighorn ewes and the need to manage for year-round habitat requirements.

## INFLUENCE OF SCALE AND TOPOGRAPHY ON GIS-BASED BIGHORN SHEEP HABITAT MODELS

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Geographic Information System (GIS) has been a powerful tool in identifying suitable bighorn sheep habitat. However, the scale of the digital data used in the GIS application can affect the outcome. The results, when using GIS to predict habitat, can be more accurately interpreted if we have an understanding of these effects. One of the key indicators in defining potential bighorn habitat is escape terrain (vertical relief). In a GIS application, escape terrain is derived from standard digital data. Early in this process, it was suspected that the resolution of these data was significantly affecting model output due to the misrepresentation of topography in the digital data. Since identification of escape terrain is paramount to delineating areas of bighorn sheep habitat, the authors sought to test the effects of bias in topographic estimates on the ability of the GIS application to accurately predict suitable habitat.

This study was based on the bighorn sheep habitat evaluation procedure (HEP) developed by Smith et al. (1991) and the GIS application developed by Johnson and Swift (1995). The primary habitat feature evaluated in the HEP was escape terrain, which provides the bighorn security from predators or other dangers. Slopes >60%, or 31° (incorrectly noted as 27° in Smith et al. 1991) were classified as escape terrain for bighorn sheep. Slope data were derived from U.S. Geological Survey (USGS) digital elevation models (DEMs). DEMs are digital files consisting of point elevations depicting the topography of an area within a spatial grid pattern. Two resolutions of DEMs were available from the USGS:

(1) A 1-degree DEM (generically referred to as a 90 m DEM) which averages the topography within 3 arc seconds (approximately 90 $m^2$) into one cell and assigns the cell one elevational height; and

(2) A 7.5 minute DEM (generically referred to as a 30 m DEM) which averages topography within a 30 $m^2$ area into one cell and assigns the cell one elevational height.

At the time of the bighorn sheep habitat evaluations, 7.5 minute DEMs were not consistently available for the entire range of parks evaluated, so the use of 3 arc second data was required in some areas. There were vast differences in the ability of GIS to determine escape terrain when these different resolutions of elevational data were employed.

To replicate the effects of varying resolutions on the ability to predict escape terrain accurately, the authors derived and calculated the area of slopes >31° from 30 m and 90 m DEMs. The DEMs were resampled into larger cells -- 30 m to 60 m and 90 m; 90 m to 120 m and 150 m cells, and again, slopes were derived and area calculated from the resampled data. By resampling the data into larger grid cells, a larger area of land was averaged and represented by a single grid cell, which was assigned a single elevational value. Therefore, the larger the surface area represented in a single DEM grid cell, the more averaging of the varying elevation. In the process, topography was smoothed and elevational changes over areas smaller than a grid cell were not represented.

Five test areas of bighorn sheep habitat were evaluated across a diverse geographic zone, from river badlands in the Dakotas to mountain canyons in the Rocky Mountains, and red rock regions on the Colorado Plateau. For a baseline estimate of escape terrain, contour lines from 1:24,000 USGS topo quad sheets were hand measured to determine 31°- 85° slopes.

Results indicate the resolution of elevation data affected predictions of bighorn sheep escape terrain. In three areas (Rocky Mountain, Canyonlands, and redrock topography), predictions of escape terrain continuously decreased with coarser resolution DEM data. In two areas (badlands topography), resolutions coarser than 30 m resulted in complete failure of the GIS application to identify any areas of escape terrain. The amount of escape terrain predicted using 30 m and 90 m DEM data was correlated to the change in elevation within a study area. Coarser resolution data always resulted in lower predictions of escape terrain than did finer resolution data. However, coarse resolution data resulted in better predictions of escape terrain in areas where there was a large amount of elevational change within the specified 30 $m^2$/90 $m^2$ area, than in areas with little elevational change. In areas with less than 200 m change in elevation, all resolutions of DEM data were insufficient to identify any significant portion of escape terrain. The greatest distortion of habitat prediction occurred in the badlands topography (affecting Theodore Roosevelt and Badlands National Parks), where there was the smallest degree of elevational change reflected in a single 30 m or 90 m cell. On the positive side, the 30 m DEM data (now available for all national parks within the Continental U.S.) was successful in predicting up to 82.5% of escape terrain in areas with more than a 475 m elevational change.

