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

Volume I: Planning, Problem Definition, Key Findings, and Restoration

Open File Report 99-102

U.S. Department of the Interior
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Restoration of Bighorn Sheep Metapopulations In and Near 15 National Parks fills a critical gap in the understanding and solution to restoring a severely fragmented vertebrate to large areas of the western United States. The program described in these pages represents a truly unique interagency and interdisciplinary effort. Many individuals and groups were involved and deserve credit. In particular, major funding was provided by the National Park Service. Science direction and final report preparation was provided by the Midcontinent Ecological Science Center, U.S. Geological Survey.

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U.S. DEPARTMENT OF THE INTERIOR

U.S. GEOLOGICAL SURVEY

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

Volume I: Planning, Problem Definition, Key Findings, and Restoration

By

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Produced by the Systems Support Division of the Midcontinent Ecological Science Center, Biological Resources Division of the U.S. Geological Survey, 4512 McMurry Avenue, Fort Collins, Colorado 80525, and the Natural Resource Ecology Laboratory of the Colorado State University, Fort Collins, Colorado 80523. Copies of the report may be requested from the Systems Support Division.

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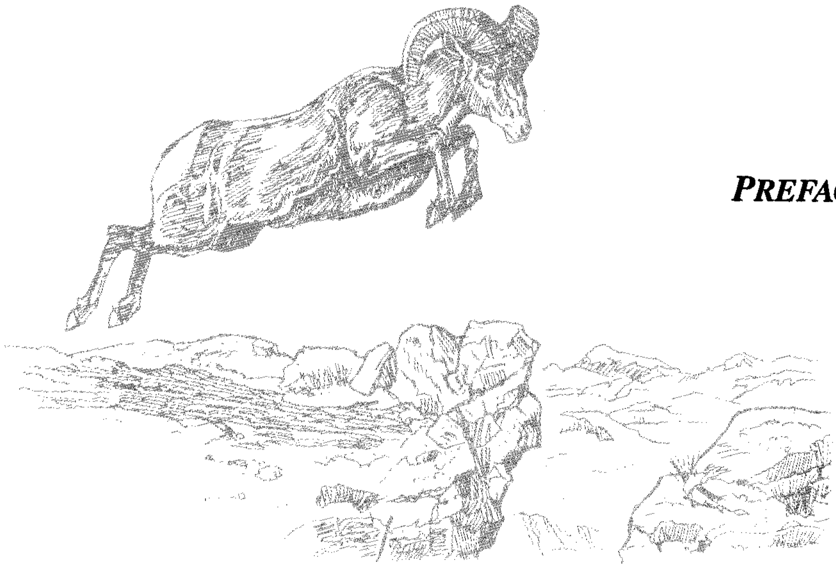


PREFACE

The restoration of bighorn sheep (*Ovis canadensis*) described in this volume began in 1987 on a river raft float trip on the Green River in Dinosaur National Monument in Colorado and Utah. Annual float trips are organized by Steve Petersburg, Chief of Resource Management of the monument. In 1987, Denny Huffman (Superintendent of the monument), William Adrian, James Bailey, Jerry Craig, John Ellenberger, Dave Stevens, and Nicki Stevens (biologists and managers of the Colorado Division of Wildlife, Bureau of Land Management, U.S. Forest Service, Colorado State University, and National Park Service) participated in the float trip.

The 3–4 day trip included stops on shore, short hikes, and searches for bighorn sheep in the precipitous, spectacular 300-m cliffs that rim the Green River. The findings were used to update the park's index of the abundance of the sheep and the annual lamb to ewe ratio. Around the campfire in the evenings, the rafters discussed an interagency approach to bighorn sheep restoration in the monument and in the entire Green River corridor.

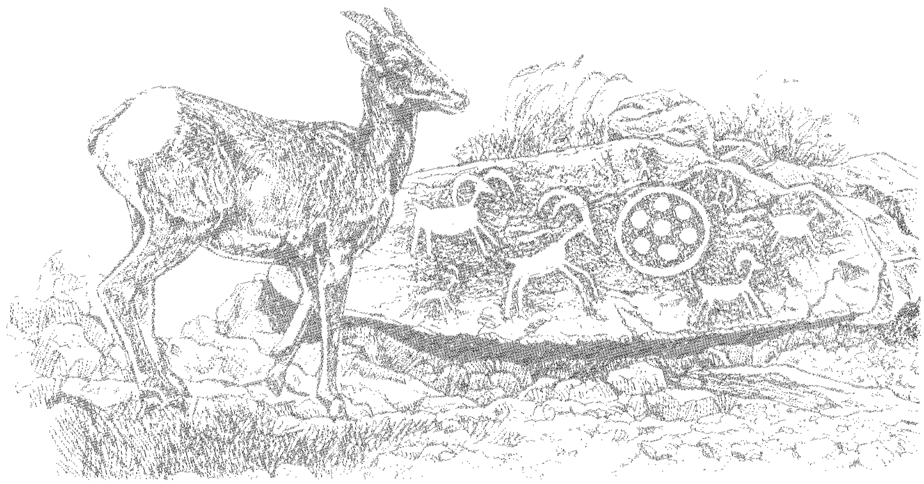
Dinosaur National Monument represented a microcosm of the regional problems with the conservation of bighorn sheep. In several areas of the monument, population declines were severe and restoration of the species was problematic. Historically, an estimated 1,000 bighorn sheep inhabited the monument and the adjacent Green River corridor. But the area was extensively grazed in the early part of the twentieth century, and after a series of disease epidemics, the species was extirpated from Dinosaur National Monument and from northern Utah and northwestern Colorado by the 1940s. The last animal was seen in 1952. Fire suppression favored large-scale encroachment of pinyon-juniper (*Pinus-Juniperus*) forests and tall big sagebrush (*Artemisia tridentata*) that diminished the preferred habitat of bighorn sheep.

Four concepts congealed during discussions on the float trip in 1987. First, the number of bighorn sheep was only a tiny fraction of the historic, reported populations in Dinosaur National Monument and the adjacent area. Second, fire suppression, forest encroachment, and domestic sheep had reduced the prospects for restoration in some areas. Third, bighorn sheep needed to be restored to all suitable historic habitat in the entire Green River corridor—not just in the monument—to ensure long-term viability of the animals. Fourth, a cooperative effort was needed by all of the agencies to raise the probability of achieving the restoration. The restorations already conducted by Dave Stevens into Rocky Mountain National Park and by the Colorado Division of Wildlife into the entire state of Colorado could be used as templates for a region-wide restoration of the sheep by the National Park Service.

Other parks, monuments, and recreation areas in the six states of the former Rocky Mountain region of the National Park Service were voicing similar needs and concerns. Research and restoration were proposed and funded by the Natural Resources Preservation Program of the Washington Office of the National Park Service. This report is about the plans, surveys, research, habitat assessment, and restoration of bighorn sheep by 15 parks.

This restoration of bighorn sheep differs from many preceding restorations in that GIS (Geographic Information System) was the key technique that preceded and guided all planning and restoration. The restoration began when many of the parks' GIS programs were in their infancy. GIS specialists were being hired, and hardware and software were being purchased. The restoration contributed to the purchase of some of the parks' GIS and digital data. The most up-to-date concepts in the new field of conservation biology were included in the restoration plans. All land management and wildlife management agencies adjoining the parks participated in every step of the process.

EXECUTIVE SUMMARY



Bighorn sheep (*Ovis canadensis*) were historically a ubiquitous species. Prior to the arrival of Europeans, they were seemingly widespread in nearly all steep habitats in the mountains, foothills, river breaks, and prairie badlands of the western United States. However, since catastrophic declines in the late 1800s and early 1900s, most extant populations have existed as small, isolated groups in a highly fragmented distribution. Stochastic events such as seasonal weather change or population fluctuations render these small populations more prone to extirpation than larger populations.

Three different subspecies of bighorn sheep were eliminated from 14 of 18 National Park System (NPS) units in the 6-state Intermountain Region of the western United States (Singer 1994). In 1990, when this restoration was initiated, only 4 (18%) of 22 discrete park populations or metapopulations were considered large enough (300–500 animals) to be secure for long-term management. Five (23%) other populations numbered 100–299 animals and 3 (14%) populations numbered 75–99 animals. But, the remaining 10 populations (45%) were either extirpated (n = 2), remnant populations (n = 5, populations of 7–10 animals), or vulnerable to extirpation (n = 3, populations of less than 50 animals). Restoration prior to 1991–96 was largely completed in one NPS unit, but was incomplete in the remaining units. Most bighorn sheep are not federally listed as endangered or threatened species, although the California peninsular population of desert bighorn sheep was recently listed as endangered. The bighorn sheep is a rare or uncommon species that is declining in many parts of its range but is abundant in other areas and still relatively easy to study and manage. The Secretary of the Department of the Interior, Bruce Babbitt, directed the Biological Resources Division of the U.S. Geological Survey in 1993 (when this agency was still the National Biological Service) to research and recover species that were declining to avoid expensive and controversial federal listing. Because the capture and moving of the species are still relatively uncomplicated and because some source stocks are available, aggressive restoration in 15 National Park System units in the former Rocky Mountain Region was recommended in 1990.

This report details the 7-year restoration of bighorn sheep to all currently suitable historic habitats in the national parks of the former Rocky Mountain Region (now the Intermountain and Midwest regions of the National Park Service). The purpose of the first phase of the restoration during 1991–93 was to conduct research and population surveys and to formulate the restoration plans. The purpose of the second phase of the initiative during 1994–97 was to conduct GIS-based habitat and biological assessments of prospective restoration sites, write restoration plans, and restore and monitor the released bighorn sheep.

Extensive planning was completed before restoration was begun. Lists of needs were solicited and obtained from 18 NPS units. So many needs were expressed by the parks that the objectives of the restoration had to be narrowed. Thus, in the early stages of the planning, Rocky Mountain, Glacier, and Yellowstone National Parks were excluded from the project because they had large, healthy populations of bighorn sheep. The services of 14 scientists and specialists were obtained to evaluate the research and restoration needs. These committees concluded that the most crucial topics were habitat assessments, population censuses, genetic conservation, and restoration of large populations of bighorn sheep. The committees also stated that, with few possible exceptions, no single park was large enough to support a self-sustaining population in the long term. The committees also recommended that clusters of metapopulations of the sheep be restored in restoration sites that included the parks and adjacent lands outside the parks. Unoccupied habitat should be evaluated with GIS, restoration of bighorn sheep near domestic sheep herds should be rigorously avoided, and the axioms of conservation biology should be closely adhered to in the restoration. The parks contributed to the planning and development of the restoration. All of the park resource staffs were gathered six times during the 7-year period. Finally, in 1995, a meeting of 46 specialists from a variety of agencies and states was convened to make more specific recommendations for the restoration protocols (Jessup et al. 1995).

Several life history and habitat-selection traits contribute to the declining status of bighorn sheep. Bighorn sheep are habitat specialists that prefer steep, rocky terrain with open visibility without or with little snow accumulations. Such patches of open, cliffy terrain tend to occur as islands of habitat in mountain chains that are surrounded by flat or forested areas that bighorn sheep avoid. Bighorn sheep characterized by longevity, low reproductive rates, slow maturation, and social mechanisms that transmit home ranges and migration routes from generation to generation. As such, bighorn sheep are notoriously poor dispersers, and translocated populations are particularly prone to be sedentary because they must establish the historic habitats and travel routes of extirpated populations. Sedentariness can increase the probability of disease transmission and vulnerability to predators and inhibit the discovery of newly created or unoccupiable habitats. Bighorn sheep seemingly have a relatively small genetically effective population size because a strict dominance hierarchy limits breeding by rams. This can contribute to a rapid loss of genetic heterozygosity in small populations[1] (Lande 1988). In addition, bighorn sheep are hypersensitive to exotic diseases transmitted by domestic sheep, and 30%–100% of a population may die in a single year from exotic diseases. Human alterations of habitat such as towns, highways, and reservoirs, and encroachment of tall, visibility-restricting vegetation further isolate and jeopardize small populations of bighorn sheep. These factors can make restoration more difficult and can increase the vulnerability of restored populations.

A 7-point program was recommended for each park: (1) survey existing populations, (2) conduct GIS-

[1]Genetic heterozygosity is defined as the mean number of loci with different alleles at a loci compared to loci with the same alleles.

based habitat assessment, (3) convene scientific panels, (4) convene an interagency meeting to discuss and plan restoration, (5) draft interagency metapopulation and restoration plans, (6) conduct translocation(s) or other management, and (7) monitor the management. The seven points were applied to restoration in 15 of the 18 NPS units from 1994 to 1996. The status of five indigenous, surviving populations and 18 populations that were translocated prior to 1990 were evaluated in 15 NPS units from helicopter and ground surveys. Geographic Information System specialists from NPS used systematic, quantitative GIS to evaluate suitable habitat in all areas except in Grand Teton National Park. A total area of 38,781 km^2—larger than the sizes of Vermont and Connecticut combined—in and near the NPS units was evaluated. Data representing escape terrain (slopes 27°–85°), distance to water, and the presence of other factors that may discourage the use of the area by bighorn sheep, such as towns or settlements, roads, large or swift moving bodies of water, and domestic sheep, were evaluated in the GIS analyses. Interdisciplinary scientific panels of 10–16 conservation biologists, disease experts, geneticists, bighorn sheep specialists, and biologists from local agencies evaluated the biological characteristics of suitable habitat such as predator abundance, competition with other native and domestic ungulates, effect of human visitor disturbances, and biomass abundance of forage.

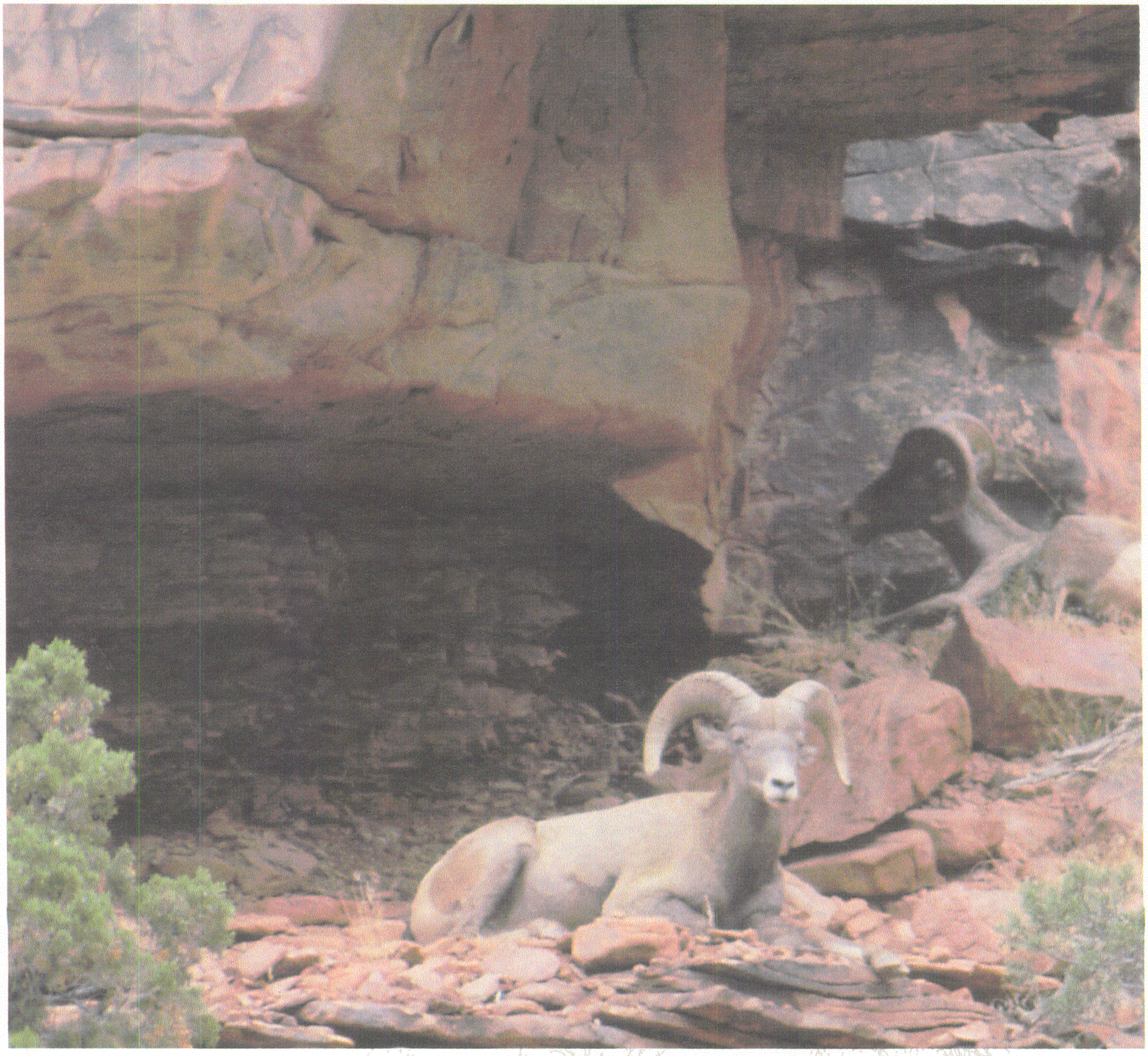
The evaluations revealed 12,329 km^2, or 32%, of the entire assessed area was suitable habitat for bighorn sheep, and the 10 scientific advisory panels recommended these areas for the restoration of bighorn sheep. We, the authors, identified 73 potential restoration sites within this total area. By 1996, 36 of these sites, or about 2,647 km^2, or 22% of the entire suitable area, had become fully or partially inhabited by bighorn sheep. Restoration in suitable habitat of participating NPS units was only 10%–61% (mean = 25%) completed. A remainder of 7,067 km^2 of suitable habitat and restoration sites, or an area about 2.7 times larger than the area occupied by bighorn sheep in 1996, was recommended for restoration of bighorn sheep.

The largest area of suitable habitat is 4,041 km^2 in the greater Canyonlands-Arches National Park areas. The next largest areas are in the greater Glen Canyon National Recreation Area and surrounding lands (2,154 km^2) and in Bighorn Canyon National Recreation Area and surrounding lands (1,799 km^2). Suitable habitats in all other remaining NPS unit areas are smaller than 1,000 km^2. If all domestic sheep allotments were eliminated from the combined area, the total suitable habitat could support 7,000–7,500 bighorn sheep if all habitat patches were fully occupied all of the time. This figure is a lofty and probably unreachable goal at any time in the foreseeable future. Also, not all of the patches would ever be occupied at the same time. Many smaller patches may only be occupied intermittently. Grazing allotments for domestic sheep are in or near bighorn sheep habitat patches in several NPS units. For example, the largest number of domestic sheep allotments (31) is near suitable restoration sites in Curecanti National Recreation Area-Black Canyon National Monument. At this time, bighorn sheep should be restored only where they will not be in contact with domestic sheep, only in restoration sites that can eventually support 125 animals, and only in clusters of sites or large sites where a metapopulation of 300 animals can be supported. Ten restoration sites were not recommended for restoration because of either the presence of domestic sheep or insufficient size.

The objective of the restoration was the translocation of new populations into clusters of suitable habitat patches or restoration sites.[2] The intention was for the bighorn sheep to spread and occupy each habitat patch and adjoining habitat patches, so that ultimately a single, interchanging metapopulation is restored. The bulk of the published

[2]A restoration site is defined as a relatively distinct patch of suitable habitat large enough to support a predicted number of ≥125 bighorn sheep and where a single translocation was recommended for restoration. Any habitat patches that were too small were not recommended as restoration sites, nor were any sites with domestic sheep present recommended for restoration.

literature suggests that given the vagaries of stochastic weather and disease catastrophes, a population goal of 300–700 or more individuals is required to ensure long-term persistence with minimal hands-on management and to minimize loss of genetic diversity. However, in some cases, restoration of smaller populations may be the only option. If so, any management to promote movements between small sub-populations and rigorous protection from disease sources are recommended.



CHAPTER ONE

INTRODUCTION

"The resulting phenomenon of mostly small, isolated, and sedentary sheep herds perpetuates population declines and habitat loss through loss of traditional movements" (Risenhoover et al. 1988:349).

Historically, indigenous populations of previously believed to be three subspecies of bighorn sheep (*Ovis canadensis nelsoni* [desert], *O. c. canadensis* [Rocky Mountains], and *O. c. audubonii* [Audubon's or Badlands subspecies]) inhabited 18 National Park System (NPS) units in the 6-state Intermountain Region (Figures 1.1, 1.2, and 1.3).

By the mid-1940s, native populations survived only in Canyonlands, Glacier, Grand Teton, Rocky Mountain, and Yellowstone National Parks. Populations in two of these five units were reduced to fewer than 100 individuals (Table 1.1). Bighorn sheep populations were completely eliminated in the remaining 13 of the 18 NPS units that historically supported populations (Singer 1994). What was previously believed to be a separate subspecies that occupied the Dakota NPS units, the Badlands or Audubon's bighorn sheep (*O. c. audubonii;* Cowan 1940), was extirpated throughout its range by 1930 (Henderson 1967). The Badlands subspecies originally inhabited the clay Badlands of the Dakotas and the low-elevation river breaks of the Missouri and Yellowstone rivers in eastern Montana. The last known individual of this putative Badlands subspecies was shot in 1926 by a member of the U.S. Armed Forces west of Sheep

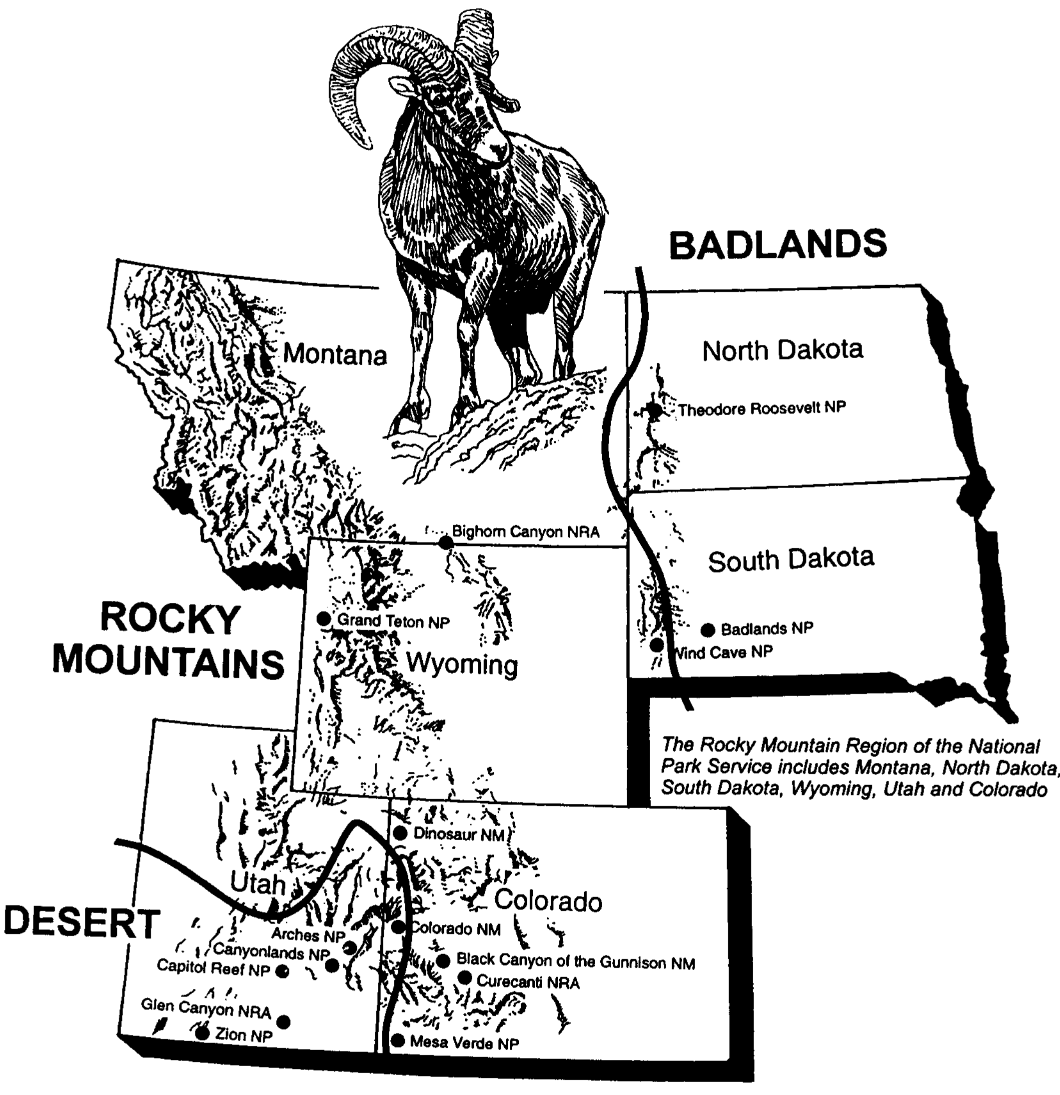


Figure 1.1. Location of 18 National Park System (NPS) units in the 6-state intermountain area that historically were inhabited by three subspecies of bighorn sheep (Ovis canadensis nelsoni; O. canadensis; O. audubonii): the desert, Rocky Mountain, and badlands subspecies. Indigenous populations survived devastating declines from 1880 to 1940 in only four NPS units, and the badland subspecies was completely extirpated (Cowan 1940, cf this volume) from North and South Dakota. The desert, Rocky Mountain, and prairie badland habitats differ in quality and characteristics of the habitat.

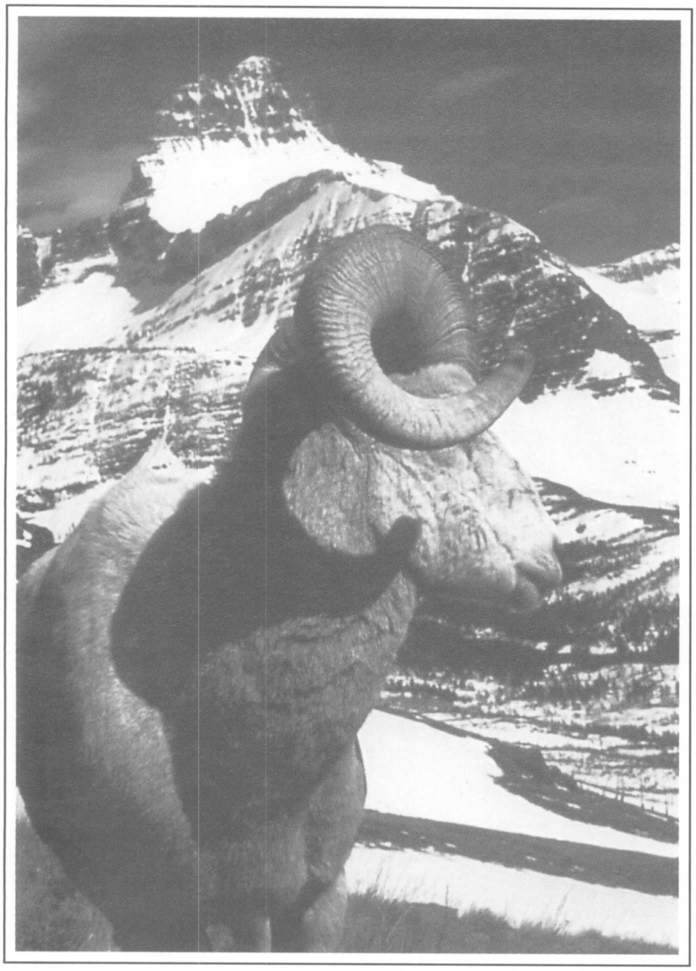


Figure 1.2. Rocky Mountain (left) (O. c. canadensis) and desert (below) (Ovis canadensis nelsoni) subspecies of bighorn sheep. The body of the desert subspecies is smaller and the body extremeties, including the ears, are longer. Desert bighorn sheep (Ovis canadensis) are generally lighter colored, the ewes have longer horns (Allen's Rule), and lambs are born over a wider time period than the Rocky Mountain subspecies.

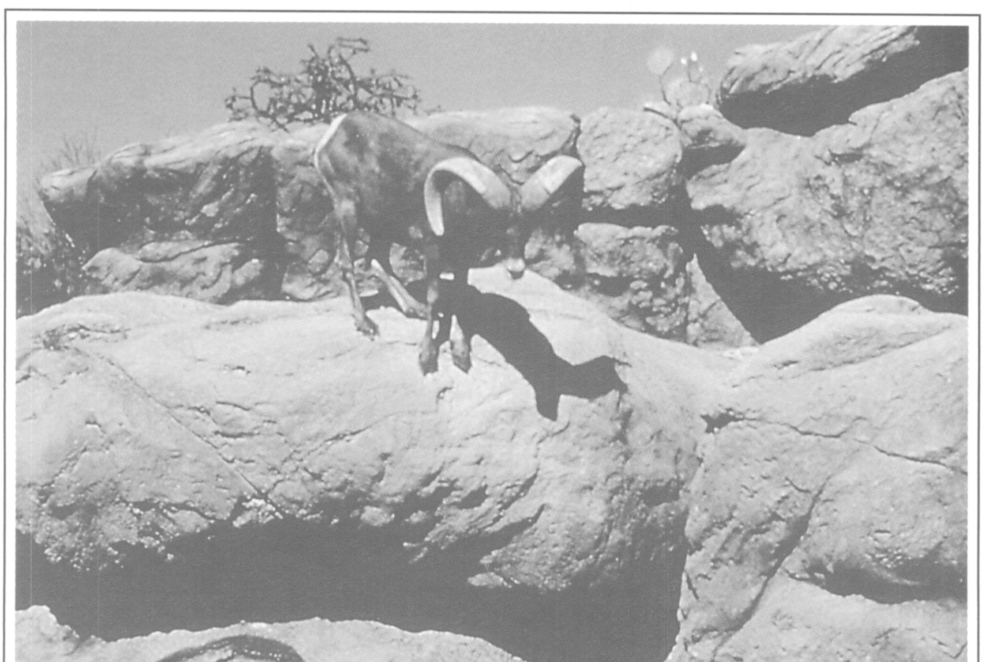


Table 1.1. Native and restored populations of bighorn sheep occurring in 18 National Park System units in 1990 at the start of the restoration initiatives.

Park unit	Original subspecies	Number of indigenous populations surviving	Number of translocations prior to 1990	Year(s) of translocations	Population trends	Comments
ARCH	Desert	0	1	1985	Increasing	Successful translocation
BADL	Badlands	0	1	1964	Slowly increasing	Recent colonization of South Unit
BICA	Rocky Mountain	0	1	1975	Increasing	Good habitat
BLCA	Rocky Mountain	0	1	1986	Severe decline	Close proximity to domestic sheep
CANY	Desert	2	1	1982	Increasing in one area; herd dieoff in a second area	Large areas of habitat
CARE	Desert	2	1	1975	Increasing	Much high quality habitat
COMO	Desert	0	1	1979	Increasing, then stable	Vegetation dense in many areas
CURE	Rocky Mountain	0	2	1974, 1975	Remnant populations	Close proximity to domestic sheep
DINO	Rocky Mountain	0	7[a]	1952, 1977, 1983, 1984, 1989	Recent increases	Very large area, some domestic sheep
GLCA	Desert	0	2		Increasing	Very large area of habitat
MEVE	Rocky Mountain	0	1	1946	Remnant	Limited suitable
GRTE	Rocky Mountain	1	0		Slowly declining	A small but indigenous population
THRO	Badlands	0	1	1966	Extirpated	Translocation enclosed--a poor practice
WICA	Rocky Mountain	0	0			Inadequate habitat
ZION	Desert	0	1	1969	Stagnant, then increase	Bighorns occupy dense vegetation
Other parks not participating in this initiative:						
GLAC	Rocky Mountain	Several	0		Stable	Very large metapopulation
ROMO	Rocky Mountain	Several	2	1977	Stable or increasing	Very large metapopulation
YELL	Rocky Mountain	Several	0		Stable or fluctuating	Very large metapopulation

[a]Seven translocations total in this part of the Green River corridor: two translocations within DINO, two more on the borders, and three more nearby.

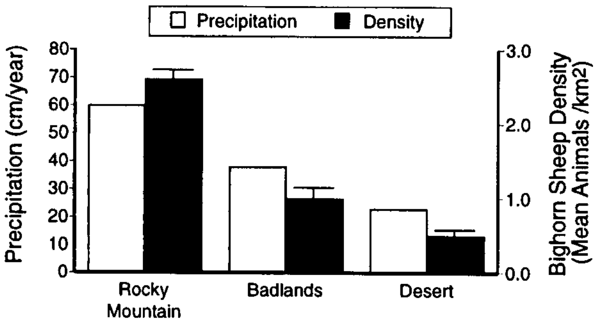


Figure 1.3. The density of three ecotypes of bighorn sheep (desert, Rocky Mountain, badlands) in the national parks is variable. The differences seemingly are related to differences in precipitation and consequent differences in biomass of forage.

Mountain Table, South Dakota (the area was then a military test site), in what is now the South Unit of Badlands National Park and the Pine Ridge Indian Reservation (Henderson 1967). Although skull remains and morphological analyses suggest that the Badlands subspecies did not differ appreciably from the Rocky Mountain subspecies (Wehausen and Ramey 1995), the animals may have possessed unique adaptations to prairie breaks and badland habitat. The dry, exposed, low-lying prairie habitats are subjected to harsh conditions and wide temperature extremes. Initially, the long period without growth (18 years) of a translocated alpine group of the Rocky Mountain subspecies into the North Unit of Badlands National Park suggested that the source stock was not well adapted to badlands habitat (Berger et al. 1995). However, the transplanted group later grew rapidly and dispersed after 1980.

Earlier attempts to restore bighorn sheep in 14 of the NPS units were variably successful. From 1949 to 1990, 22 separate groups were translocated to or immediately adjacent to 14 of the NPS units. However, most restorations were limited. Only four parks translocated more than one group. One NPS unit each translocated four groups, and three other units each translocated two groups. The remaining 10 NPS units translocated only one group (Table 1.1). In five translocations, an average of only 15 founders was used (range 13–20 animals), far fewer than the typical founder group of 28 bighorn sheep used in translocations in the western United States (Singer et al. 1997a). Also, many years went by before further restorations were made (28–50 years). Minimal restorations such as these have a low probability of success (Griffith et al. 1989). Whenever possible, founders for vertebrate translocations should be carefully selected from a high density, increasing source population, and founder sizes should consist of more than 60 individuals (Griffith et al. 1989). In spite of falling below conventional guidelines, three of the earlier translocated groups in the parks grew to moderately large populations of bighorn sheep (70, 125, and 160–200 animals).

During 1991–96, the Rocky Mountain region of the National Park Service received Natural Resources Preservation Program (NRPP) funds to research the problem, to assess the parks for restoration, and to conduct translocations and other restoration. The objectives of the initiative were the restoration of bighorn sheep into all currently suitable, historic habitat in national parks. First, the research and assessments were conducted. Second, bighorn sheep were translocated into unoccupied, suitable habitat. This report details the background of the problem, the assessments of suitable restoration sites, the restoration process, the status of the translocations, and the key research findings. Greater detail of the research may be found in Volumes II and III of this report series.

CHAPTER TWO

BACKGROUND

"Granted the biology of mountain sheep, we have little choice but to transplant. However, I deem the present transplant efforts as less than successful since they have .... produced many small, relict-like populations" (Geist 1975). Although some [groups of] transplanted bighorn sheep have increased to become viable populations, many groups have remained small or failed [to establish themselves]. Transplanted herds may be small, isolated, and non-migratory. Transplanted sheep may fail to expand into adjacent habitats because they do not provide attractive forage, or .... security (i.e., there is poor visibility or lack of suitable escape terrain)" (Risenhoover et al. 1988:349).

STATUS AND RESTORATION OF BIGHORN SHEEP IN NATIONAL PARK SYSTEM UNITS BEFORE 1990

Small populations of vertebrates are at high risk of extirpation from stochastic events such as climatic and demographic changes. Few of even the largest western national parks are large enough to sustain self-perpetuating migrating populations of wide ranging mammals (Schoenwald-Cox 1983; Newmark 1985). Inbreeding, or the breeding of close relatives in small populations, may reduce survival rates (Greenwood and Harvey 1978; Parker 1979; Ralls and Ballou 1983). Bighorn sheep (*Ovis canadensis*) are a formerly ubiquitous and widespread large mammal (Cowan 1940; Buechner 1960; Wishart 1978) that has been reduced by human activities to a series of small, isolated, and fragmented populations (Figure 2.1). The large population decline in the late 1800s and early 1900s was so extensive that all populations of the Rocky Mountain subspecies were extirpated from Nevada, New Mexico, Utah, and Washington and nearly all of Oregon (Thorne et al. 1985). Populations in Colorado were also greatly reduced. Currently in the western United States, 64% of 166 populations consist of fewer than 100 animals (Thorne et al. 1979). In Arizona, 88% of 59 populations consist of fewer than 100 animals (Krausman and Leopold 1986). This is also the pattern in the largest national parks and preserves of the United States.

A declining abundance of bighorn sheep was precipitous in the western United States from the late 1800s until about the 1940s. These declines were due to a combination of overgrazing of habitat by domestic livestock, unregulated market hunting, human developments on bighorn sheep habitat, and die-offs from diseases after contacts with domestic livestock. The two factors that were probably most harmful were market hunting and die-offs from the *Pasteurella*-pneumonia complex (*P. haemolytica, P. multocida*) contracted from domestic sheep (Buechner 1960; Stelfox 1976; Wishart 1978; Jessup 1981, 1985). Single year population die-offs of 35%–100% have been reported and low lamb survival may be chronic for 2–5 years after the all-age die-offs (Thorne et al. 1979; Onderka and Wishart 1984; Festa-Bianchet 1988, 1989). Bighorn sheep died within 28 days after having been held with domestic sheep in the same enclosures in three different experiments (Bunch et al. 1989; Foreyt 1989; Callan et al. 1991).

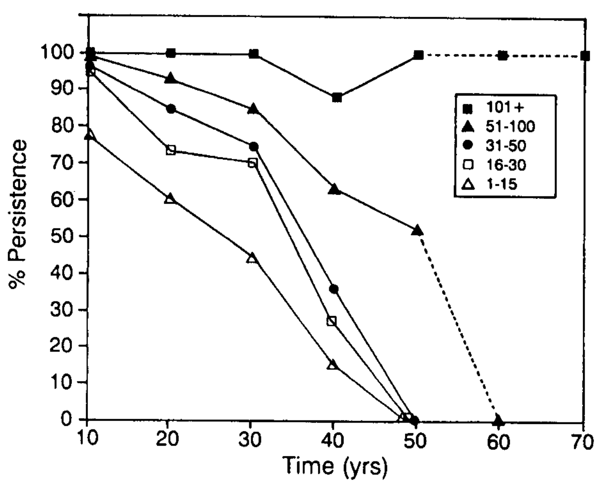


Figure 2.1. Persistence of native populations of bighorn sheep in the western United States, taken from Berger (1990). Only populations of more than 100 individuals persisted during the study period, and all populations of less than 50 individuals became extirpated. Populations of 51–100 individuals generally declined during the period.

The abundance of domestic sheep on western range lands declined from 45 million in the late 1930s to only 4 million in 1998 (Figure 2.2). Numbers of producers declined 20% just in the last 3 years, 1995–98. The decline is attributable to the changing attitudes of Americans toward wool and lamb. Wool has been largely replaced by synthetic fibers in clothing. Lamb is eaten less because some people view lamb as fatty food and view grazing by sheep as destructive to western grasslands. This large decline in the sheep industry in the West is conducive to large-scale restoration of bighorn sheep.

Three NPS units judged to be completely or nearly completely occupied by bighorn sheep at the start of this project in 1990, Yellowstone, Glacier, and Rocky Mountain National Parks, were not included in the 1991–96 restorations because of the secure status of their sheep. For example, the northern metapopulation in Yellowstone National Park consisted of several hundred animals on the northern range in the park, in the Cinnabar Basin, Tom Miner Basin, and in the Red Lodge-Absaroka area just outside of the park (Irby et al. 1986). Bighorn sheep in the northern range in Yellowstone Park have fluctuated drastically because of disease (*Chlamydia* spp.; Meagher et al. 1992). But gene flow and connectedness exist between this population and other nearby subpopulations (Irby et al. 1986; Simmons et al. 1987). Also, a large and

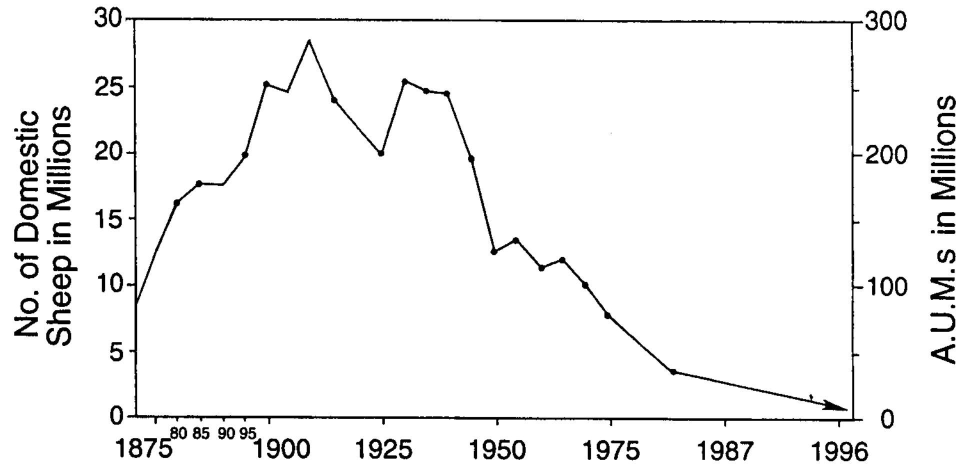


Figure 2.2. The decline in numbers of domestic sheep on western rangelands in the United States, 1930–present.

secure Yount's Peak-Wapiti Ridge metapopulation of about 1800 animals occupies the southeastern boundary area of the park, suggesting Yellowstone National Park did not require restoration.

In 1990, the Glacier National Park population was also considered large and secure. The Glacier National Park population is connected through movements of individuals to adjacent large metapopulations in Canada and along the Rocky Mountain chain south into Montana. These movements were verified during the spread of a *Pasteurella haemolytica* epizootic from Maguire Creek in southeastern British Columbia into Glacier National Park in 1982 (Onderka and Wishart 1984). The size of the total metapopulation, combined with a prior research effort, resulted in the decision that Glacier National Park was not in immediate need of restoration.

Previous restoration of bighorn sheep in Rocky Mountain National Park was highly successful and we also concluded that the park was not in need of further restoration. Visual inspections in the 1970s identified the historically inhabited Cow Creek and St. Vrain areas at lower elevations as suitable habitat (Stevens 1982). Groups were translocated into both sites in 1977 (Stevens 1982; Stevens and Hanson 1986). Monitoring later suggested the translocated animals were joined by older rams from established herds, and the translocated groups were increasing.

The long-term persistence of these three largest metapopulations (13% of 23 populations) was thus rated secure (Figure 2.3). Five (22%) other metapopulations of 100–300 animals were rated

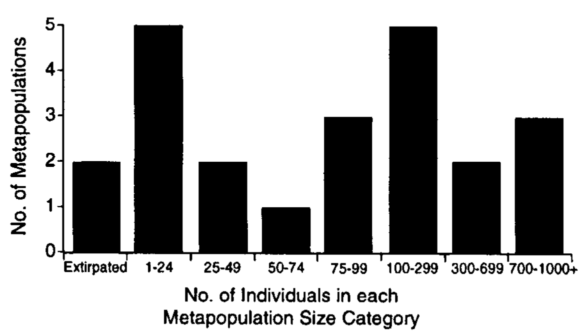


Figure 2.3. Size of discrete populations or metapopulations of bighorn sheep in or contiguous to 15 National Park System units in 1991. About 60% of the populations consisted of less than 100 individuals and were rated as vulnerable to extirpation or only moderately secure.

moderately secure, the short-term persistence of 3 (13%) populations of 75–99 animals was rated only marginally secure, 8 (35%) populations of fewer than 74 individuals were rated as vulnerable to extirpation, and another 2 (9%) populations were extirpated. Five of the vulnerable populations are remnant and each supported only 7–10 individuals (we defined remnant status as fewer than 25 animals and almost no chance of population recovery).