When accurate prediction of escape terrain is a factor, the authors suggest that 30 m resolution, or finer DEM data should be used for habitat evaluations, particularly in the badlands areas. (Note: USGS can produce more accurate 7.5 minute DEM data with 10 m resolution by special order.)

## APPLYING GIS TECHNOLOGY TO HABITAT USE BY A TRANSPLANTED BIGHORN SHEEP HERD IN THEODORE ROOSEVELT NATIONAL PARK

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A habitat suitability model for Rocky Mountain bighorn sheep (*Ovis canadensis*) was developed by Smith et al. (1991) and modified by Gudorf (1994) for California bighorn sheep (*Ovis canadensis californiana*) using geographic information system (GIS). This model was applied to the translocation of 19 radiocollared California bighorn sheep (14 ewes/5 rams) from British Columbia, CA to the North Unit of the Theodore Roosevelt National Park during January of 1996. The predictive capability of this model was evaluated by comparing the model's predicted areas of bighorn sheep habitat use with actual bighorn sheep habitat use of this transplanted herd as observed within the habitat assessment area on a seasonal basis. In addition, smaller scale analyses of habitat type use, physiographic type use, forage use, and behavior patterns were conducted during this study.

The model proved to be a useful tool in predicting bighorn sheep use of the basic suitable habitat, escape terrain, winter habitat, summer habitat, and lambing habitat GIS layers developed for this model. The proportion of randomized, independent point locations of sheep that were collected and categorized as within 25 m of the respective habitat layers was consistent over the course of this two-year study. A test of proportions was used to detect significant differences for point locations that were classified as within 25 m of the designated GIS habitat layer and greater than 25 m away from the designated

GIS habitat layer. This test provided me with a good measure of how well the transplanted herd used seasonal habitat in light of the fact that each respective GIS layer represented only a small proportion of the habitat assessment area. Significant differences were indeed detected for seasonal habitat use on the basis of the collected point locations of bighorn sheep.

Sheep activities were focused in the *Agropyron smithii-Stipa comata* and *Artemisia tridentata-Atriplex confertifolia* habitat types. The physiographic types most frequently used by the sheep were the River Breaks and Upland Grassland types. Forage use analysis suggested utilization of areas by sheep averaged 54% before the study animals moved to other feeding sites. Feeding was heaviest during the mid-morning and late evening hours for most sampling seasons.

The predictions of the GIS habitat suitability model (Smith et al. 1991 and Gudorf 1994) for this study were generally validated by my observations over the course of the 1996 and 1997 field seasons. However, the data collected during the two years of this study suggest that the model could be modified in the following areas: 1) increase the recognition of water sources to include seeps which occur at the lignite coal layer within the Badlands; 2) relax the topographic constraints on lambing habitat built into the model; 3) increase the flexibility of the model by including a "burn sub-routine". (Burns could be used in the western portion of the North Unit to increase visibility and forage.); and 4) an intensive evaluation of bighorn sheep forage utilization appears to be a necessity in the evaluation of "basic suitable habitat". The current GIS model does not consider this variable in the habitat evaluation process.

Further years of field research are needed in order to refine the predictive capabilities of the model. The model simply does not consider the entire range of factors (i.e. bighorn sheep forage use) that should be considered for "optimum" bighorn sheep habitat. However, this study revealed that the model could be used effectively if used with sound biological judgement. In essence, GIS technology can refine bighorn sheep management by utilizing available databases and identifying key habitat variables needed for future transplant sites.