Most bighorn sheep populations are not yet listed as endangered or threatened under the Endangered Species Act of 1973 (16 U.S.C. 1531 et seq. as amended), except the peninsular population of desert bighorn sheep in California (U.S. Federal Register: May 1992, Vol. 57, page 19837). The listing of peninsular desert bighorn sheep may set a precedence for other declining, indigenous populations. Colorado and several other western states list bighorn sheep as a species of concern.

In spite of declining abundance in some areas, bighorn sheep from other healthy, increasing populations are trapped for source stock for restoration. Capture of the species and its transportation across county and state lines are still relatively easy. Thus, translocation of the species to unoccupied habitat is a logical management option for all the parks.

THE NATIONAL PARK SERVICE INITIATIVES

In 1990, special funds (NRPP Project No. RMRO-N-411.01) were made available to analyze problems, conduct research and population surveys, and plan restoration of bighorn sheep during 1991–93. Additional NRPP funds were received for the restoration of bighorn sheep in 1994–96. The restoration included habitat and biological assessments, restoration plans, translocations, and monitoring of translocated populations.

The first step in the planning was the solicitation of specific written requests for restoration from the parks. It was accomplished by 1 May 1991. All 18 units that historically had supported populations of bighorn sheep were contacted and all 18 submitted project requests (Appendix A). The requests ranged over a broad array of needs from determining the effects of visitors on bighorn sheep to the effects of potential competition from wild horses (*Equus callabus*).[3] The focus of the restoration was directed on one primary objective, namely the restoration of bighorn sheep to all currently occupiable historic habitat.

THE 1990–1991 ADVISORY COMMITTEES

The services of 14 different specialists in five separate committees were solicited in 1990 and 1991, and they identified five large, overriding issues (Berger et al. 1995; Hobbs et al. 1995; Murphy et al. 1995a,b; Vyse et al. 1995):

1. A unified regional approach was needed. Except one or two parks, the NPS units could not support self-sustaining populations of bighorn sheep on their own (Schoenwald-Cox 1983; Newmark 1985, 1987). Thus, interagency cooperation and a unified regional or area approach to restoration were needed (Salwasser et al. 1987). Large metapopulations that minimize chances for local extinctions should be restored to encourage dispersal and to minimize genetic isolation. Other benefits of interagency cooperation included: (a) potential cost-sharing of costly expenses such as helicopter surveys and translocations, and (b) joint competition for federal funding and resources by focusing on interagency partnerships. In response to the committees' advice to have a lead agency for such a large task, the Intermountain Region (formerly the Rocky Mountain

[3]Other funds ($179k) were later obtained from parks and the former Rocky Mountain Region to work on localized problems, including studies of possible competition with wild horses in Big Canyon National Recreation Area and basic ecology of bighorn sheep in Zion National Park.

Region) of the National Park Service assumed that role.

2. More information was needed about the historical subspecies or ecotypes of bighorn sheep, about their distribution and migrations, and about the characteristics of the sheep's habitat before the appearance of Eurasians. The changes in the landscape from modern humans and the effects of those changes on bighorn sheep needed to be evaluated. The cumulative effects on forest succession from fire suppression and overgrazing by domestic livestock and on habitat and travel routes from anthropogenic developments may have made many areas uninhabitable for bighorn sheep. The persistence of large, healthy, self-sustaining populations of bighorn sheep may no longer be possible in these locations.

3. The potential for disease transmission needed to be evaluated. Some past restorations increased the abundance of sheep but were followed by population crashes and die-offs. Managers attributed the die-offs to contact with domestic sheep, high densities of bighorn sheep, or lack of genetic diversity. Contact with domestic sheep must be rigorously avoided because nose-to-nose contact of the two species transmits the disease that has caused large, all-age die-offs in bighorn sheep. Restorations should not be made into areas of close proximity to domestic sheep.

4. Unoccupied but potentially suitable habitat needed to be objectively and quantitatively evaluated across vast areas of the landscape. The GIS procedures developed at Bear Mountain, Utah, by Smith et al. (1991) provided one of the best evaluations. The five committees recommended this technique in the parks. The extent of steep, rocky escape terrain preferred by bighorn sheep, the proximity to water sources, open visibility of habitat, proximity of other patches of suitable terrain in clusters, and adequate separation of the restoration sites from domestic sheep should be evaluated. Restoration of bighorn sheep in small, isolated patches of habitat should not be conducted. The need for management of grazing allotments, prescribed burning, or management of visitor use needed to be evaluated. Potential translocation sites needed to be systematically ranked with objective and quantitative GIS analysis. The priority of translocations had to be made in accordance with quantitative rankings of the largest and best habitat patches and not in accordance with politics.

5. The basic axioms of conservation biology should be applied to the restoration of bighorn sheep. Populations that are as large as possible, as widely distributed as possible, and as well connected by corridors as possible to facilitate dispersal and demographic and genetic mixing were recommended. Two committees differed on the recommended spatial distributions of subpopulations. Murphy et al. (1995a) suggested that participating agencies translocate animals in all vacancies to link up isolated herds. But Murphy et al. (1995b) suggested a more judicious placement of translocations and concluded that, because of the presence of domestic sheep, only a fraction of the former bighorn sheep range was occupiable. The committee cautioned against restoration of bighorn sheep to any former habitats near domestic sheep and against connecting all bighorn populations. A network of restorations may be necessary for gene flow but may also increase transmission of diseases (Bleich et al. 1990). Managers had to determine whether gene flow with other populations or the avoidance of disease transmission was more important (Simberloff and Cox 1987). Lacy et al. (1987) concluded that for the short term the avoidance of disease transmission was more important than gene flow.

The committees also provided a list of more specific needs for restoration, namely:

(1) Evaluation of population numbers and distributions.

(2) A new reliable and repeatable census technique with which to detect a ±15% change in numbers and to calculate confidence intervals.

(3) An interagency steering committee to guide the restoration.

(4) A quantitative habitat evaluation procedure with LANDSAT imagery, USGS maps, and GIS procedures.

(5) Removal of illegal, exotic caprids (mouflon [*Ovis orientalis*, *O. musimon*], ibex [*Capra* spp.],

aoudad [*Ammotragus lervia*]) from the area, such as the escaped mouflons from the Black Canyon area.

(6) A detailed restoration plan that includes habitat modifications, management of domestic livestock allotments, and prescribed burning.

(7) Augmentation of existing populations.

(8) Translocations into suitable areas. In the opinion of one genetic expert (E. Vyse, Montana State University, personal communication), the mixing of source stocks in founder groups is preferable because little of the available heterozygosity can be captured in a single founder group of 15 to 28 animals. But in the opinion of a second expert (F. Allendorf, Professor, University of Montana, personal communication), all founder animals should come from a single, indigenous source population that was as closely related to the original stock as possible. By using larger founder groups from the single source herd or by releasing multiple founder groups on the site in successive years, sufficient genetic heterozygosity is made available in the founder groups.

(9) Monitoring of the success of restorations or management with radiotelemetry.

The committees also made recommendations for several local issues. Theodore Roosevelt National Park should use the California subspecies for translocations because the state of North Dakota was already doing so (Vyse et al. 1995). The two fenced units of the park may support only 50–70 animals each and therefore the animals would always have to be closely managed. Structures should be placed to allow movement by bighorn sheep through the fences, and, if necessary, the animals should be periodically captured and transported across fences to effect dispersal and gene flow.

The staff at Theodore Roosevelt National Park attempted to raise bighorn sheep in a small 81 ha (200 acres) enclosure adjacent to the park. Three adult sheep were present in 1991, but no lambs had been reared in recent years. The practice of raising bighorn sheep in enclosures fosters transmission of diseases and has proved largely unsuccessful (Wilson and Douglas 1982; Desert Bighorn Council 1990). Thus, the enclosure in Theodore Roosevelt National Park should be taken down.

Wind Cave National Park contains less than 1 km^2 of suitable habitat for bighorn sheep, and, because the park is fenced, the prospects for a self-sustaining population are almost nonexistent. At the suggestion of the committee (Vyse et al. 1995) and with the concurrence of the park staff, Wind Cave National Park was removed from further evaluation and assessments as a restoration site, thus reducing the number of park areas to be assessed to 14.

In accordance with the committee recommendations, 10 formal interagency groups were convened to pilot the restoration in the 14 remaining NPS units. Representatives from 10 different agencies participated in these groups and shared the cost and in-kind support of the restoration. For example, four state agencies (Colorado, Nevada, North Dakota, Utah) assisted with the capture of bighorn sheep for release into 11 NPS units during 1995–98. Four state agencies provided aerial radiolocation information on research of translocated animals. Three federal and two state agencies participated in aerial helicopter censuses.

RESEARCH PLANNING

After evaluating the recommendations and written requests for restoration from the parks and after a meeting of the participating NPS units in Grand Junction, Colorado, in September 1991, the following research design was decided:

The Idaho aerial ungulate visibility model of Samuel et al. (1987) and Bodie et al. (1993) was selected for modification and use in two major ecological types—the canyon country of southeastern Utah and the clay badlands of South Dakota. Three different techniques, and the advantages and disadvantages of each technique, were discussed at the meeting (Table 2.1). Of the three techniques, the Idaho model was selected because it required the capture and radio-collaring of fewer animals and only 3–4 years of surveys. After development in Idaho, the model was validated or tested in two populations in other states

Table 2.1. Comparison of three potential census techniques considered by national park managers in 1991. The Idaho sightability model was selected for development.

Technique	Time investment to build models	Precision and reliability	Cost	Number of marked animals	Number of overflights/year
1. Idaho sightability model	3–4 years	tested well with elk	least, following the initial development are required[a]	n = 20–40, 100 data points on these animals	1
2. Double counting with two aircraft	during each survey	promising	intermediate expense	0	2
3. Mark-resight	ongoing	enormous variance with ungulates	most expensive	10–40% of the population on a continuous basis	5–7

[a]A data point is each time that a marked animal is searched for (e.g., if 25 marked animals are searched for four times = 100 data points).

with known numbers of elk (Unsworth et al. 1990; Edward Garton, unpublished data), where its accuracy was high. Another advantage of the Idaho model is that confidence intervals for the estimated population size can be calculated.

Restoration methods should be evaluated by analyzing the success of all prior translocations in the entire 6-state area.

The GIS habitat evaluation procedure of Smith et al. (1991) specifically designed for restorations in Utah should be tested for application on a regional scale. Several tests of the predictions of the model and the effects of scale and topography were planned.

Potential source and recipient populations should be surveyed for genetics and diseases.

Current levels of genetic heterozygosity and the effects of decline in genetic heterozygosity on fitness should be evaluated. Whether managers must be concerned about current levels of heterozygosity or reduced vigor of herds and what can be done to protect heterozygosity during restoration should be determined. Any possible inbreeding should be identified.

Genetically effective population size or N_e of bighorn sheep should be determined to better define for managers a minimum population size of bighorn sheep that conserves genetic resources (Figure 2.4). N_e is also a useful number for estimating the loss of genetic diversity for a given population size. National Park Service managers were directed to protect genetic diversity to the largest extent possible (National Park Service 1988, 1991).

PROBLEMS OF INSULARITY AND FRAGMENTATION IN BIGHORN SHEEP

Bighorn sheep occur in insular or fragmented distributions across the western United States. Several ecological and anthropogenic factors contribute to this distribution pattern. Bighorn sheep are habitat specialists that depend on steep, rocky terrain with open visibility and generally shallow snowcover (Figure 2.5). The species may travel through but will not reside in forested areas because of restricted visibility

Genetically effective population size (N_e) is defined as that number of animals that actually breeds and whose progeny survives into the next generation. Effective population size is a useful number in that the loss of heterozygosity can be estimated over time by the formula: H (loss of heterozygosity) = $1/2(N_e)$. Effective population size is at a maximum when the sex ratio of breeding adults is 50:50, the variance in reproductive success of adults is zero, generations are non-overlapping, and fluctuations in population sizes are minimal. But these conditions are rarely met by large ungulates. For example, if each of two herds of zebras, consists of 10 adults, and where the effect of sex ratio of breeding adults on N_e = 4NmNf/Nm+Nf, where Nm = number of males and Nf = number of females. In the case of the herd with one male and nine females, N_e = only 1.6, N_e:census count is only 0.16, and the offspring are all half or full siblings. In fact, with one male and an infinite number of females, N_e never exceeds 4. In the second case of five males and five females, N_e = 10, and the ratio of N_e:N = 1.0, the offspring will on average be less closely related and less likely to lose alleles from its parents (from Caughley and Gunn 1996).

Figure 2.4. Explanation and example of the concept of genetically effective population size (N_e). Adapted from Caughley and Gunn (1996).

(Figure 2.6; Geist 1971; Van Dyke et al. 1983; Risenhoover and Bailey 1985a). Bighorn sheep outmaneuver predators by rapidly escaping to rugged slopes. They are blocky, short-legged animals that are poorly adapted for cursorial flight across flat terrain or through deep snows (Geist 1971). Open slopes of 27°–85°, rocks and ledges, and open, gentle slopes or flat areas immediately adjacent to these slopes are preferred bighorn sheep habitat (Buechner 1960; Van Dyke et al. 1983; Hurley and Irwin 1986; Bentz and Woodard 1988; Smith and Flinders 1991). Radiotelemetry studies revealed that bighorn sheep spend nearly 95% of their time on slopes or less than 300 m of steep, rugged slopes (Smith and Flinders 1991). These patches of open, cliffy terrain often occur as islands of habitat in mountain chains that may be separated by flat or forested areas that bighorn sheep will only travel through.

Bighorn sheep have poor dispersal tendencies that further confine them to islands of habitat. The species is characterized by high longevity, low reproductive rates, slow maturation, and social mechanisms that transmit home ranges and migration routes from generation to generation (Geist 1971). Young sheep acquire the knowledge of traditional home ranges and traditional migration routes by learning (Geist 1968, 1971, 1975b; Bailey 1980). Ewes tend to live in matrilineal groups that retain the young females (Geist 1971). Adult ewes acquire a high fidelity for any areas where they first produce lambs, and this fidelity can limit future movements or pioneering of new ranges (Dodd 1983). Most 2-year-old rams disperse from their natal areas but usually follow and adopt seasonal ranges and travel routes from older rams and seem to depend on older rams for initiating migrations (Geist 1971; Festa-Bianchet 1986).

Dispersal into new habitats is rare in mountain sheep[4] (McQuivey 1978; Bleich et al. 1996). The animals usually disperse into contiguous habitat that is already occupied by other bighorn sheep and rarely disperse into completely unoccupied habitat (Geist 1971, 1975; Hoefs and Cowan 1978; Bailey 1980; Wehausen 1980; Holl and Bleich 1983; Festa-Bianchet 1986). For example, Bleich et al. (1996), after observing radio-collared individuals, reported only one

[4]We define mountain sheep as both the thinhorn [(*Ovis dalli*); including Dall and Stones sheep)], and bighorn sheep (*Ovis canadensis*).

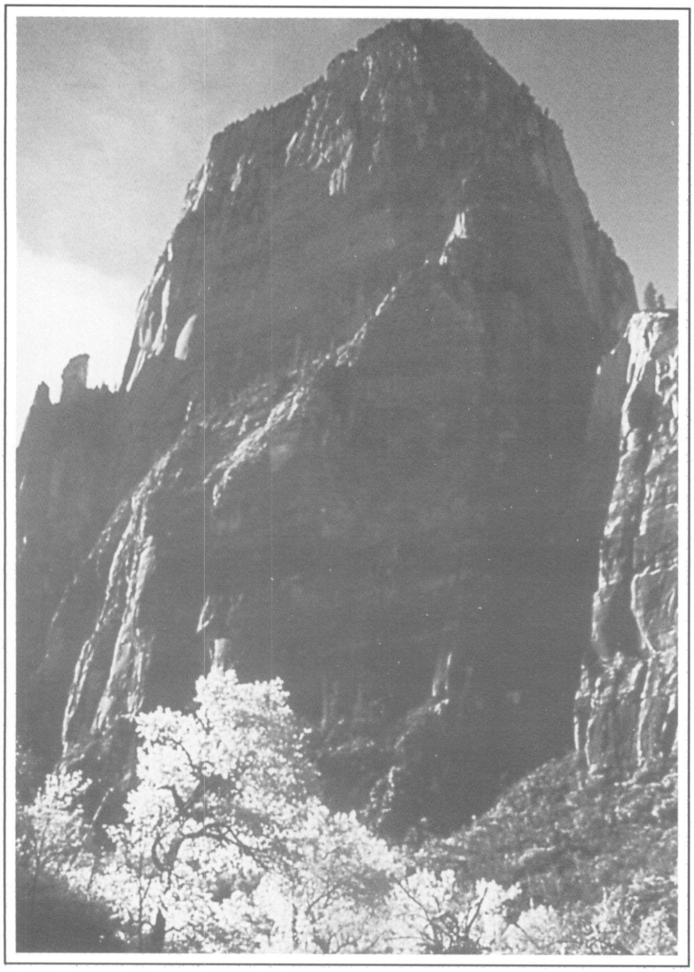


Figure 2.5. Bighorn sheep are habitat specialists that depend on steep, rocky terrain with open visibility and generally shallow snow cover. In Capitol Reef National Park, Utah, the sheep typically inhabit canyons, slick rock, and open shrub habitat (left). Ledges, cliffs, and bunchgrass characterize the habitat of the Rocky Mountain subspecies (O. c. canadensis) in Rocky Mountain National Park, Colorado (below).

emigration by one ewe from its natal home range and subsequent reproduction in and fidelity to a new mountain range. In another study of marked animals, McQuivey (1978) reported only four dispersals by single ewes. Some bighorn sheep explore new habitats but return to their original home ranges if they do not encounter conspecifics (Geist 1971).

Translocated populations are even more prone to use restricted areas because they must discover feeding areas and travel and migration routes that the extirpated, indigenous populations previously used. But the historic habitats or travel routes may now be occupied by anthropogenic development or may be overgrown with conifers such as Douglas fir (*Pseudotsuga menziessii*), junipers (*Juniperus scopulorum, J. occidentalis*), pinyon pine (*Pinus edulis*) or tall, visibility-limiting shrubs such as tall big sagebrush (*Artemisia tridentata*) because of fire suppression (Figures 2.6 and 2.7). *Sedentariness* in bighorn sheep was defined as the restriction of animals to limited areas, lack of gene flow, and lack of dispersal (Risenhoover et al. 1988). Sedentariness, the single largest problem facing bighorn sheep populations, can raise transmission rates of lungworms (*Protostrongulus sp.*), can overcrowd limited habitats, and can result in overuse of forages from year-round use of the same range (Risenhoover et al. 1988). Sedentariness may raise the rates of predation on bighorn sheep because the predator densities may be set by more numerous ungulates such as elk (*Cervuus elaphus*) or mule deer (*Odocoileus hemionus*) and because the predators may repeatedly search small locales where they know bighorn sheep are usually present.

Distinct seasonal migration between ranges, except in desert (Bleich et al. 1996) or prairie badlands environments, was the norm in native mountain-dwelling populations of bighorn sheep (Geist 1971; Demarchi and Mitchell 1973; Thorne et al. 1979; Festa-Bianchet 1986). Studies of indigenous, mountain-dwelling populations reveal that bighorn sheep traveled annually between 5–7 different seasonal ranges that were 8–18 km apart. These migrations span several hundred to more than 1,000 vertical meters in elevation because the animals move up to take advantage of seasonal changes in plant phenology (Geist 1971; Demarchi and Mitchell 1973; Geist and Petocz 1977; Thorne et al. 1979; Festa-Bianchet 1986). Desert and prairie populations are not as clearly migratory (McQuivey 1978; Bleich et al. 1990), although annual shifts in distributions of 3–15 km were observed in some desert populations (Bates 1982; Jaeger 1994) and in the prairie badlands habitats of South Dakota (Gamo et al. 1998). But many translocated populations are nonmigratory and spend the entire year on the same, small range.

ANTHROPOGENIC HABITAT ALTERATIONS

The gregarious social system of bighorn sheep facilitates the detection of predators in open habitats (Geist 1971; Bailey 1980; Woodard and Vannest 1988). Bighorn sheep have good eyesight, and open habitat provides good visibility where, once detected, the presence of predators can be communicated between animals through alert postures (Risenhoover et al. 1988). Mountain sheep find open habitats in predictable situations in early successional, post-glacial environments (Geist 1971, 1975b) or in climax grassland, desert, or shrubland habitat that is in a long-term open condition because of edaphic and climatic features (Buechner 1960; Geist 1971; Oldemeyer et al. 1971; Stelfox 1971; Bailey 1980; Van Dyke et al. 1983). Modern fire suppression during the twentieth century effected considerable encroachment of seral bighorn sheep habitat by tall shrubs and conifers (Wishart 1978; Peek et al. 1979; Wakelyn 1987). In mesic environments such as the mountains of Colorado, Montana, and Wyoming, bighorn sheep occupy habitat that is composed of seral grasslands or shrublands that are maintained in an open state by periodic fire (Stelfox 1976; Peek et al. 1979; Wikeem

Figure 2.6. Formerly occupied bighorn sheep habitat that has become overgrown with tall conifers because of a lower frequency of natural fires in Colorado National Monument. Bighorn sheep are less secure in such habitats and may be more vulnerable to stalking predators. Areas with less than 62% horizontal visibility are generally not suitable bighorn sheep habitat, although bighorn sheep travel through such areas.