# F. RESPONSES TO VISITORS

## EFFECTS OF INCREASED RECREATIONAL ACTIVITY ON DESERT BIGHORN SHEEP IN CANYONLANDS NATIONAL PARK, UTAH

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The National Parks of the desert southwest, like parks in other areas of the country, have exploded in popularity among outdoor enthusiasts, with a concurrent rise in the number of potentially negative human-wildlife interactions. This has been especially true in Canyonlands National Park, located just outside of Moab in southeastern Utah. As a result, protecting resources while providing opportunities for people to enjoy those resources will remain a challenge. Park managers are concerned that the dramatic increases in visitation, especially in the backcountry, may disrupt the native desert bighorn population. To maintain the health of the bighorn population, park managers need to assess the effects of increased park visitation on desert bighorn behavior. Park managers need to determine if limits to continued growth should be considered, if visitors should be channeled away from certain key locales and habitats, and what effects, if any, further increases in visitation will have on wildlife.

Bighorn sheep (*Ovis canadensis*) adjust poorly to human presence and are considered excellent indicators of ecosystem health. Desert bighorn sheep (*O. c. nelsoni*), like other bighorn subspecies, experienced major declines since European colonization due to habitat destruction, disease, competition with livestock, hunting, and loss of watering sources to other wildlife.

Increased human recreational activity can cause desert bighorn to abandon habitat, as occurred in the Pusch Ridge Wilderness, Arizona and California's San Gabriel Mountains. Alternatively, bighorn sheep exposed to high numbers of human visitors have habituated to humans in some cases.

We compared bighorn behavioral response, distance fled, and duration of response to human disturbance in two areas of the Island in the Sky district of Canyonlands National Park with different amounts of human activity to determine how desert bighorn responded to increased amounts of human recreational activity. During peak visitation in May, desert bighorn in the High Visitor Use area were exposed to up to 138 vehicles per day, 15 times more than in the Low Visitor Use area. Field crews observed bighorn responses to visitors and when necessary, approached bighorn and recorded their reactions. The effects of environmental variables on bighorn response to a hiker and a vehicle were examined and ranked using a best-fit model.

The results indicate that bighorn may be habituating to vehicles and bicycles along the backcountry roads in the Island in the Sky district of Canyonlands National Park. Bighorn responded to a vehicle less often and for less time in the High Visitor Use area than in the Low Visitor Use area. Additionally, bighorn in the High Visitor Use area reacted less severely to a bicycle than those in the Low Visitor Use area.

Though bighorns may be habituating to road traffic along the White Rim and Shafer trails, bighorns were still very sensitive to the presence of hikers. A hiker caused bighorns to react more severely and flee twice as far as did a vehicle. Furthermore, ram group responses to a hiker increased in frequency in the High Visitor Use area.

Bighorn generally reacted more often during the spring and summer, a critical time for lambing and lactating ewes, than during the fall. Ewes in the Canyonlands give birth in the latter half of May, a period that coincides with peak visitation in the Park. Bighorn disturbed by a hiker while feeding responded more severely in the High Visitor Use area. This could have detrimental effects on bighorn, especially in the summer, when forage is at its lowest nutrient levels. Bighorn also reacted more severely when approached by disturbances from above and at the same level, than when approached from below.

Bighorn response to a vehicle was influenced by distance of the animals from the road. Bighorn located closer to the road reacted more severely that those further away. A flight response occurred when sheep were at a mean distance of 116 m. In contrast bighorn generally ignored disturbances when they were more than 792 m from the road. Bighorn responses were more severe when they were at greater distances from escape terrain.

As Canyonlands National Park continues to attract more visitors, the number of interactions between people and bighorn sheep will increase. The overt responses of bighorn to disturbance, which were examined in this study, can be deceiving and may hide physiological changes. Heart rate monitoring of bighorn (see MacArthur et al. 1982, Stemp 1983) is needed to discover the true energetic costs of disturbance on bighorn.

Additionally, whether bighorn are abandoning habitat, especially critical lambing grounds, as a result of human disturbance needs to be studied.

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