Figure 2.7. Bighorn sheep habitat opened up by a prescribed burn by the U.S. Bureau of Land Management in Beaver Creek near Dinosaur National Monument, Colorado and Utah. Fire benefits bighorn sheep by increasing visibility, biomass, and quality of forage.

and Strang 1983). Fires caused by lightning and Native Americans were more frequent in the western United States in the previous century, and thus considerable areas of historic habitat are no longer suitable for bighorn sheep.

Bighorn sheep also benefit by burning of their habitat in several other ways. The enhanced visibility of burned habitat allows bighorn sheep to use areas farther from escape terrain than similar adjacent unburned habitat (Shannon et al. 1975; Bentz and Woodard 1988). Bighorn sheep quickly found and used areas where trees and shrubs had been clear-cut (Risenhoover 1981). Bighorn sheep forage more efficiently in open habitat with good visibility than in shrub-dominated habitats (Hurley and Irwin 1986). Burning of bighorn sheep habitats increase forage abundance (Elliott 1978; Peek et al. 1979; Riggs and Peek 1980; Johnson and Strang 1983). Burning increased the protein content and digestibility of grasses by only a small percentage; but bighorn sheep diets improved markedly in burned habitats because more green grass was available (Hobbs and Spowart 1984). In burned sites, grasses stayed green all winter and spring green-up of grasses was earlier (Elliott 1978; Peek et al. 1979; Hobbs and Spowart 1984; Seip and Bunnell 1985). Also, lungworm concentrations were reduced in recently burned habitats (Wiseley 1983; Seip and Bunnell 1985).

A population that became more sedentary because of vegetation encroachment is the Waterton Canyon herd in Colorado. Fire suppression induced the loss of migration routes and range area of this population that consequently became sedentary (Bailey 1986). Between 1970 and 1982, the herd abandoned nearly two-thirds of its range because of vegetation encroachment. By 1981, the population was concentrated at densities of 31 bighorn sheep/km^2 on its summer range, and the concentrations and resultant stress in 1982 may have contributed to an epizootic with considerable mortality (Bailey 1986).

Bighorn sheep, because of their narrowly defined habitat niche, are especially vulnerable to human disruptions of the landscape. Reservoirs, constructed lakes, concrete lined canals, and aqueducts are usually complete barriers to bighorn movements (Graham 1980; Wilson et al. 1980; Smith and Flinders 1991). Some woven wire fences, all major highways, and towns also severely disrupt travel by bighorn sheep (Figure 2.8).

Bighorn sheep may have historically occurred in metapopulations (Bleich et al. 1996). A metapopulation is defined as a collection of interacting subpopulations with limited exchange of individuals (Figure 2.9). Metapopulations may be more stable than isolated subpopulations (Gilpin 1987; Hanski 1991). Thus, restoration in metapopulations spreads the risk of single extirpation among the subpopulations. Restoration into all habitat patches within any potential metapopulation seems to be advantageous for long-term persistence (Levin 1976; Gilpin 1987; Hanski 1991). But some researchers remain unconvinced that metapopulations are a more persistent structure over time (Levin 1976; Hanski 1991). Bighorn sheep metapopulations may be the product of a former, naturally fragmented distribution (Schwartz et al. 1986; Bleich et al. 1990, 1996) but also the more recent product of anthropogenic fragmentation of the landscape (Figure 2.9).

HYPERSENSITIVITY TO DISEASES TRANSMITTED FROM DOMESTIC LIVESTOCK

Nearly all major die-offs of bighorn sheep have been caused by bronchopneumonia. The pneumonia is typically traced to *Pasteurella*, Corynebacterium, *Diploccus*, and Mycoplasma, but some viral agents such as bluetongue, epizootic hemorrhagic disease, and PI-3 may predispose the animals to pneumonia (Spraker and Hibler 1982). The most lethal agents are typically Pasteurella haemolytica serotypes 3 and 4. Protostrongylid lungworm infestations, a native parasite associated with mesic mountainous environments, may also predispose bighorn sheep to bacterial and viral agents and to the pneumonia-complex (Spraker and Hibler 1982; Jessup 1985).

The decimation and extirpation of local populations of bighorn sheep have been associated with close

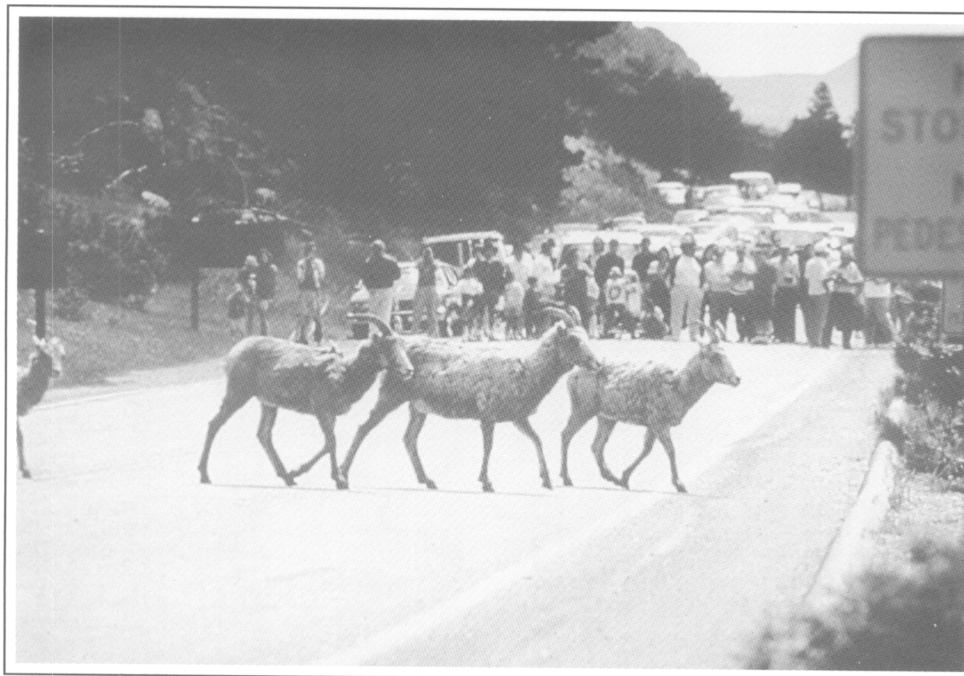


Figure 2.8. Major highways, large impoundments, and certain woven wire fences are barriers to travel of bighorn sheep.

contacts with livestock, particularly domestic sheep (Figure 2.10; Buechner 1960; Barmore 1962; Robinson et al. 1967; Stelfox 1971; Lange et al. 1980; Jessup 1981; Blaisdell 1982; Foreyt and Jessup 1982; Goodson 1982; Onderka and Wishart 1984; Clark et al. 1985; Sandoval 1988; Coggins and Matthews 1992). A series of experiments provided strong evidence that: (1) bighorn sheep that come into nose-to-nose contact with domestic sheep die in a few days thereafter of bacterial pneumonia, and (2) the pathogens known to be absent earlier in the bighorn sheep but present in clinically healthy domestic sheep were confirmed to be present in the dead bighorn sheep (Onderka and Wishart 1984; Foreyt 1989; Callan et al. 1991). Onderka et al. (1988) found that bighorn sheep and domestic sheep were susceptible to pneumonia induced by bighorn sheep and by domestic sheep strains of *P. haemolytica*. Titers to *P. haemolytica*, however, can occur in other free-ranging populations of bighorn sheep, seemingly without significant mortality in some cases (Thorne and Miller 1989).

A strong inverse relation has been observed between the presence of domestic sheep and the abundance of wild bighorn sheep (Figure 2.11). Goodson (1982) reported that nine herds that shared ranges with domestic sheep experienced die-offs, and no herd increased when domestic sheep were present on its range. Also, eight herds increased after domestic sheep were removed from their ranges. The correlations were not perfect, however. For example, some bighorn sheep herds survived for years, although domestic sheep were on their ranges. Moreover, some die-offs occurred on ranges where domestic sheep were not present (Goodson 1982).

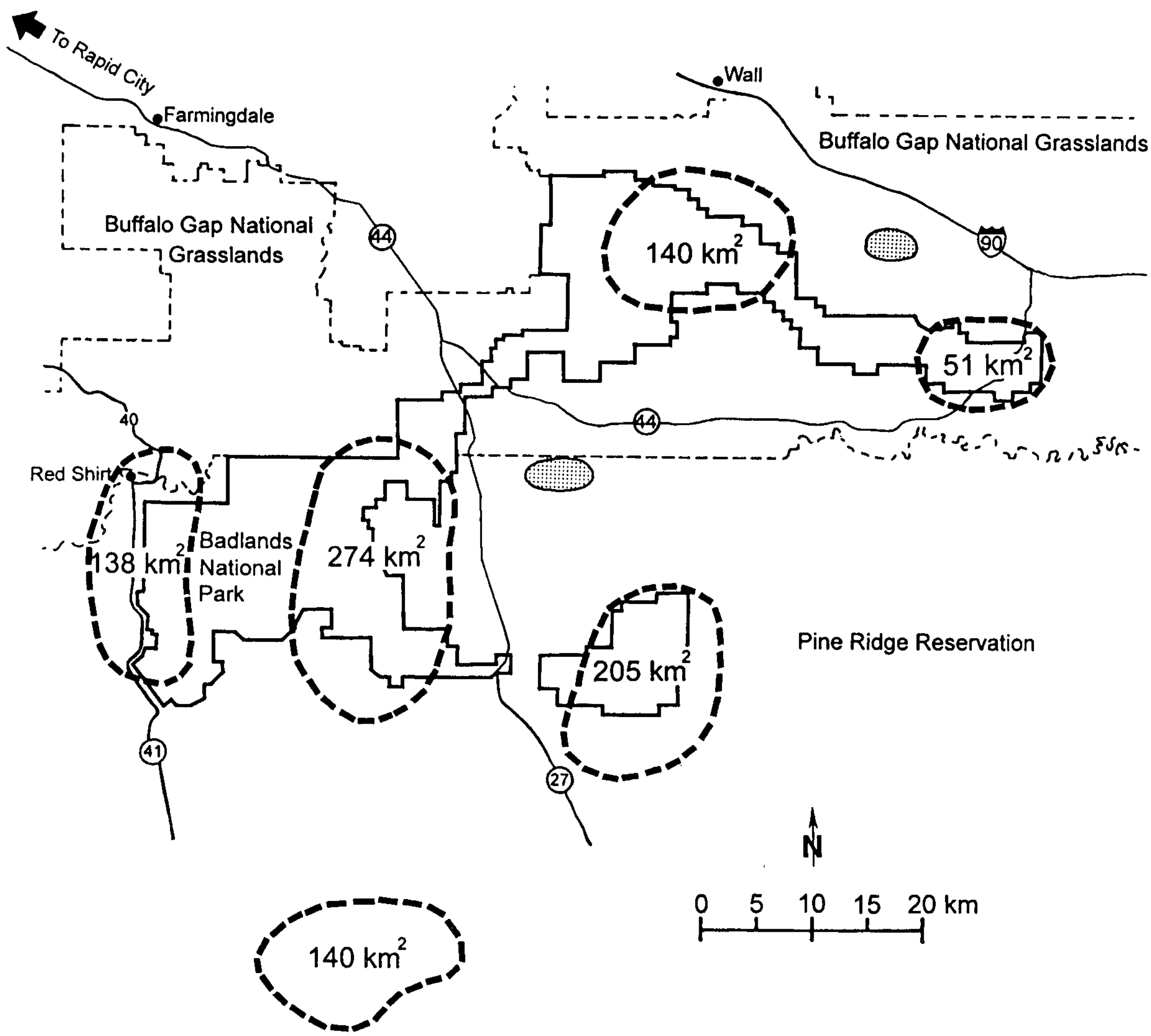


Figure 2.9. The bighorn sheep of the Badlands National Park-Lakota Sioux Tribal lands complex form a metapopulation. They occupy patches of steep elevated buttes and clay badlands that are separated by eroded, low-lying, and relatively flat grassland and low breaks. Interchange and colonization across these low-lying areas between the better patches of habitat are limited.

Figure 2.10. A wild ram in the midst of a flock of domestic sheep ewes who may be in estrus. Such nose-to-nose or close physical contact may cause an epizootic and respiratory die-off in the bighorn sheep population if animals, such as this young ram, return to their herd and infect their conspecifics.

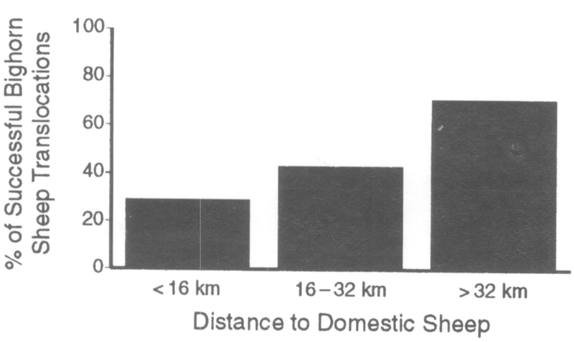


Figure 2.11. The persistence of translocated bighorn sheep was less when the founding site was near the ranges of domestic sheep.

The history of bighorn sheep on western ranges in the United States may be characterized by three distinct periods:

1. Pre-1870: The earliest explorers reported large numbers of bighorn sheep in a wide variety of desert, mountain, and prairie badland habitats (Buechner 1960; Wishart 1978).

2. From 1870 to 1945: Declines of the abundance of bighorn sheep were catastrophic, especially where large numbers of domestic sheep were grazed in bighorn sheep habitat. Unrestricted market hunting for new mining centers, new towns, and overgrazing of the ranges by other domestic livestock also contributed to the widespread declines.

3. 1945 to present: The number of domestic sheep on western rangelands peaked around 1945 but has continuously declined to one-tenth of its former size. The declines in the prevalence of domestic sheep have

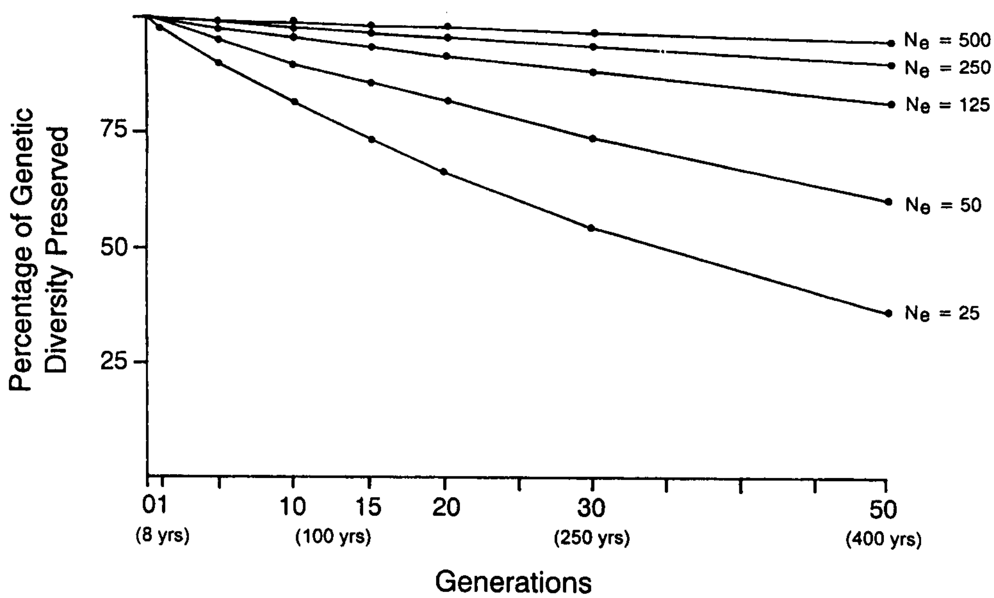


Figure 2.12. Smaller populations and populations with smaller genetically effective numbers (N_e), will lose genetic heterozygosity over time, especially over tens of generations.

created an opportunity for the restoration of bighorn sheep and many translocations were conducted. Also, prescribed fires improved some ranges.

GENETICS

Fragmented, small and isolated populations are prone to extirpation from stochastic and demographic events. Small, genetically effective population sizes effect loss of genetic heterozygosity (Figure 2.12). A genetically effective population size (N_e) is the number of animals that recruit offspring and transmit genes into the next generation. N_e is a useful concept because it summarizes the population that contributes directly to the maintenance of genetic variability in the population. Although rules of thumb such as the 50–500 rule (N_e of 50 = short term minimum; N_e of 500 = long-term minimum) for N_e have been criticized for their low applicability to wild mammals (Lacy et al. 1983), a lowest minimum N_e is useful to managers for setting goals for population recovery.

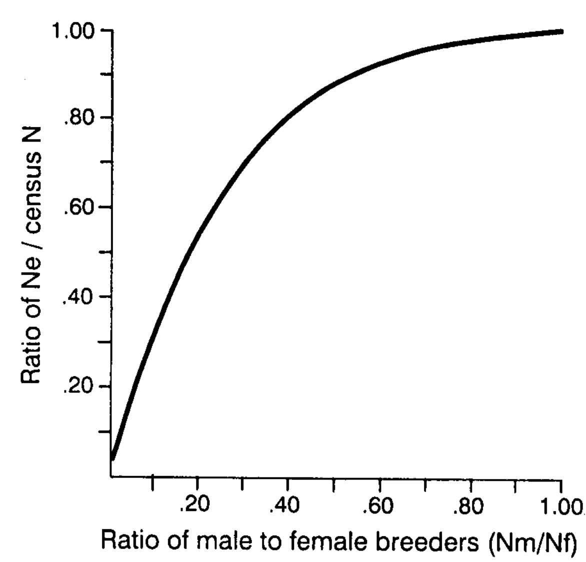


Figure 2.13. The least abundant sex among the breeding members of a bighorn sheep population may greatly affect N_e and the concomitant loss of genetic heterozygosity.

Fragmented groups are more prone to harm from genetic drift, inbreeding, and founder effects (Lacy 1987). In general, a genetically effective number of fewer than 50 animals that persist for 15–20 or more generations may lose substantial genetic diversity (Franklin 1980; Ramey 1993).

Several factors contribute to relatively small N_e in mountain sheep. Female mountain sheep do not produce young until 2 years old (more typically 3 years old). The dominance hierarchy keeps males from breeding until they are 7 years old (Geist 1971; Hogg 1983, 1984, 1988), although 1- and 2-year-old males are capable of breeding (Berger 1978; McCutcheon 1981). The generations are overlapping and the variance in reproductive success of both sexes is high (Geist 1971; Festa-Bianchet 1988; Hogg 1988). Dominant, large-horned rams typically guard or tend ewes during the entire 2-3 day estrus. By keeping all other rams away, a male gains exclusive breeding with a female (Geist 1971; Nichols 1971; Hogg 1987). The older rams approach ewes slowly and deliberately with frequent displays. Younger rams tend to perform fewer displays and often rush at a female to attempt copulation (Geist 1971; Singer et al. 1991; Shackleton 1991). Ewes accepted as many as 30 copulations per 2-day estrus from older, tending rams but ran or walked away from 94% mating attempts of subordinate rams (Hogg 1984). In one study, Class IV rams (the class of the largest horned or 6–14 year-old rams) constituted only 28% of all rams but performed 60% of all copulations (Geist 1968, 1971). Even then, not all Class IV rams breed. Only 20%–50% of the Class IV rams bred, depending on the study area (Geist 1971), and thus only 10%–25% of all the rams in a typical population may breed (Geist 1971). Shackleton (1973) who studied mountain sheep in Alberta also reported that a clear dominance hierarchy restricted breeding to only the biggest rams.

N_e can be limited by the least abundant sex that participates in breeding, and thus in highly polygamous species such as bighorn sheep, where few males breed, the ratio of N_e to census population (N) is low (Figure 2.13). Additionally, sex ratios that favor females in many natural or hunted populations of mountain sheep (Aldous 1957; Murphy and Whitten 1976; McQuivey 1978; Wehausen 1980; Hogg 1983) and hunting focused only on older males can further reduce the proportion of breeding males to breeding females. The works of Geist (1971) and Shackleton (1973) suggest that the ratio of N_e to census N is only 0.12–0.25 in mountain sheep populations. But more recent evidence suggests that more males may breed through alternate mating strategies (Hogg 1984; Hogg and Forbes 1997). Hogg (1984, 1988) observed subordinate rams copulate with ewes through forced strategies of coursing or blocking estrous ewes. He found that forced copulations were not trivial. For every hour of watching estrous ewes, Hogg (1988) observed 0.92 copulations by tending rams and 0.80 forced copulations by coursing, subdominant rams. Coursing rams attempted more forced copulations late in the estrous period of ewes, probably because the probability of ovulation is greater in late estrous and when the risk of injuries from larger, tending rams is better justified (Hogg 1988).

The observations of Hogg (1984, 1988) suggest many more rams, probably 50%–60% of all rams, breed and that the ratio of N_e to census N is larger, perhaps 0.50. But how generally applicable the observations of Hogg (1984, 1988) are has not been established. The National Bison Range population, where Hogg (1984, 1988) worked, is small (50–60 animals), isolated, and sedentary, and the climate is temperate. Geist (1971) and Shackleton (1973), however, studied larger, migratory, northern populations that inhabited harsher environments. The difference in climates, population sizes, or movements between the study areas may explain the reported difference in male breeding behavior.

Other researchers applied widely different ratios of N_e to census N ranging all the way from 0.12 to 0.95 (mean = 0.49; Skiba and Schmidt 1982; Schwartz et al. 1986; Hass 1989; Fitzsimmons et al. 1995). For the example of a hypothetical viable census population of 125 males, subsequent estimates of loss of genetic diversity per generation using the formula for loss of $H = 1/2\ N_e$, ranged widely from 0.03 to 0.004. Thus, the estimated time during which 20% of the genetic variation would be lost from the hypothetical population of 125 animals also ranged widely from seven generations (32–35 years) for the first example, but 50 (225–250 years) for the second example. This range in estimates and level of uncertainty is unacceptable for managers, and the estimates of N_e to census N for bighorn sheep must be better defined.

Other factors may serve to further reduce N_e in mountain sheep. High variance in reproductive success of males (Geist 1971; Hogg 1984, 1988) and females (Festa-Bianchet 1986, 1988) and fluctuating population size reduce N_e (Caughley and Gunn 1996). Simulations by Ryman et al. (1981) revealed that hunting of predominantly one sex can severely reduce the amount of genetic variation in a population of ungulates. Mountain sheep are typically harvested by trophy hunting that is restricted to only older, large-horned males.

Low heterozygosity and inbreeding have been identified in only a few populations of wild bighorn sheep (cf Haas 1989; Boyce et al. 1996). But most recent bottlenecks of herds (the forcing of populations into small population sizes for periods of time) have only occurred for one to four generations. Also, some subpopulations of bighorn sheep may be connected by the regular travel of rams and some travel by ewes across as many as 6–20 km of intervening terrain (Bleich et al. 1990, 1996), thus effecting gene flow between some mountains.

Several factors may contribute to a close relatedness of bighorn sheep. Females and young seemingly live in matrilineal societies (Geist 1971; Bleich et al. 1996). Thus, many of the females on one range may be close relatives of each other. Bleich et al. (1996) felt that matrilines were the operational unit of mountain sheep metapopulations. Also, rut areas are traditional (Festa-Bianchet 1986). Geist (1971) reported that 77% of recognizable rams returned to the same rut area in successive years, and Festa-Bianchet (1986) reported a similar 77% rut-site fidelity in radio-collared rams in successive years. Thus, older rams could dominate the breeding in a particular area for several years (Lenarz 1979). Additionally, dispersal of rams from small, fragmented populations, especially translocated populations, is rare (Risenhoover et al. 1988). Another factor that contributes to relatedness in translocated groups is the practice of capturing the animals with a drop net. Group of females with young in close proximity to one another that may be caught under a net may be closely related individuals of a maternal line. Earlier restoration guidelines even called for the capture of family groups because they would probably remain together after their release in the new habitat and the translocation of only a few young males because the capture and transportation of older males are difficult (Wilson et al. 1975). Both practices increase the risk of inbreeding.

Extreme inbreeding is the breeding of close relatives in populations, whereas mild inbreeding is the mating of individuals with a closer common ancestry than the ancestry of the species (Shields 1987). Extreme inbreeding is always deleterious (Figure 2.14). Extreme inbreeding typically reduces survival of young (Ralls et al. 1979, 1986; Sausman

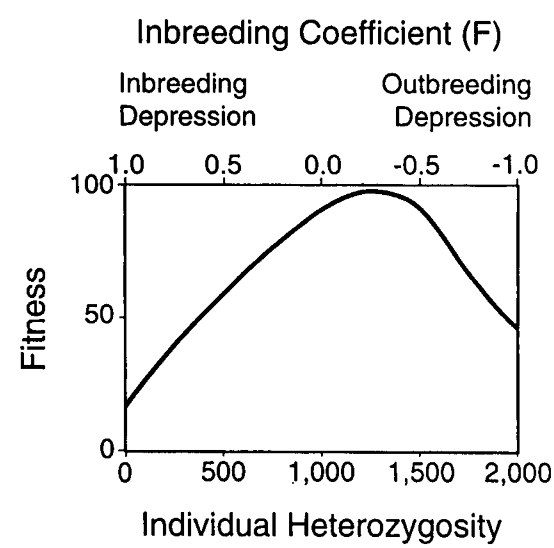


Figure 2.14. Relations between genetic heterozygosity, inbreeding, and fitness in mammals. Unlike extreme inbreeding, mild inbreeding is not always deleterious in wild populations. Adapted from Caughley and Gunn (1996) and Mitton (1993).

1982), resistance to disease (Hamilton and Zuk 1989), sperm number and sperm motility (O'Brien et al. 1983; Wildt et al. 1983), and growth rates (Mitton and Grant 1984).

Mild inbreeding, on the other hand, is not always deleterious to natural populations. Mild inbreeding may raise adaptation to local conditions and erase maladapted traits that could occur because of outbreeding depression. Mild inbreeding and philopatry enhance familiarity with an area and are favorable in all stable habitats (Greenwood and Harvey 1978; Greenwood 1980). Only small amounts of gene flow are sufficient to stem inbreeding depression (Hooper 1971). Several rare ungulates, namely, the European bison (*Bison bonasus*), Pere' Davids deer (*Elaphus davidianus*), and fallow deer (*Dama dama*) in British parks have been inbred to some extent. Yet, their reproductive success, at least in the short-term, is excellent (Smith et al. 1979; Frankel and Soule 1981; Sage and Wolff 1986). However, these protected and semi-domestic populations were not exposed to natural predation. Inbred populations may be less well adapted to intense natural predation or to changes in habitat or climate conditions (Frankel and Soule 1981).

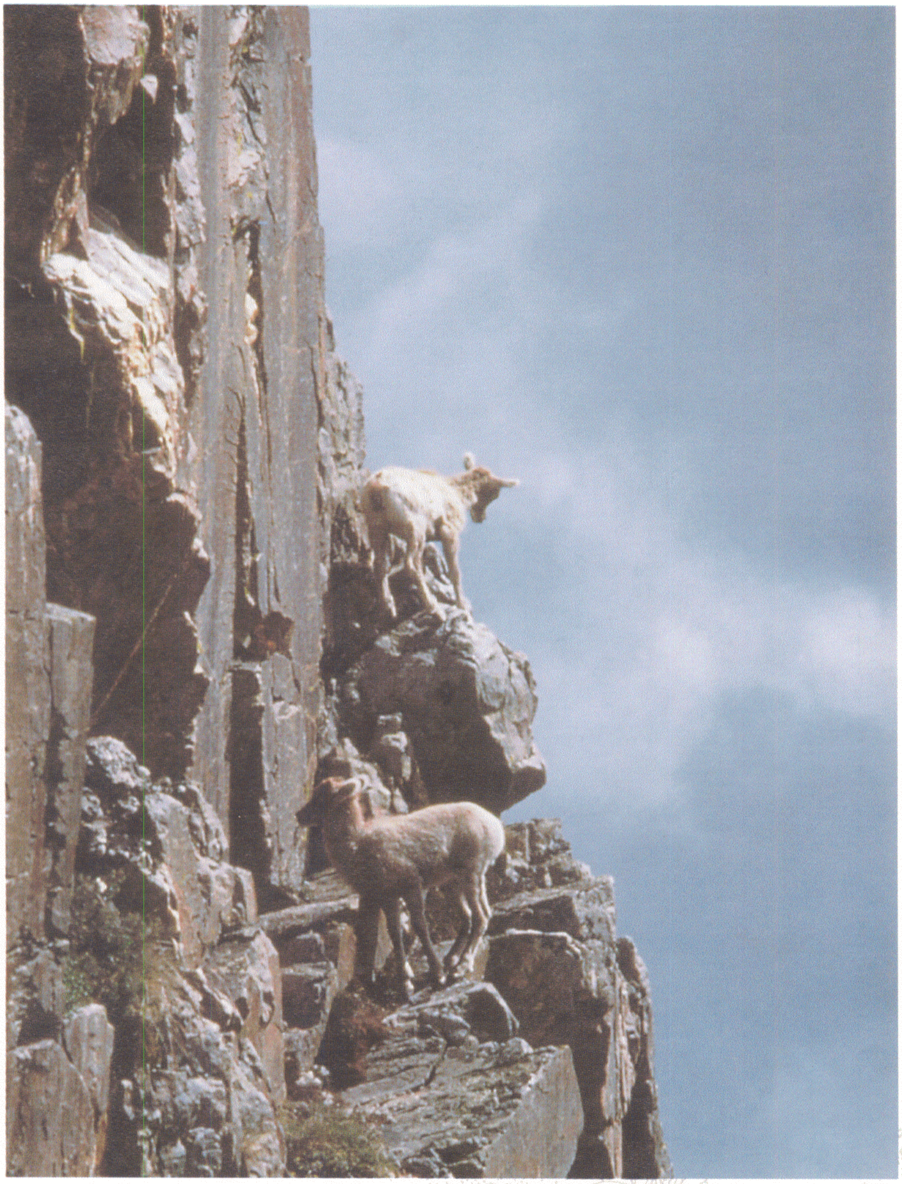
Any evidence and consequences of inbreeding in bighorn sheep remain poorly documented. Sausman (1982) reported that lambs from extremely inbred lines of bighorn sheep in zoos survived at a lower rate than lambs from non-inbred lines. Although this work has been criticized for its setting in a benign, artificial environment, the evidence is even more convincing because the effects of inbreeding on survival would be greater in more rigorous natural environments. Two authors hypothesized that extreme inbreeding occurred in small populations of wild bighorn sheep (Skiba and Schmidt 1982; Haas 1989). Stewart and Butts (1982) and Fitzsimmons et al. (1995) reported a negative influence of reduced genetic heterozygosity on the growth of horns in bighorn sheep. Because horn size, dominance, and breeding success are closely associated in bighorn sheep rams, reduced genetic heterozygosity may reduce individual fitness through reduced horn sizes. Higher fitness, including greater fetal growth rates, higher twinning rates, larger adult body weights, higher social dominance, and large antler size have been associated with higher genetic heterozygosity in some mammals (Craig and Baruth 1965; Cothran et al. 1983; Mitton and Grant 1984). To date, however, the effect of genetic heterozygosity in bighorn sheep on fitness has not been studied. Rapidly growing populations maintain a higher proportion of their initial genetic heterozygosity than slower growing populations, and thus managers should encourage rapid growth rates of translocated populations (Allendorf 1986; Scribner and Stuwe 1994).

The effects of reduced genetic heterozygosity on fitness in mammals is controversial (Figure 2.14). Controversy surrounds the cheetah (*Acinonyx jubatus*; Mills 1996), a species with low genetic variation. Reduced sperm quality, low cub survival, and a high incidence of disease in captivity have been attributed to low genetic variation in cheetahs (O'Brien et al. 1983; Wildt et al. 1983). However, other studies from the wild revealed that low cub survival was from predation by lions (*Panthera leo*) and hyenas (*Crocuta crocuta*) and that outbreaks of feline distemper was also observed in other species of wild cats (Laurenson 1994; Laurenson et al. 1995). In an attempt to reconcile the controversy, Mills (1996) pointed out that inbreeding depression may operate through subtle modification of birth and death rates that interact with other factors such as increased predation. Evidence of limited inbreeding may be subtle. Hamrick et al. (1979) also pointed out that the identification of fitness traits with genetic markers and current technologies is difficult.

Genetic conservation may present a dilemma for managers in the restoration of an animal species. National Park Service policy (U.S. Department of the Interior, National Park Service 1988) states that the restoration of native animals on park lands will be done with organisms from populations that are genetically and ecologically as closely related as possible to the extirpated, indigenous populations. In some cases, the original subspecies or race, such as the extirpated, hypothesized distinct Audubon's subspecies of bighorn sheep, no longer exists (cf, Wehausen and Ramey 1995). The abundance of the closest related population may not be sufficient for the removal of individuals for translocation. Obviously, a different subspecies or ecotype may then be used.

Another dilemma is presented to managers by mounting evidence that mixing source groups of sheep during a translocation increases the probability of successful translocation (Bailey 1980; J. Bailey, New Mexico Fish and Game Department, Santa Fe, New Mexico, personal communication). A manager may mix genetic stocks of bighorn sheep if it increases the probability of a successful new population.

Grieg (1979) recommended that locally adapted genotypes or phenotypes be conserved, except if use of other sources is necessary for survival of the species. In any species, differences in litter sizes, adaptation to arid conditions or winter climates, birth dates, and length of digestive tracts may be unique adaptations to a given environment (Grieg 1979). Introgression or the purposeful introduction of genes from one subspecies or group into another should be avoided. For example, the southern white rhino (*Ceratotherium simum simum*) was introduced into the range of the seriously endangered northern subspecies of the white rhino (*C. s. cottoni*), potentially swamping its genetic resources. Introgression also occurred when plains bison (*Bison bison*) were introduced into the range of a pure population of wood bison (*B. b. athabascae*) in Wood Buffalo National Park, Manitoba (Grieg 1979). Cougars (*Felis concolor*) were introduced from stocks in the northern and western United States into the range of the severely inbred and declining Florida panthers (*F. c. coryi*). Land managers concluded that in the latter case, persistence of the panther population was more important than genetic purity.



CHAPTER THREE

SELECTION OF RESTORATION SITES AND RECOMMENDED RESTORATION PROCEDURES

"I do not see any reason why we should not be able to reintroduce and establish new sheep populations. .... There is no reason whatsoever why our children and grandchildren should not look at multifold populations of the bighorn populations that are available today. ... I do know various methods have been partially successful, ... I believe you can get better results" (Geist 1975a:101)

EXPLANATION OF THE SEVEN-STEP ASSESSMENT AND RESTORATION PROCESS

Step 1. Survey of Populations

The history of each bighorn sheep herd was assembled, including reviews of the original range and the probable cause and date of extirpation of indigenous populations. All physical evidence of extirpated animals was gathered from park collections or museums.

Surviving indigenous or restored populations were surveyed on the ground, from helicopters, or both on the ground and from helicopters. Population sizes, apparent trends, and lamb and ram ratios were recorded. The Idaho visibility model was applied to populations in Canyonlands and Badlands National Parks (Moses and Singer 1996).

Step 2. GIS-Based Habitat Assessments

The National Park Service used a Geographic Information System (GIS) for bighorn sheep habitat evaluations for several reasons. Very large land areas can be rapidly and quantitatively assessed with GIS, thereby enabling resource managers to make objective comparisons of potential habitat. GIS enables managers to evaluate and document each habitat criterion to determine which most significantly affect the extent of suitable bighorn habitat. GIS helps with identifying the cause of habitat reduction such as forest encroachment and development and gives managers the opportunity to improve habitat through mitigation. Updating the analysis to determine the suitability of altered habitat is quick and simple.

Critical parameters of bighorn sheep habitat were processed linearly with the model of Smith et al. (1991) as modified by Johnson and Swift (1995; Table 3.1). A tertiary classification of land was developed. Its categories were: (1) suitable as bighorn sheep habitat, (2) suitable if managed or manipulated, and (3) unsuitable for bighorn sheep occupation.

Public lands in and around 12 national parks were evaluated with GIS to determine their suitability for reintroduction of bighorn sheep. Some digital data for habitat analysis were obtained from the U.S. Geological Survey and included digital elevation models (DEMs) to determine slope and aspect; digital line graphs of roads, trails, and perennial waters; and land use-land cover of urban development and vegetation. Analog data were digitized from maps of the U.S. Geological Survey, Bureau of Land Management, and U.S. Forest Service at various scales to represent fences, development, roads, trails, livestock grazing allotments, and natural barriers. The data were analyzed in the Geographic Resource Analysis and Support System (GRASS) in a 30-km^2-raster (or pixel) environment as detailed in Johnson and Swift (1995).

All habitat was evaluated by a six-key criterion (Table 3.1). Escape terrain and areas were identified. Rugged vertical relief provides refuge from danger or disturbances and was considered the primary prerequisite of bighorn sheep habitat (Buechner 1960; Ferrier and Bradley 1970; Geist 1971; Wilson et al. 1980; Van Dyke et al. 1983). Also mapped were distance to perennial water, natural and constructed barriers, developments, horizontal visibility, and livestock grazing allotments. Eliminated were areas with dense vegetation that caused poor visibility and were not within the specified proximity to water, and areas too close to domestic sheep grazing allotments. Any isolated patches of habitat not large enough to support a viable population and too far from other patches of suitable habitat were eliminated.

Seasonal habitat needs were also quantified with GIS (Table 3.1). For example, winter range was defined as steep habitat with north, west and east-facing. Lambing range was defined as those slopes 27°–85° with north-facing slopes removed, and less than 1 km from water.

Suitable habitat was subdivided into logical restoration sites. Escape terrain is defined as 27°–85° slopes (Smith et al. 1991). Slopes were derived from 7.5 minute DEMs, delineating potential suitable habitat. Those suitable habitat patches large enough to support a viable population were considered potential restoration sites.

Step 3. Scientific Advisory Panels

An interdisciplinary team of conservation biologists, disease experts, geneticists, bighorn sheep specialists, and local agency biologists convened to evaluate the results of the GIS analysis and other factors and to make recommendations for restorations by managers.

Step 4. Interagency Planning

A meeting was held that was attended by representatives of all agencies in the region of each national

Table 3.1. Criteria for determining suitable habitat for bighorn sheep (Smith et al. 1991; Johnson and Swift 1995).

Parameter	Criteria
Buffered escape terrain (habitat template without all other criteria)	Must provide security from predators and other disturbances. Comprises escape terrain with 27° to 85° slopes and land areas within 300 m of escape terrain or within 1,000 m of escape terrain if bordered by escape terrain on more than two sides.
Horizontal visibility (indicates density of surrounding vegetation)	Must allow bighorn sheep to detect predators and maintain contact with members of their herd. Must be 60% or greater. (Areas with visibility of 30%–60% and a greater than 4,500 m width are not suitable habitat.)
Water sources	Should be perennial and within 3.2 km of buffered escape terrain.
Development	Absence of residential areas, commercial and industrial developments, highways, roads, and structures. If disturbances of such areas may elicit their avoidance by bighorn sheep, an additional 150-m buffer of land bordering the area is not suitable bighorn sheep habitat.
Livestock	Distances between livestock and bighorn sheep must be 16 km or greater to preclude transmission of diseases.
Barriers	Absence of natural barriers (large or swift moving water bodies, impassable cliffs, large patches of dense vegetation) and constructed barriers (development, fences, highways, reservoirs, high activity areas) that may block travel by bighorn sheep. If such areas are less than 17 km^2 and without seasonal ranges, they are not suitable for bighorn sheep habitat.
Summer range (used by sheep other than ewes with lambs and yearlings with ewes)	Predominantly grassy suitable habitat surrounding escape terrain, but excluding the 27°–85° slopes. Must be at appropriate distances from livestock.
Winter range	All southern exposure of suitable habitat that does not exceed 27°. Snowpack must not exceed 25 cm. Must be at appropriate distances from livestock.
Lambing range (for ewes and lambs)	Contiguous areas of escape terrain >2 ha to reduce vulnerability to predation and sensitivity to disturbance. Must meet the criteria for escape terrain, visibility, development, livestock, and barriers, excluding all north-facing slopes. Water sources must be buffered 1,000 m.

park and adjacent areas, i.e., the National Park Service, state agencies, the U.S. Bureau of Land Management, and the U.S. Forest Service. The agency managers were given three options:

1. No action

Feasibility of restoring bighorn sheep is low in the study area because of limited habitat, extensive anthropogenic habitat modifications, or threat of contact with domestic sheep.

2. Wait-and-see

Future restoration may be possible. The existing populations of bighorn sheep are still growing and dispersing, and their status should be monitored.

3. Restoration recommended

Any or all of the following actions are selected: obtaining easements on some lands, retiring or transferring domestic sheep grazing allotments, prescribing burning of the habitat, or restoring bighorn sheep.

Step 5. Metapopulation Restoration Plan

Each NPS unit took the lead role in drafting its area restoration plan based on the recommendation of the interagency group, the habitat assessment, and the scientific advisory panels. Guidelines and recommendations of the various review committees were also followed. The restored populations should persist with a minimum of intervention. Clusters of several restoration sites were selected to create a metapopulation. Restoration sites were prioritized based on the total amount of suitable year-round and seasonal habitat in each area and the distance from domestic sheep. Areas that were more than 32 km (20 miles) from domestic sheep were classified as the most suitable restoration sites. Areas at a distance of 16–31 km (10–15 miles) were of medium risk, and areas at a distance of less than 16 km (less than 10 miles) were at high risk and not recommended for restoration sites. Political boundaries were not part of the rankings, i.e., the first translocations were to be made to the best restoration sites regardless of land stewardship.

Each restoration plan included selection of the most appropriate source stock based on information about subspecies, ecotype, morphometrics, genetics, and diseases. The appropriate permits or requests for source stock were detailed in the plan. The agencies and personnel in all phases of the permitting, requests, capture, handling, and release were identified in the plan. Plans for the no-action or wait-and-see options were brief, but details that supported such decisions were provided.

Step 6. Translocation or Other Restoration

Management followed a logical sequence of events. With few exceptions, prescribed burning, other habitat management, or relocation of domestic sheep allotments were made prior to the first translocations.

Step 7. Monitoring and Later Evaluations of Restoration

Most of the translocated animals (50%–100%) were fitted with long-lasting radio collars. Animal travel was closely monitored. Mortality and its probable causes and dispersals or unique long distance travel were recorded. The populations were censused regularly.

Periodic scientific evaluations of the entire multi-park restoration must be made at 5-year intervals. Nominated were the Biological Resources Division of the U.S. Geological Survey for taking the lead responsibility for statistical and scientific analyses of the biological success of the restoration, and managers were nominated for collecting data.

RECOMMENDED RESTORATION PROCEDURES

These procedures were developed by 46 workshop participants from universities, states, and federal agencies in Grand Junction, Colorado, on 29 August 1995 (Jessup et al. 1995). The workshop was sponsored by this initiative.

DISEASES AND TRANSLOCATIONS

1. Active *Pasteurella* epizootic is a reason to exclude a herd as a source population. But the presence of *Pasteurella* titers or a *Pasteurella* outbreak in the past is not a reason for excluding the population from being a source for translocations. If clinical contagious eczema, Paratubercullosis, pinkeye, or Mycoplasma (the latter two are rare) is detected, the herd should not be used as a source. If nonclinical scabies is detected, the animals should be treated with Ivermectin before translocation. If clinical scabies is detected, the animals usually should not be used as a source. In southeastern Utah, where the strain of scabies does not seem to be particularly virulent and where agencies decided to use only animals indigenous to the area (which all have scabies), native infected animals may be used as a source after they have been treated. The disease titer backgrounds of the source should be matched to those of recipient groups of bighorn sheep.

2. Herds that exhibit an active pathogen, as evidenced by deaths of lambs and older animals, coughing, and poor body condition, should not be used as source herds.

3. In general, three or more years without evidence of respiratory problems and three or more years of healthy lamb crops should suffice as a waiting period after a disease outbreak to use a herd as source stock. Repeated disease outbreaks or chronic disease over several years should disqualify a population as source stock.

4. Deep ear swabs, blood samples, punch biopsy, nasal swabs, fecal samples, and tick samples should be collected from source stock. The samples should be stored cryogenically and archived for future reference. A database should be established for the translocated animals.

5. A distance of at least 16 km (10 miles) should be established between domestic sheep and translocated bighorn sheep (Wilson et al. 1980; U.S. Department of the Interior, Bureau of Land Management 1988). This is a general guideline and several factors may influence another, more appropriate distance. For example, if a large river or a major highway separates the two species, a distance of less than 16 km may be acceptable. Exotic wild sheep, such as mouflon and Barbary sheep (*Ammotragus lervia*), are also threatening to the welfare of translocated bighorn sheep. Domestic goats are a lesser threat because no known die-offs have been attributed to their presence but should nevertheless be viewed as potential threats. Llamas (*Llama* spp.) may or may not pose a serious threat to wild bighorn sheep. Each park will have to make an assessment. Domestic cattle (*Bos taurus*) are a lesser threat, but close contacts between cattle and bighorn sheep should be avoided. Shared use of water sources should be strictly avoided because gnats that breed near water can pass bluetongue from cattle to bighorn sheep (Spraker and Hibler 1982; Jessup 1985).

GENETIC CONSIDERATIONS

1. Morphometrically, a northern desert type of bighorn sheep was identified by Wehausen and Ramey (1995). This type includes indigenous animals from southeastern Utah and the northern Great Basin. The southern desert type of bighorn sheep should not be brought into southeastern Utah. Specifically, animals from the Lake Mead National Recreation Area, which National Park Service managers have used as a prime source stock, should not be brought to the southeastern parks such as Canyonlands, Arches, or Glen Canyon national recreation areas, except to sites separated from the indigenous, native groups by major rivers or other barriers.

2. Populations should not be translocated into habitat patches unless greater than or at least 100–125 animals are predicted to occupy the restoration site because the probability of the persistence of populations of fewer than 100 animals is low. Periods of restricted population size should be avoided. Populations held at a genetically effective size (N_e) of 20 or fewer animals for 10 or 20 generations will experience serious losses of genetic resources. Short periods of restricted population size for 2–3 generations (10–15

years), however, should not cause serious loss of genetic diversity. Small populations are also in danger of extirpation from weather, other catastrophes, or demographic chance events during periods of restricted population size even before genetics becomes a concern.

TRANSLOCATION PRACTICES

1. Net gunning is the preferred capture technique because of a concomitant low mortality rate (about 1%–3%). Drop nets work well in some locales. Soft releases, i.e., the holding of animals in acclimation pens, are not recommended. Holding the animals 4–5 hours at the most in a dark place to release them as a group is suggested. Holding animals for longer periods, e.g., 2–3 days, is not recommended because their serum cortisol levels become elevated. Statistically significant differences in mortality have not been detected between transportation to the release site by helicopter and by truck. The animals should be translocated in midwinter for two reasons. First, temperatures are coolest then and fewer problems are encountered with chases and capture stress. Second, if the source animals are trapped, they are more attracted to bait in midwinter. But one park, Badlands National Park, successfully translocated animals during fall.

2. Vaccinations including injections of antibiotics, selenium, and clostridial vaccines for overeating disease if alfalfa hay is offered should be made at the capture site. All sampling and vaccinations should be done at the same time. Double handling of animals must be avoided.

3. A minimum of 25 animals should be moved during a translocation. A ratio of 3 females:1 male, or about 16–18 ewes per translocation, is recommended (Wilson et al. 1975) to maximize reproductive potential. However, the panel recommended more natural sex ratios (1–2 females:1male) for translocations into NPS units. An unnaturally high ratio of females in transplants tends to skew sex ratios toward males in the source herd. New translocations should be made about 16–24 km (10–15 miles) apart in continuous Rocky Mountain habitats and 40–48 km (25–30 miles) apart in continuous desert habitats. Ideally, the populations will increase and fill in the adjoining habitats. These distances are only general. If barriers exist, the distances between the translocated animals should be smaller. Placing translocations too close together (a few km) was not recommended, because the translocated animals may immediately join the established group, thus negating the translocation.

4. Augmentations[5] were not recommended in most cases because a new disease risk is associated with each augmentation. The cause(s) for the unsuccessful attempt of the first translocation must be addressed before more animals are placed into the habitat. However, augmentations can occasionally be beneficial.

5. Genetically, a new founder group should be as similar to the original, extirpated, indigenous population as possible. The similarity should include taxonomic, genetic, geographic, and ecological characteristics. However, source stocks that meet all of these similarities may not be available, and if so, the next most similar available stock may be used.

MANAGEMENT OF THE SOURCE POPULATION

1. Annual capture and removal of 5% of the population are safe for most source stocks. As much as 15% of a population may be removed annually for translocations from more productive ranges in mountainous habitats with predictable precipitation. A minimum of 50 breeding-aged ewes must be left in the source population. Thus, about 65–70 adult females should be present prior to the removal. Source populations should be monitored closely before and after the removal. Recruitment rates should be monitored, but simple lamb:ewe ratios can be misleading, and the population rate of increase should be sampled. A 1-year downward trend in the herd size after the removal

[5]Augmentations were defined as the translocation of additional sheep into an area that either already supported a population or into which animals had already been translocated at least 3 years prior.

is not a cause for concern. But if the downward trend continues for several years or the decline approaches 20%, the removals should be temporarily suspended.

HABITAT CONSIDERATIONS

1. Dense, shrubby areas with high mule deer (*Odocoileus hemionus*) densities are poor restoration sites for bighorn sheep. These areas are good habitat for mountain lions (*Felis concolor*) and coyotes (*Canis latrans*), and the heavy cover provides good stalking conditions for the predators. Founder animals should come from areas with similar vegetation and similar predator populations to minimize initial mortality.

2. Bighorn sheep should be translocated into habitats that are similar to the habitats of the source herds. For example, alpine dwelling animals are not preferred source stock for translocations into low elevation habitats.

INTERAGENCY COOPERATION

1. The National Park Service should establish a cooperative network for receiving and providing source animals. Restoration on a park cluster basis was recommended, i.e., one park in a cluster with abundant sheep may provide animals to the other parks or trade with a state for more appropriate source stock for another park.

2. Restoration of bighorn sheep should be done with interagency cooperation, and political unit boundaries should be ignored in the pursuit of the higher goal of restoration of large metapopulations.

3. Several states did not have bighorn sheep source stock for restorations into NPS units. The state of Wyoming indicated that only about 100 animals are trapped for source stocks in the Whiskey Basin each year. The Wyoming Fish and Game Commission must approve releases out of state. The wait for animals is typically about 1 year. Disease in the Whiskey Basin in 1990–91 held up translocations for more than a year.

The state of Montana has even fewer available sources. Waiting time for Montana bighorn sheep for translocations is about 5–6 years.

The state of Colorado has an extensive program of trapping and translocating bighorn sheep. The first site on its priority list gets the first group trapped in Colorado in any given winter, regardless of genetics, habitat type, or other considerations. Only desert animals should go to areas west of the Delores River and west of Grand Junction. Requests to the state of Colorado from the National Park Service should be signed by the Regional Director of the Service and should be addressed to the Wildlife Commission. Colorado requested a written agreement from the Service for the exchange of animals. The state of Colorado indicated that NPS units would be given highest priority for bighorn sheep trapped along Fall Creek on the edge of Rocky Mountain National Park.

The state of South Dakota does not have adequate bighorn sheep populations to provide source animals for NPS units.

The state of Utah indicated that it has several healthy desert bighorn sheep herds that can be used as source stock. They include the South and North San Rafael and the Potash herds.

The state of North Dakota has no large, increasing populations suitable for source stock, but they obtain animals of the California subspecies from British Columbia or Idaho.

CHAPTER FOUR

RESTORATIONS OF BIGHORN SHEEP IN AND NEAR NATIONAL PARKS

"As many as 39,117 km² were evaluated. A total of 12,329 km² (32% of total area) and 73 restoration sites were rated as suitable. The habitats could support 7,000–7,500 bighorn sheep."

OVERVIEW OF RESTORATIONS

As many as 39,117 km^2 of habitat (an area the size of Vermont and Connecticut combined) were evaluated in and near the 15 national parks (Table 4.1). A total of 12,329 km^2 (32% of total area) and 73 restoration sites were rated as suitable. At the time of the assessment, bighorn sheep fully or partially occupied 36 (2,647 km or 49%) restoration sites or 22% of the suitable area. The restoration of bighorn sheep into an additional 7,067 km^2 of suitable habitat in 27 empty patches was recommended through the translocation of founder groups. Restoration of the remaining 10 sites was not recommended because of either the presence of domestic sheep or insufficient size of the patch to support a viable population (see Appendix B for full reports for each NPS unit).

The largest area (4,041 km^2) of suitable habitat is in the greater Canyonlands National Park-Arches National Park areas. The next largest area of suitable habitat is in the Glen Canyon National Recreation Area and surrounding lands (2,154 km^2) and in the Bighorn Canyon National Recreation Area and surrounding lands (1,799 km^2). If all domestic sheep allotments were eliminated, the identified suitable occupied and unoccupied habitats could support 7,000–7,500 bighorn sheep (Table 4.1). This estimate is based on the assumption that all habitat patches are fully occupied all of the time. This goal may never be achieved because populations in some patches may periodically be extirpated by disease or other stochastic events.

Habitat effectiveness was defined as the proportion of the total area evaluated that was rated as suitable. More than 40% of the total assessed area was suitable in six NPS units (Arches

Table 4.1. Assessment of current and potential occupation of 15 western National Park System units by bighorn sheep in 1997.

NPS unit	Estimated number of bighorn sheep	Estimated potential total population	Recommended number of translocations in 1998–2000
Arches and Canyonlands NP	685	>1,500	0[a]
Badlands NP	160	400	2
Bighorn Canyon NRA	200	1,000	0[b]
Capitol Reef NP	150	600	1
Colorado NM	125–175	300–500	1
Curecanti NRA and Black Canyon NM	100	700–1,000	0[b]
Dinosaur NM	300	500–700	1
Glen Canyon NRA	770	>1,500	5
Grand Teton NP	100	ND	0[b]
Mesa Verde NP	1–4	<40	0
Theodore Roosevelt NP	140–150	300	1
Wind Cave NP	0	0	0
Zion NP	65–85	300	0[b]
Total	2,830	7,500	11[c]

NPS = National Park System; NM = National Monument; NP = National Park; NRA = National Recreation Area; ND = Not determined.
[a]Translocations deferred until the needs of Capitol Reef NP are met.
[b]NPS unit staff selected the wait-and-see option.
[c]Approximately 225–275 animals will be required as source stock to complete these translocations.

National Park, Bighorn Canyon National Recreation Area, Black Canyon of the Gunnison Natural Monument, Canyonlands National Park, Curecanti National Recreation Area, Glen Canyon National Recreation Area), i.e., habitat effectiveness was more than 40%. These units contained the most contiguous bighorn sheep habitats with the fewest breaks. In two other units, habitat effectiveness was 24%–26% (Capitol Reef National Park, Dinosaur National Park). But in the two prairie badlands parks (Badlands National Park, Theodore Roosevelt National Park), only 10%–15% of the area assessed was suitable. Restored populations in these areas will probably be a series of small fragmented groups. The clay-hill habitats of these two parks also support low densities of animals (0.2 animals/km^2), suggesting long-term persistence in these areas requires ongoing management. The combined Badlands National Park-Oglala Sioux Reservation area of South Dakota may support a metapopulation of 400 animals, and the entire Little Missouri River Badlands complex of North Dakota (including Theodore Roosevelt National Park) may support 300 animals. But more than half of the suitable habitat in the Badlands National Park metapopulation is on tribal reservations and national grasslands and about 80% of habitat in the Little Missouri Badlands metapopulation is outside of Theodore Roosevelt National Park, suggesting close working relations with adjacent land management agencies will be needed.

Two NPS units selected the no-action option, because of a lack of suitable habitat. Only a fraction (less than 1%) of Wind Cave and Mesa Verde National Park areas were suitable bighorn sheep habitat. The size of the habitat in Wind Cave National Park (less than 10 km^2) is too small to support a viable group of bighorn sheep, and because the park is fenced, prospects for interchange with nearby groups is also low. Mesa Verde National Park is densely vegetated and only three small patches of suitable habitat were identified. Interchange of animals between the patches is not probable. Several large wildfires, however, may increase the prospects for restoration of bighorn sheep in Mesa Verde National Park.

Five parks selected the wait-and-see option. Population sizes of bighorn sheep in these three units were increasing, and the herds were expanding their ranges at the time of the assessments (Arches National Park, Bighorn Canyon National Recreation Area, Zion National Park) or were being studied (Grand Teton National Park), and the park staffs wanted to see whether the populations would occupy adjacent areas on their own. However, this decision should be re-examined because the Bighorn Canyon National Recreation Area population has since declined and the herd stopped expanding into adjacent areas. An isolated, indigenous population survived in Grand Teton National Park. The park's resource managers hesitate to augment this herd with animals from outside stocks. The population is seemingly restricted to a high elevation winter range where mortality from avalanches and predation is extensive. Grand Teton National Park is waiting for the completion of a multi-year study of movements, survival, and genetics before determining final management.

The nine remaining NPS units (Badlands National Park, Black Canyon of the Gunnison, Canyonlands National Park, Capitol Reef National Park, Colorado National Monument, Curecanti National Recreation Area, Dinosaur National Park, Glen Canyon National Recreation Area, and Theodore Roosevelt National Park) decided to aggressively pursue restoration. In 11 translocations, 198 bighorn sheep were placed in these units during winters 1995–96 and 1996–97 (Table 4.2). The staff of Canyonlands National Park decided to defer restorations until Capitol Reef National Monument has met its needs for founder populations. Thereafter, Canyonlands National Park will conduct translocations. An additional 16 translocations are recommended as soon as possible to complete the

Table 4.2 Summary of management decisions and translocations conducted under this NRPP restoration initiative 1994–96.

Park	Management decision as of 1996	Date of translocation	Number of bighorn	Source herd	Area of translocation	Number of translocations accomplished	Number of additional translocations desired
ARCH	Wait-and-see[a]						
BADL	4 translocations	10/96	16	Pinnacles unit, South Dakota Badlands NP	Cedar Pass	1	2
BLCA	No action					0	0
BICA	Wait-and-see[a]						
CANY	Wait until CARE source stock needs met						3[b]
CARE	3 translocations	1/96	20	CANY NP, UT	Pleasant Creek	2	1
		1/97	20	CANY NP, UT	Capitol Gorge		
COLM	3 translocations	10/95	22	Lake Mead, NV	Knowles Canyon	1	2
CURE	Wait-and-see	1/96	19	Rampart, CO	Dillon Pinnacles	1	0 (6)[c]
DINO	3 translocations	3/97	21	Dome Rock, CO	Tanks Peak	1	2
GLCA	10 translocations	11/95, 12/95, 12/96	17, 21, 24	Escalante, UT	Bounds and Long Canyons, North Wash	3	5
GRTE	Wait-and-see[d]						
MEVE	No action						0
THRO	2 translocations	1/96	19	B.C., Canada	Hagen Divide	1	1
WICA	No action						
ZION	Wait-and-see[a]						

[a]Arches NP, Bighorn Canyon NRA, and Zion NP decided to wait and see how far the existing population would disperse on its own. (**Editors Note**: 1996 and 1997 observations suggest the BICA herd has stopped growing and expanding.)
[b]Canyonlands NP will defer their translocations until CARE needs are met.
[c]Curecanti NRA requires six translocations but only after domestic sheep allotments are managed in the focus area. Thus, restoration can only be accomplished at some point in the future.
[d]Grand Teton NP has deferred restoration until a multi-year research study into herd survival, productivity, movements, and genetics is completed. This native herd is subjected to high rates of mortality and may be inbred.

restoration of metapopulations in six of these nine NPS units (Table 4.2).

RESTORATION IN SPECIFIC PARKS

Arches and Canyonlands National Parks

Four bighorn sheep herds were present in Canyonlands and Arches National Parks prior to 1991: Island in the Sky, Needles, Maze, and Arches. The first surveys of sheep in the park were conducted in the early 1970s from fixed-wing aircraft. Later surveys were conducted from helicopter by the state of Utah. In the early 1980s, a double count census method (comparing results from helicopter and ground counts) was initiated and the estimates were used to justify the removal of sheep from the Island in the Sky District to other areas. Results of the double-count method were highly variable, and an analysis of the data showed extreme fluctuations in the interpretation of the results. In 1992, the development of a visibility model for the Island in the Sky District in Canyonlands National Park was initiated. The model is still under refinement.

The Island in the Sky herd was censused annually from 1974 to 1979, from 1982 to 1990, and from 1992 to 1996. The Maze and Arches herds were censused in 1989 and 1994, and the Needles herd was censused annually from 1974 to 1977, and in 1989 and 1992. The primary use area of the Arches herd is along the Colorado River corridor. Secondary use areas are the interior canyons of the Courthouse Wash and the Great Wall. The total area of occupied habitat is approximately 60 km^2 (15,000 acres) with an unused (but occupiable) habitat range of approximately 121 km^2 (30,000 acres; Table 4.3, Figure 4.1). The only areas of the Island in the Sky district that are not suitable habitat are the Red Sea Flats and the Gray's Pasture. Both are small areas (810 ha; 2,000 acres) on the flat top of the Island in the Sky. A 12 km^2 (3,000 acres) area along the Green River is currently unoccupied because of lack of escape terrain and little vegetation. The remaining 506 km^2 (125,000 acres) of the district are occupied. Sixty percent of the district is probably fully stocked with bighorn sheep. The number of bighorn sheep in the remaining 40%, the western portion of the district, is still low, but the population in that area seems to be increasing.

The Needles herd is seriously depressed by an unknown disease. The herd was estimated to be 125 animals in the early 1980s but recent estimates are 30 animals. The 1997 census revealed 50 animals in the park and another 50 outside of the park in the Lockhart Basin area. Only a few desert bighorn sheep inhabit the southern river corridor, an area that previously was inhabited by sheep. A ewe band of 10 animals was seen twice immediately south of the park boundary during the 1997 lambing season, indicating recovery in that area. Of the total 502 km^2 (124,000 acres) in the Needles District, approximately 20 km^2 (5,000 acres) are unsuitable bighorn habitat (Table 4.3, Figure 4.1). The current populations of sheep occupy 16 km^2 (4,000 acres) of habitat along the Colorado River and in the lower portions of the Elephant and Salt Creek canyons. The remaining 465 km^2 (115,000 acres) may be suitable habitat for bighorn sheep range, although some areas may not be able to support large numbers of sheep.

Of the 291 km^2 (72,000 acres) in the Maze District, only 8 km^2 (2,000 acres) are unsuitable habitat for sheep. Bighorn sheep currently occupy only 25% of the habitat in the Maze (73 km^2 or 18,000 acres), and densities are low. Although exceedingly difficult to census, the Maze herd increased from the original release of 23 animals. The herd has slowly occupied new areas. This herd may benefit from additional transplants into areas north and south of its range.

The Island in the Sky and the Needles herds are native herds. The Arches herd was reintroduced and now contacts both the native Island in the Sky - Potash herd and the reintroduced Professor Valley herd. The Arches herd was established in two transplants from Island in the Sky: 6 sheep (2 males, 4 females) were released in 1985, and 19 sheep (5 males, 14 females) were released in 1986. The Maze herd was also introduced in 1982, although twenty-three animals (8 males, 15 females) were released into the Maze

Table 4.3. GIS assessment of bighorn sheep habitat in Arches and Canyonlands National Parks, Utah, 1995. Water-source was considered available in all seasonal ranges based on Resource Managers' knowledge of area. Risk of potential contact with exotic sheep existed in Restoration Sites 2, 3, and 5 and was significant in Restoration Site 7. The biological panel did not prioritize restoration sites for translocations and park management does not intend to translocate bighorn sheep into these sites at this time because the population size is growing and the sheep are dispersing. Monitoring of the population will be continued. Bighorn sheep from Canyonlands National Park have been the source stock for translocations into Capitol Reef National Park (1996, 1997) and Glen Canyon National Recreation Area (1995; Sweanor et al. 1995).

	Restoration Site							MVP[a] requirements (Smith et al. 1991)
	1	2	3	4	5	6	7	
Evaluated land area (km^2)	1,938	1,661	527	780	1,206	814	2,802	ND
Suitable habitat (km^2)	449	224	184	181	442	1,145	1,416	17.0
Summer range (km^2)	350	192	146	151	318	865	1,080	9.7
Winter range (km^2)	169	93	53	0	164	429	429	6.5
Lambing range (km^2)	54	20	18	15	73	170	153	3.6
Distance from domestic sheep (km)	>16	<16	<16	>16	<16	>16	<16[b]	>16[c]
Estimated carrying capacity[d]	>125	>125	>125	>125	>125	>125	>125	125
Estimated number of bighorn sheep in 1995	63	90	5	0	335	80	30	
Estimated number of bighorn sheep in 1997	100	125	10	0	300	100	50	
Survey type	ground & aerial	ground & aerial	ground	aerial	ground & aerial	ground & aerial	ground & aerial	
Estimated land occupied by bighorn sheep, 1996 (km^2)	131	42	0	0	433	97	296	
Estimated land area available for occupation by bighorn sheep, 1996 (km^2)	318[e]	182[e]	184	181	9[e]	1,048	0[b]	

[a]Minimum viable population.
[b]Domestic sheep grazing allotments may adversely affect the entire restoration site.
[c]Not referenced in Smith et al. (1991) but identified in Singer et al. (1998a).
[d]Carrying capacity based on biomass production of forage that supports 1 bighorn sheep/54 ha of suitable habitat. However, this is a preliminary estimate because forage requirements of desert bighorn sheep are poorly understood.
[e]Most of the largest and contiguous patches of suitable habitat are already occupied by bighorn sheep.

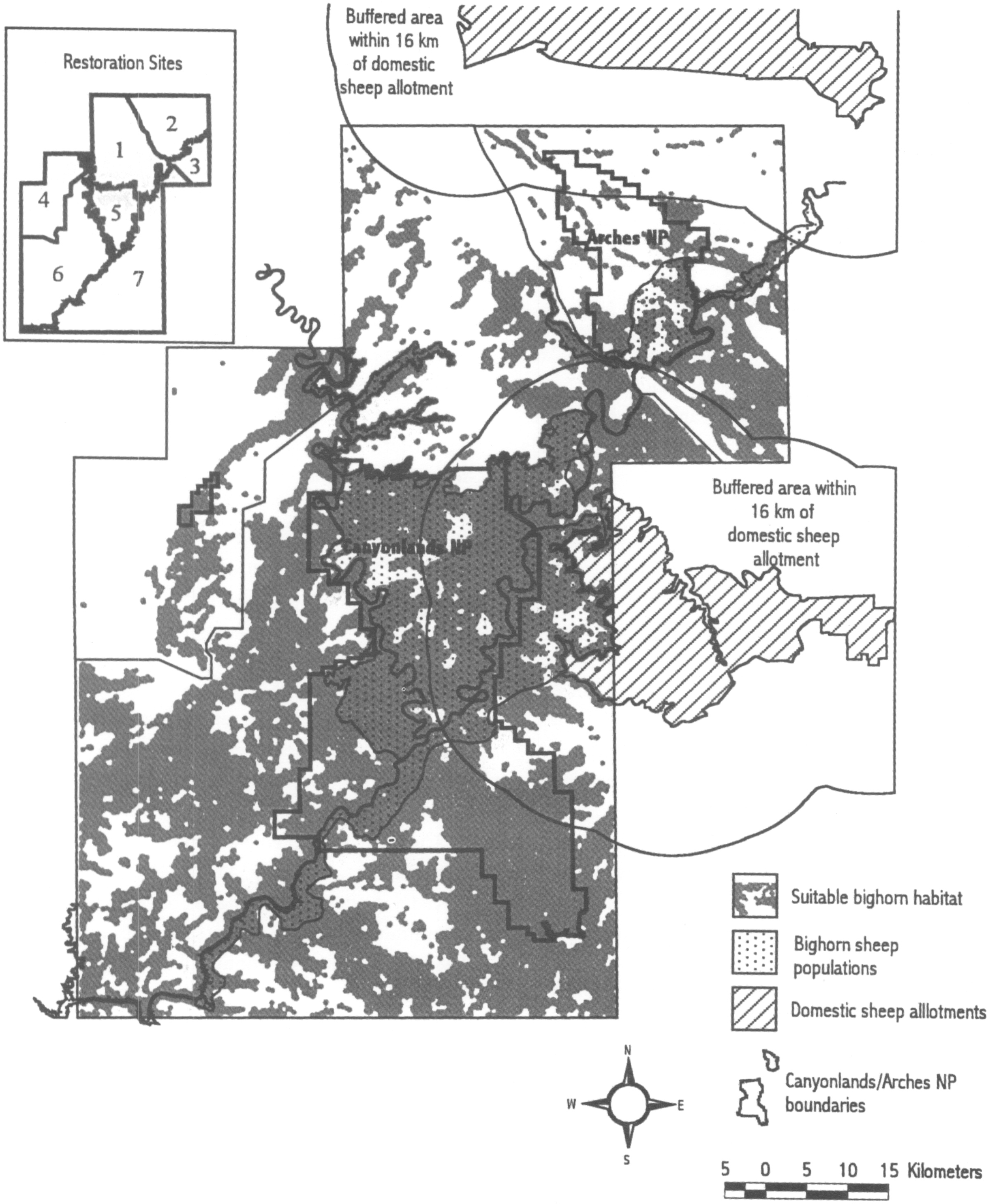


Figure 4.1. Suitable bighorn sheep habitat in Arches and Canyonlands National Parks, Utah, and surrounding areas.

District from the Island in the Sky. Although a few remnant sheep may still have been living since some sightings were reported in the late 1970s.

The Arches herd seems to be doing well and is increasing. The herd increased from 25 sheep released in 1985-86 to approximately 125 in 1994. There seems to be some movement between the Arches herd and sheep in the Professor Valley and Potash areas. Desert bighorn sheep in Arches National Park show some signs of pioneering into interior sections of the park. The Island in the Sky herd also is increasing and has been used as source stock for Capitol Reef for 2 years (1996 and 1997). From approximately 80 animals in the 1970s, the herd has grown to 350 animals. The herd extended its range from the canyons on the east side of the Island to areas as far north as Canyonlands Field, 12 km (20 miles) north of the park on the east, and as far as Spring Canyon along the Green River. Most of the available habitat in the Island in the Sky District is now occupied. Increasing evidence of *Psoroptes sp.* mites suggests that the population is reaching a density-maximum size.

The Orange Cliffs and areas west of the Green River were identified as potential restoration sites. Restorations in cooperation with the bordering Glen Canyon National Recreation Area are planned. Management to improve the land is not necessary because no domestic sheep are grazed in the area and there is suitable habitat. Cattle have been removed from some of the area because of lack of water and incompatibility with National Park Service management. Monitoring of the Needles District herd for signs of recovery will continue. The Island in the Sky herd will continue to serve as source stock for Capitol Reef National Park and will be monitored as stock is removed.

Badlands National Park

The Audubon's bighorn sheep (*O. c. auduboni*) once occupied suitable habitat throughout the Black Hills and Badlands of South Dakota (Buechner 1960). However, by 1925, the Audubon subspecies was considered extinct throughout its range (Buechner 1960) as a result of market hunting, urban development, mining, and agrarian development. In 1964, the National Park Service in cooperation with the South Dakota Department of Game, Fish and Parks and the Colorado Division of Wildlife reintroduced 22 Rocky Mountain bighorn sheep (*O. c. canadensis*) from the Pikes Peak herd, Colorado, herd into a 150-ha (370 acre) enclosure 0.8 km (0.5 miles) west of the Conata Road Picnic Area in Badlands National Park. The goal of the cooperative agreement between NPS and the Department was the establishment of a captive herd from which animals would be taken to initiate additional populations in suitable habitat of the greater Badlands area and in two locations in the northwestern part of the state (Hjort and Hodgins 1964).

After a 50% reduction of this fenced population from a *Pasteurella* infection (Hazeltine 1967; Powell 1967; Weide 1967), the remaining 14 bighorn sheep (2 ewes, 2 rams, 4 yearling ewes, and 6 lambs) were released into the wild on 31 August 1967 (Badlands National Park Bighorn Sheep Restoration Program 1969). For 2 years, 10–12 animals remained within 2 km of the release site.

During a one-person, one-week ground survey, 27 bighorn sheep (9 ewes, 8 rams, 2 yearlings, and 8 lambs) were observed in a 13.5-km^2 area adjacent to the release enclosure in 1980 (McCutcheon 1980). Based on the yearling:ewe ratio of 22:100, McCutcheon (1980) considered the population to be stable but not increasing. McCutcheon (1980) observed a shortage of water and forage that may have been limiting population increase. During the early 1980s, the population continued to inhabit about 40 km^2 area.

During 1987–90, the South Dakota Game Department conducted surveys and concluded the herd increased to 133–200 bighorn sheep. The a lamb:ewe ratio during winter 1989–90 was 53:100 (Benzon 1992). During an aerial survey in September 1991, 30 bighorn sheep were observed approximately 20 km south of the Pinnacles population in the South Unit of Badlands National Park. Qualitative accounts from local ranchers suggested that animals dispersed to the South Unit as early as 1981.

During 1992–94, Badlands National Park conducted aerial surveys of the North and South Units. Incorporating these data into a bighorn sheep visibility model (Unsworth et al. 1994), an estimated 163 ± 55 (90% C.I.) bighorn sheep inhabited Badlands National Park in 1994. A lamb:ewe ratio of 39:100 was derived from an October 1994 aerial survey.

Four ewes and one ram were removed from the North Unit in February 1992 and translocated to augment the Spring Canyon herd in the Black Hills.

GIS analysis of geophysical and biological parameters revealed that 806 km^2 or approximately 15% of the greater Badlands study area contains adequate habitat for bighorn sheep (Table 4.4, Figure 4.2). Bighorn sheep in the Greater Badlands area can support a minimum of five geographically separate subpopulations at distances of 20–40 km. Ultimately, a stable metapopulation of 420–795 bighorn sheep may populate the area. GIS modeling indicated that the current population uses approximately 10% of the available suitable habitat. Sweanor et al. (1995) estimated that the restoration site 1 (Pinnacles herd in the North Unit of Badlands National Park) closely matches the approximated carrying capacity of 90–170 sheep.

The Pinnacles herd may be used as source stock for relocations in the park. The estimated lamb:ewe ratio in fall was 30:100 to 39:100. Lamb:ewe ratios of greater than 37:100 were indicative of a stable or growing population (Thorne et al. 1979). Restoration Site 1, which is inhabited by 83–168 bighorn sheep, has an estimated long-term carrying capacity of 90–170 bighorn sheep. Ideally, the Pinnacles herd will expand into adjacent suitable habitat.

The Cedar Pass restoration site contains 51 km^2 of suitable habitat and 1.2 km^2 of lambing habitat and has an estimated carrying capacity of 40–76 bighorn sheep. This area is approximately 25 km from the source subpopulation and is relatively easily accessible for post-release radio-telemetry monitoring. It also provides a high degree of protection against illicit activities.

The Cedar Creek restoration site contains 88.3 km^2 of suitable habitat, 2.0 km^2 of lambing habitat and estimated carrying capacity of 67–126 bighorn sheep. This area is approximately 45 km from the source subpopulation, is relatively inaccessible for post-release radio-telemetry monitoring, and is more difficult to patrol for illicit activities.

The Palmer Creek restoration site contains 29.7 km^2 of suitable habitat and 1.0 km^2 of lambing habitat and has an estimated carrying capacity of 33–63 bighorn sheep. This area is approximately 40 km from the source subpopulation and very inaccessible for post-release radio-telemetry monitoring. It presents difficulties to patrol for illicit activities.

The Sheep Mountain Table-Cedar Butte-Stronghold Table restoration sites contain 173.2 km^2 of suitable habitat and 5.7 km^2 of lambing habitat and has an estimated carrying capacity of 190–360 bighorn sheep. This area is approximately 35–45 km from the source subpopulation and relatively accessible for post-release radio-telemetry monitoring. This area currently supports a subpopulation of 25–50 bighorn sheep.

On 2 October 1996, the first translocation of 12 ewes and 4 young rams from the Pinnacles Unit into the Cedar Pass site was made. The animals were captured by net-gunning and transported to a release area about 30 km from the capture location. Fifteen of the animals were radio-collared. We observed the mating of ewes by at least four mature rams that traveled from the Pinnacles population and later returned there. All translocated animals survived the subsequent harsh winter with protracted snow cover and below normal temperatures. Three of the four young rams returned with bachelor groups to the Pinnacles source population during the following spring. During 1–20 May 1997, 9 ewes produced 10 lambs. Between mid-July and the first week of December 1997, six adult ewes, all of whom had lambed in spring, died. Three intact carcasses were recovered. One of the carcasses was infected with the epizootic hemorrhagic disease (EHD), a virus that is

Table 4.4. GIS assessment of bighorn sheep in Badlands National Park, South Dakota, 1995. Water was considered available in all seasonal ranges based on Resource Manager's knowledge of area. Lambing habitat was the most limiting feature but, because of the unique topography, lambing habitat may have been underestimated. The biological panel considered this factor in the prioritization of the restoration sites (Sweanor et al. 1995).

	Restoration Site					MVP[b] requirements (Smith et al. 1991)
	1	2	3	4	5	
Priority of site for restoration	[a]	1	3	4	2	
Evaluated land area (km^2)	1,231	738	1,363	804	1,185	ND
Suitable habitat (km^2)	139	51	205	274		17
Summer range (km^2)	137	50	201	269	135	9.7
Winter range (km^2)	44	1.5	63	84	42	6.5
Lambing range (km^2)	2.7	1.2	5.1	8.7	3	3.6
Distance from domestic sheep (km)	<16	<16	<16	>16	>16	>16 km[c]
Estimated carrying capacity[d]	90–170	40–176	170–322	290–549	100–189	125
Estimated number of bighorn sheep, 1995	83–168	0	0	25–50	0	
Number of translocated bighorn sheep, 1995–97	0	15	0	0	0	
Estimated number of bighorn sheep in translocated herd or total population	ND	25	ND	ND	ND	
Survey type	ground & aerial	ground & aerial	ground & aerial	ground & aerial	ground & aerial	
Estimated land area inhabited by bighorn sheep, 1996 (km^2)	55	2	0	15	0	
Estimated land area available for bighorn sheep, 1996	0	24 (49)[e]	95 (205)[e]	260	138	

[a] Already occupied.
[b] Minimum viable population.
[c] Not referenced in Smith et al. (1991) but identified in Singer et al. (1998a).
[d] Carrying capacity based on biomass production of forage that support 1 bighorn sheep/13 ha of suitable habitat.
[e] The number in parentheses denotes the available area for bighorn sheep if grazing allotments for domestic sheep are discontinued.

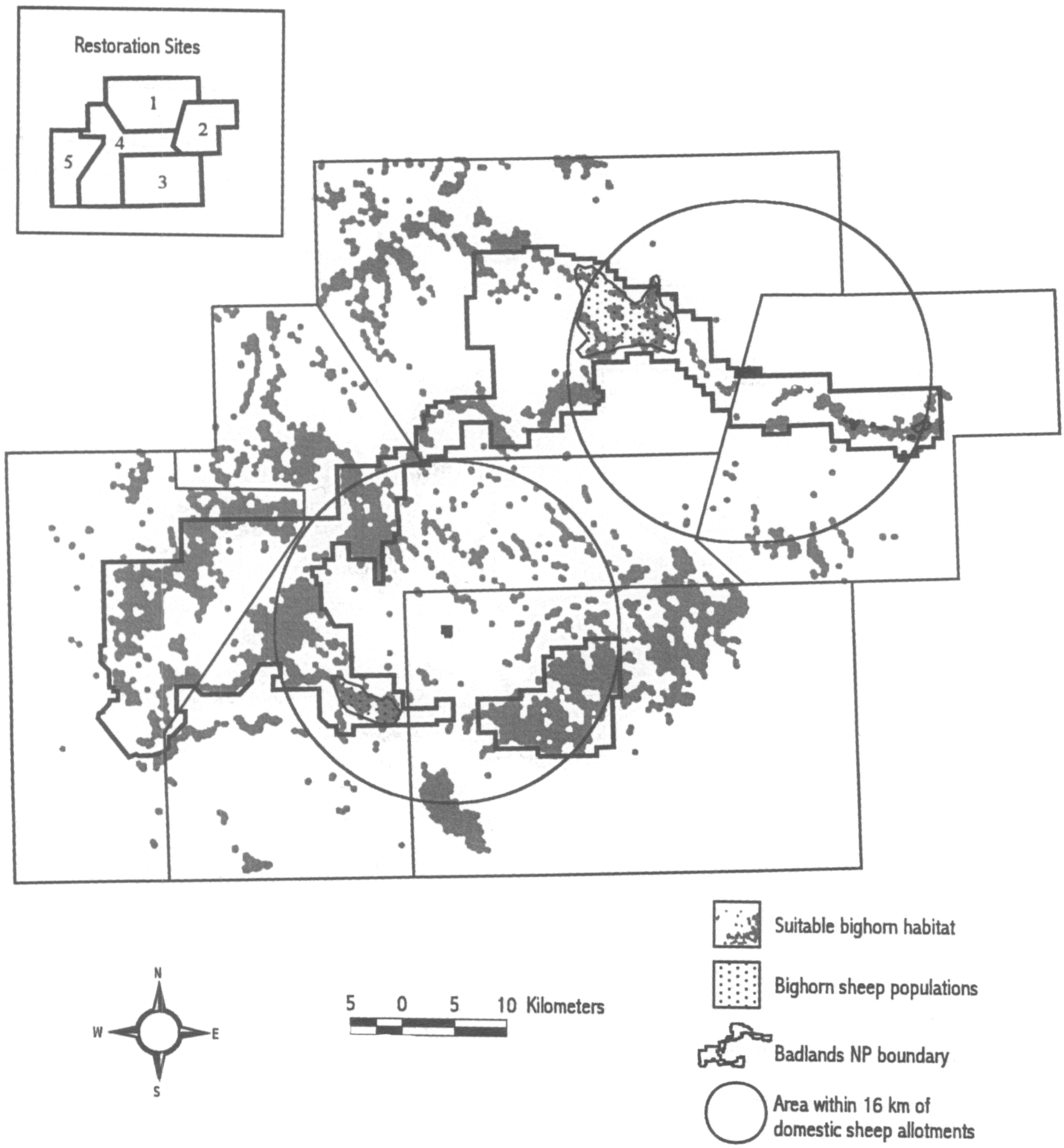


Figure 4.2. Suitable bighorn sheep habitat in Badlands National Park, South Dakota, and surrounding areas.

more often associated with white-tailed deer (*Odocoileus virginianus*) and transmitted by gnats. In January 1998, the population of 13 animals consisted of 6 ewes, 6 lambs (4 females, 1 male, 1 of unknown sex), 1 young ram, and 1-3 transient mature rams.

The Pinnacles herd was thought to be healthy enough for removals. But a ground and air count in October 1997 revealed only 8 ewes, 3 lambs, and 25 rams. The reduced population size, skewed sex ratio, and reduced lamb:ewe ratio in the Pinnacles herd since the removal are cause for concern, although the reason for the decline is not known.

Bighorn Canyon National Recreation Area

The native bighorn sheep in the area were extirpated. Between 1971 and 1974, the Montana Department of Fish and Wildlife and Parks released 77 sheep from the Sun River herd in Idaho into the Bear Canyon in the Pryor Mountains, 14 km west of the sheep's core-use area. In 1973, the Wyoming Game and Fish Department transplanted 39 sheep from the Whiskey Basin herd near Dubois, Wyoming, into the head of Devils Canyon, 15–20 km east of the park and across the canyon from the park. In 1995, the Wyoming Game and Fish Department confirmed sightings of 13 bighorn sheep 12 km east of the park in the Devils Canyon area, suggesting that bighorn sheep from the transplant into the Devils Canyon survived. Remnants from both transplants seemingly joined and initiated the herd in the park. In 1993–94, the park herd increased to about 211 sheep but declined to approximately 125 in 1996. The core use area is the Devil Canyon Overlook, but bighorn sheep range north to the North Trail Creek, south to the Crooked Creek, and west to the Big Coulee Drainage. In March the rams leave the main herd and remain at higher elevations in the Pryor Mountains until October. They return to the main herd during the breeding season. The area used by bighorns includes lands of the U.S. Forest Service, U.S. Bureau of Land Management, National Park Service, and private lands.

Bighorn sheep were studied between June 1986 and November 1987. The population contained an estimated 38–42 animals in fall 1986. The population consisted of an estimated 60–64 animals in fall 1987. The age and sex classifications in fall 1986 included 36% adult ewes, 34% lambs, 12% yearlings, 18% rams, and less than 1% unclassified females. The researchers predicted that the herd would grow to about 130 by 1990 and to more than 300 animals by the year 2000. During this period, bighorn sheep dispersed northward to Barry's Landing. The area of distribution in 1996 is currently about 174 km^2.

GIS habitat assessment identified four restoration sites (Table 4.5, Figure 4.3): (1) the western Bighorn Canyon and Pryor Mountains; (2) the eastern Bighorn Canyon, Little Mountain, and Devils Canyon; (3) the southern and southeastern Pryor Mountains; and (4) the northeastern Bighorn Canyon National Recreation Area and adjacent lands. Bighorn sheep currently inhabit the western Bighorn Canyon and Pryor Mountains and the eastern Bighorn Canyon, Little Mountain, and Devils Canyon. No sheep inhabit the southern and southeastern Pryor Mountains, the northeastern Bighorn Canyon National Recreation Area, or adjacent lands.

Lack of suitable vegetation type and the presence of domestic sheep rendered the southern half of the Cedar Creek Site unsuitable at this time. If suitable lambing habitat was identified in restoration site 4 and a management agreement was established among the Crow Indian Nation, National Park Service, and Montana Department of Fish, Wildlife and Parks, this area may be suitable for a translocation. Also, the western side of Big Pryor seems to be a desirable restoration site. The park, in 1995, decided on a wait-and-see option because the size of the sheep population was increasing and the herd was dispersing. The herd's precipitous decline since 1995 may alter the park's wait-and-see decision.

Capitol Reef National Park

The indigenous desert bighorn sheep in the Capitol Reef area were extirpated by 1934. The Escalante Herd, which includes the Red Slide herd, is composed of translocated animals from the San Juan

Table 4.5. GIS assessment of bighorn sheep habitat in Bighorn Canyon National Recreation Area, Montana and Wyoming, 1996. Lack of lambing range and close proximity to domestic sheep were the most limiting features (Gudorf et al. 1996).

	Restoration Site				MVP[b] requirements (Smith et al. 1991)
	1	2	3	4	
Priority for restoration	[a]	1	[a]	[a]	
Evaluated land area (km²)	1,275	1,274	502	300	ND
Suitable habitat (km²)	736	940	42	81	17.0
Summer range (km²)	570	580	41	73	9.7
Winter range (km²)	307	275	18	18	6.5
Lambing range (km²)	64	144	0.1	1.4	3.6
Distance from domestic sheep (km)	>16	293 (km²)	>16	>16	>16[c]
Estimated carrying capacity[d]	>125	>125	0	35	125
Estimated number of bighorn sheep, 1995	158	40	0	0	
Number of translocated bighorn sheep, 1996	none planned	none planned	none planned	none planned	
Survey type					
Estimated land area inhabited by bighorn sheep, 1996 (km²)	73	52	0	0	
Estimated land area available for bighorn sheep, 1996 (km²)	0[e]	888	0[f]	0[f]	

[a]Not recommended for restoration at this time or already occupied.
[b]Minimum viable population.
[c]Not referenced in Smith et al. (1991) but identified in Singer et al. (1988a).
[d]Carrying capacity based on biomass production of forage that support 1 bighorn sheep/7 ha of suitable habitat.
[e]Biological panel recommended not to supplement the herd because the current population may be expanding its range.
[f]Biological panel recommended not to restore the population because of inadequate size of the lambing habitat.

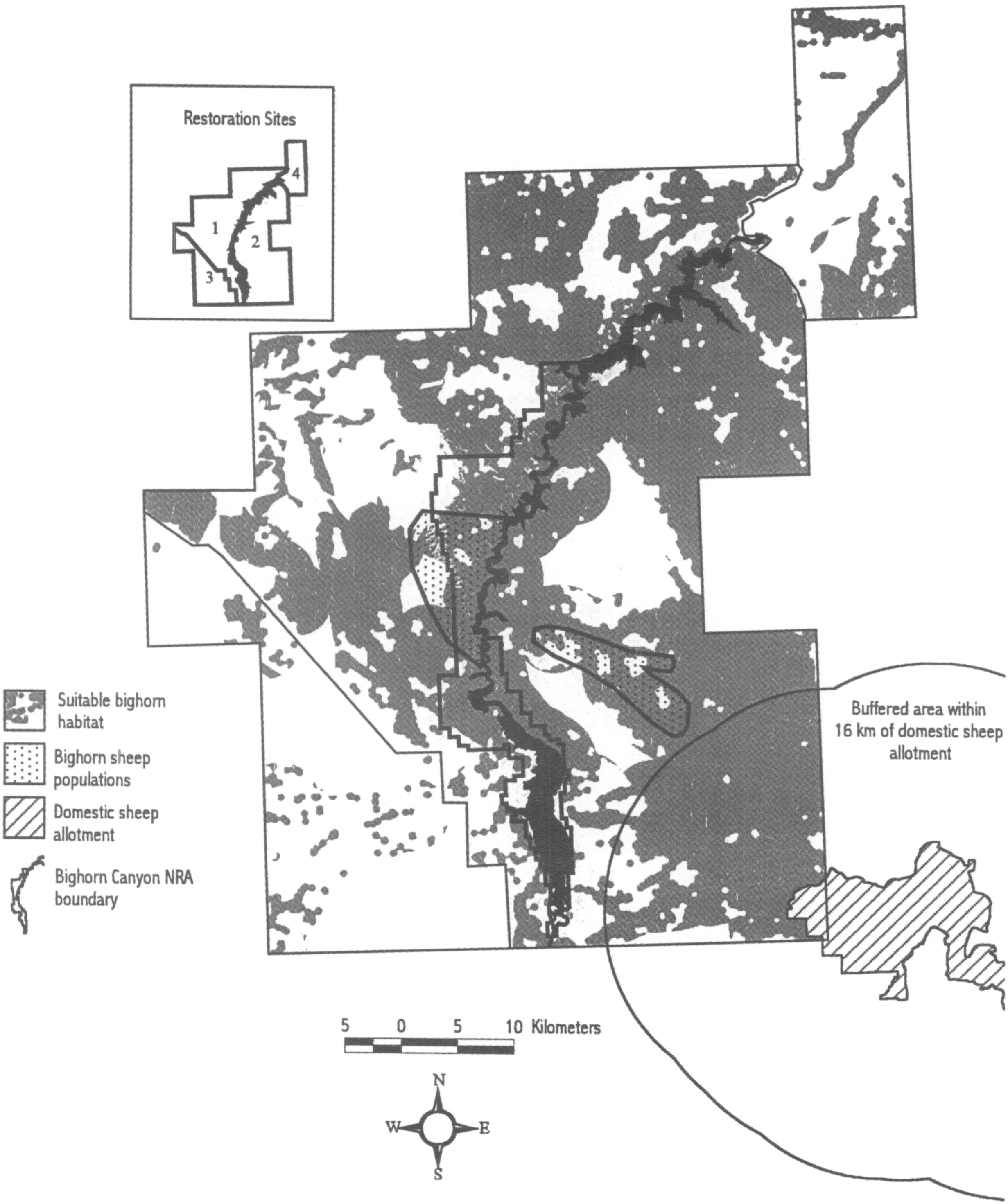


Figure 4.3. Suitable bighorn sheep habitat in Bighorn Canyon National Recreation Area, Wyoming, Montana, and surrounding areas.

herd and from Canyonlands National Park. From the former, 4 sheep (1 male, 3 females) were translocated in December 1975; 12 sheep (3 males, 9 females) in November 1976 and 7 sheep (2 males, 5 females) in January-February 1978. From the latter, 21 sheep (5 males, 16 females) were translocated in January 1984 and 10 sheep (2 males, 8 females) in January 1985. Surveys indicate that the herd size is increasing.

Assessment with GIS revealed four potential restoration sites (Table 4.6, Figure 4.4). The park decided to reintroduce three groups of 20 animals in the central portion of the park in the Pleasant Creek and Chimney Rock restoration sites. One release each was made in 1996 and 1997 in the Pleasant Creek location (one at the creek and one in the Capitol Gorge). A third release was scheduled for the earliest convenient time (in 1998 or 1999). Forty bighorn sheep (10 males, 30 females) from Canyonlands National Park were released in the two sites. One sheep died during the translocation, seemingly from capture stress.

The translocated populations are being monitored with bimonthly aerial surveys and occasional ground surveys. Monitoring revealed three fatalities since the translocations and dispersal about 3 km to the north and 3 km to the south. An Escalante survey in 1996 revealed 30 bighorn sheep (10 males, 12 females, and 8 lambs).

Colorado National Monument

The herd is referred to as the Black Ridge herd. The herd was surveyed from the air, on the ground, and with telemetry from November 1979 to 1989. The estimated size of the herd's range is 236 km^2. The sheep range from the Monument Canyon to the Knowles Canyon near the Colorado-Utah state line.

The Black Ridge herd was founded by the translocation of 11 sheep (3 males, 8 females) from the Kofa Game Refuge, Arizona, in November 1979; 16 sheep (4 males, 7 females, 3 male lambs, 2 female lambs) from Lake Mead Recreation Area, Nevada, in June 1980; and 9 sheep (9 females) also from Lake Mead Recreation Area in November 1981. The herd size decreased by approximately 50% during 1993–96. Losses are attributed to predation by mountain lions and possibly disease. The herd is not dispersing but seems to be maintaining its range.

Assessments with GIS revealed four restoration sites (Table 4.7, Figure 4.5). Inside the monument, particularly in the central and eastern sections, resident populations are not established. Because of the declining population size and concerns over the unsuccessful translocation in 1995, management chose a wait-and-see option. If future translocations are made, the Colorado Department of Wildlife may try to establish herds in the central and eastern sections of the monument. The biological panel prescribed controlled and prescribed natural fires to improve and maintain suitable bighorn sheep habitat.

On 27–28 October 1995, 22 sheep (4 males; 18 females) from Lake Mead Recreation Area were translocated into one restoration site (Knowles Canyon). The translocation was funded by Colorado National Monument and was made in cooperation with the National Park Service, Colorado National Monument, Bureau of Land Management, Colorado Division of Wildlife, Rocky Mountain Bighorn Sheep Society, Mesa County Woolgrowers Association, Sierra Club, Grand Junction, Colorado Mountain Club, and ranchers and citizens from Glade Park, Colorado. Five of the eight radio-collared sheep died. Monitoring is being conducted by the Colorado Division of Wildlife with funds from Colorado National Monument to evaluate the success of the first translocation.

Curecanti-Black Canyon

Three herds existed in the Curecanti-Black Canyon prior to 1991: the Dillon herd, Lake Fork herd, and Black Canyon herd. The Dillon herd fluctuates between 25 and 35 animals and ranges in an area west from the Soap Creek to the Red Creek drainage in the east to 3 km north of the Dillon Pinnacles. Rams sometimes wander outside of this area. The sheep do use NPS, U.S. Forest Service, U.S. Bureau of Land Management, and private lands. The Dillon herd was established with 25 transplanted animals in 1974.

Table 4.6. GIS assessment of bighorn sheep habitat in Capitol Reef National Park, Utah, 1996. Data of critical habitat parameters such as forage production, horizontal visibility, and water sources were not consistently available. The assessment was prepared independently by park staff and did not include determination of the seasonal ranges and assessment by restoration site.

	Restoration site[a]	MVP[b] requirements (Smith et al. 1991)
Evaluated land area (km^2)	1,964	ND
Suitable habitat (km^2)	466	17.0
Summer range (km^2)	ND	9.7
Winter range (km^2)	ND	6.5
Lambing range (km^2)	ND	3.6
Distance from domestic sheep (km)	>16	>16[c]
Estimated carrying capacity	ND	125
Estimated number of bighorn sheep, 1995	150	
Number of translocated bighorn sheep, 1996	20	
Number of translocated bighorn sheep, 1997	20	
Survey type	aerial and ground	
Estimated number of translocated bighorn sheep/population, 1997	45/195	
Estimated land area inhabited by bighorn sheep, 1996 (km^2)	140	
Estimated land area available for bighorn sheep, 1996 (km^2)	326	

[a]The biological panel prioritized four sites for translocations: Priority 1 = Pleasant Creek-Burro Wash; Priority 2 = Chimney Rock Canyon north to Water Canyon; Priority 3 = Burr Trail; Priority 4 = The Henry Mountains.
[b]Minimum viable population.
[c]Not referenced in Smith et al. (1991) but identified in Singer et al. (1998a).

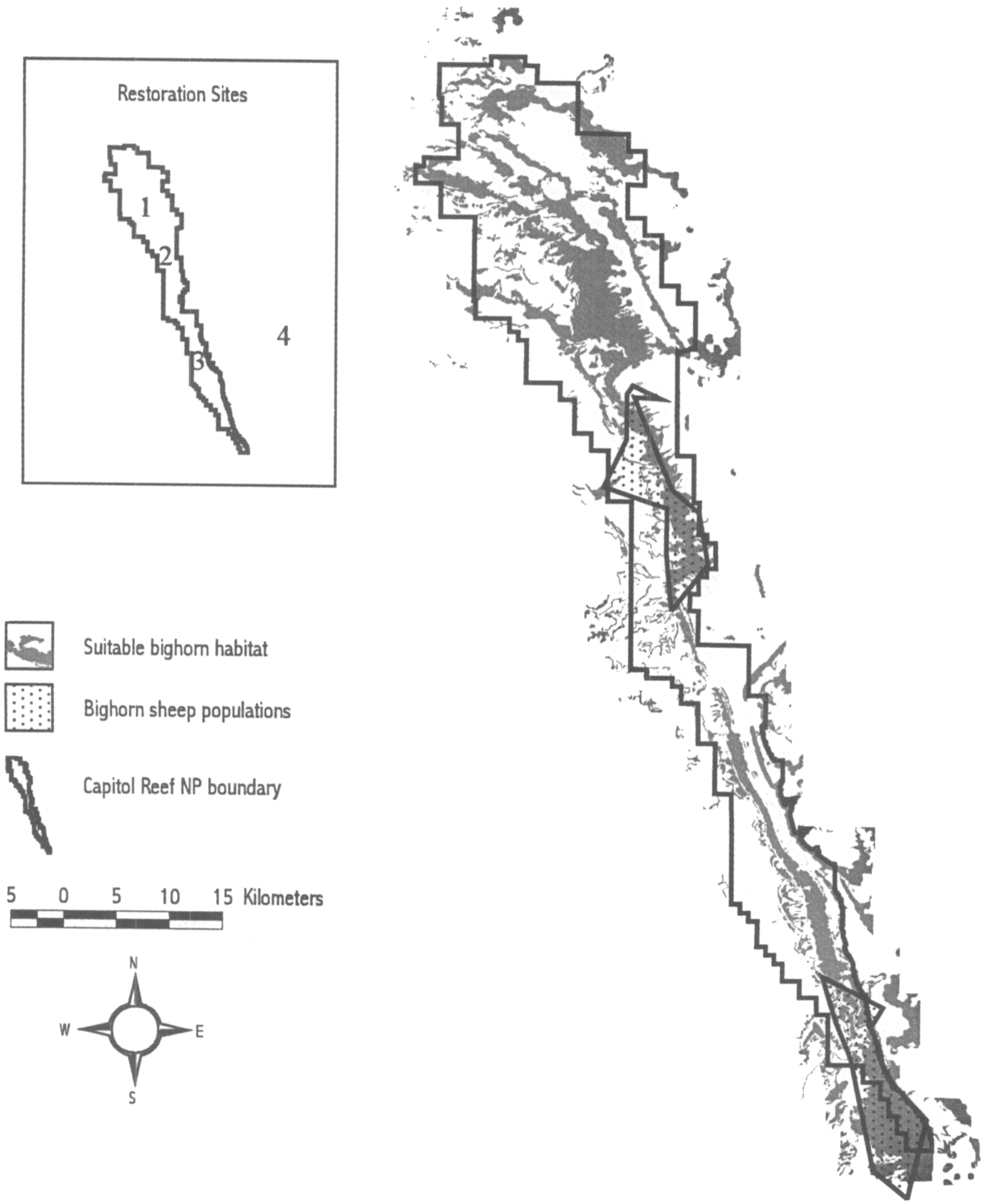


Figure 4.4. Suitable bighorn sheep habitat in Capitol Reef National Park, Colorado, and surrounding areas.

Table 4.7. GIS assessment of bighorn sheep habitat in Colorado National Monument, Colorado, 1995. Water was considered available in all seasonal ranges based on Resource Manager's knowledge of area. Risk of contact with domestic sheep was present in Restoration Sites 1, 2, and 3. The risk of contact in Restoration Site 4 was reduced because of the significant barrier of a major river between bighorn sheep habitat and grazing allotments for domestic sheep (Gudorf et al. 1995).

	Restoration Site				MVP[b] requirements
	1	2	3	4	(Smith et al. 1991)
Priority of site for restoration	2	1	3	[a]	
Evaluated land area (km^2)	89	1,015	347	798	ND
Suitable habitat (km^2)	61	624	152	79	17.0
Summer range (km^2)	48	520	137	73	9.7
Winter range (km^2)	14	133	51	36	6.5
Lambing range (km^2)	6	52	6	4	3.6
Distance from domestic sheep (km)	<16	<16	<16	>16	>16[c]
Estimated carrying capacity[d]	150	650	150	100	125
Estimated number of bighorn sheep, 1995	occasional use	125–175	0	0	
Number of translocated bighorn sheep, 1996	0	22	0	0	
Estimated number of translocated bighorn sheep/population	ND	ND	ND	ND	
Survey type	aerial	aerial & ground	aerial	aerial	
Estimated land area inhabited by bighorn sheep, 1996 (km^2)	0	95	0	0	
Estimated land area available for bighorn sheep, 1996 (km^2)	0 (61)[e]	0 (529)[e]	0 (152)[e]	79	

[a]Not recommended for restoration.
[b]Minimum viable population.
[c]Not referenced in Smith et al. (1991) but identified in Singer et al. (1998a).
[d]Carrying capacity based on biomass production of forage that support 1–2.5 bighorn sheep/km^2 of suitable habitat.
[e]Numbers in parentheses denote the available area for bighorn sheep if grazing allotments for domestic sheep are discontinued.

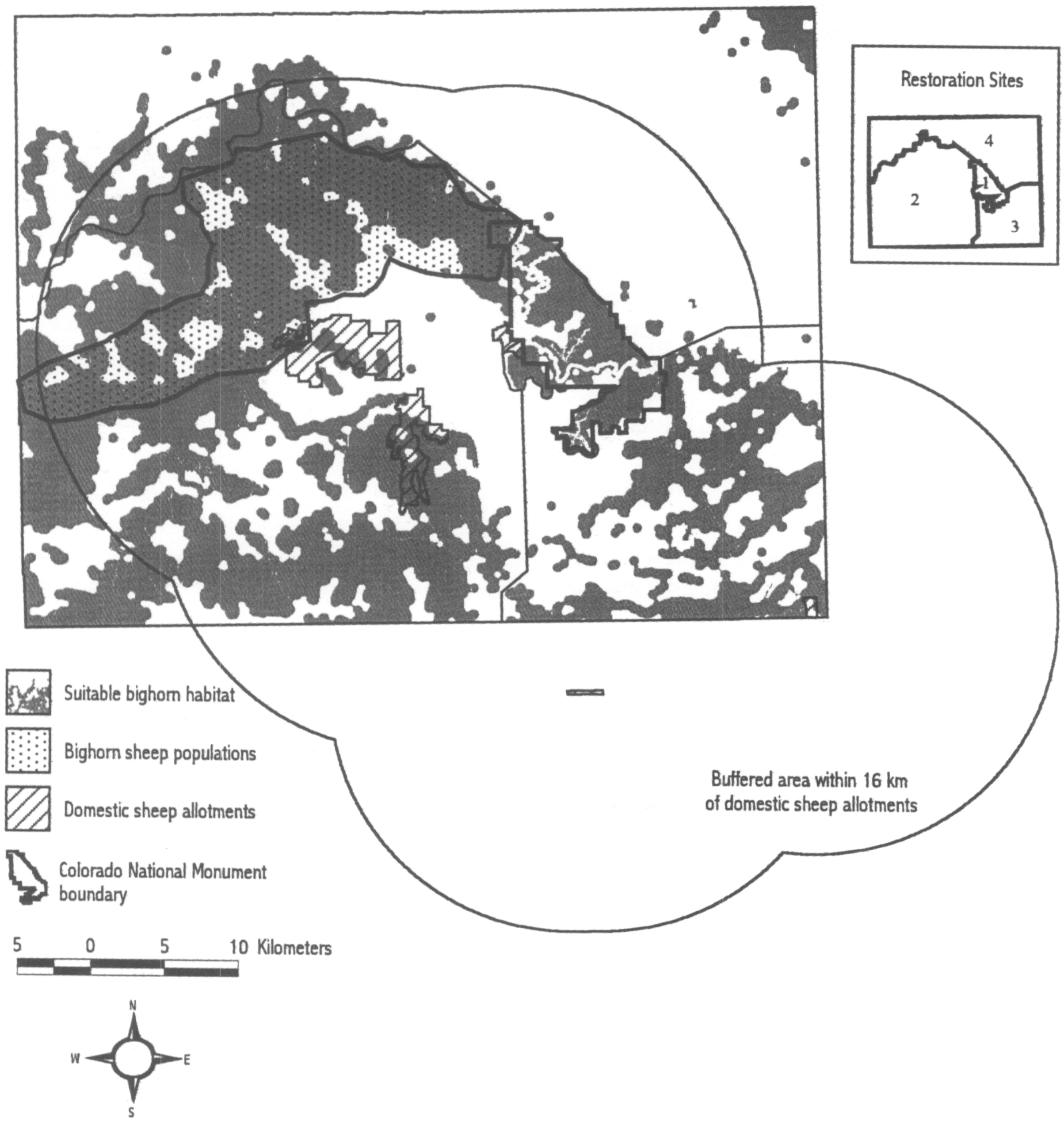


Figure 4.5. Suitable bighorn sheep habitat in Colorado National Monument, Colorado, and surrounding areas.

The Lake Fork herd numbered about 12 animals since 1994. The herd was established with 16 transplanted animals in 1975. The animals range along 5.4 km of the eastern Lake Fork Arm of the Blue Mesa Reservoir. Sheep were occasionally seen on the western side of the arm. Domestic sheep allotments in the range of the wild sheep may be restricting population growth.

The Black Canyon herd numbers less than 40 animals. The sheep use the eastern and western sides of the Black Canyon and lower Gunnison Gorge. The most extensively used area is west of the main park complex on the south rim. The herd was established with animals from four translocations in 1986 (20), 1987 (23), 1988 (19), and 1990 (20) into the lower Gunnison Gorge. Some of the sheep later moved east into the Black Canyon area. The size of the Black Canyon herd is also probably restricted because of the presence of domestic sheep.

The Dillon herd consists of 25 animals (3 males, 22 females) that were introduced in 1974 from stock in the Trickle Mountain and Saguache. These animals range from the Soap Creek to the Red Creek drainage and to 3 km north of the Dillon Pinnacles (57 km^2). The Lake Fork herd was translocated in 1975 from stock in the Trickle Mountain and Saguache. The 16 animals (5 males, 11 females) range from the east side of the Lake Fork arm from the main body of the reservoir south to Highway 149 and about 0.9 km east. The 15.54 km^2 range has a width of 0.8 km.

The Black Canyon herd ranges on the northern and southern sides of the canyon from the East Portal to the western boundary of the Black Canyon or over an area of about 23 km^2. The herd consists of animals from four different stocks. Twenty animals (5 males, 14 females, 1 unknown) from Powderhorn were released in 1986; 23 animals (7 males, 16 females) from Powderhorn were released in 1987; 19 animals (3 males, 16 females) from Almont were released in 1988; and 20 animals (5 males, 15 females) from Georgetown were released in 1990.

The size of the Dillon herd is relatively stable, but the size of the Lake Fork and Black Canyon herds is decreasing, probably because of disease transmitted from domestic sheep. Rams from the Dillon herd occasionally disperse to areas outside of range north to the West Elk herd during fall. Occasionally, rams that may also be from the Dillon herd are seen as far east as the Beaver Creek. Limited monitoring revealed that animals of the Lake Fork herd do not disperse outside their range. A portion (ewes and rams) of the Black Canyon herd drifted into the Red Rocks Canyon area. In previous years, the sheep also crossed the river and wintered near the Crystal Reservoir. Since the size of this herd declined, sightings of sheep have been primarily on the western side of the lower gorge near Red Rocks Canyon and Warren Point.

Assessments with GIS revealed 12 restoration sites (Table 4.8, Figure 4.6): one in the Dillon herd range, four in the Lake Fork herd range south of the Blue Mesa Reservoir, and seven in the Black Canyon-Gunnison Gorge range east of the Blue Mesa Dam. Only one of these restoration sites (in the Dillon range) was suitable bighorn sheep habitat. Three areas in the Black Canyon-Gunnison Gorge area were suitable if the domestic sheep allotments were removed or exchanged. Another restoration site in the Black Canyon-Gunnison Gorge region may be made more suitable with burning to reduce the density of vegetation.

Restoration of bighorn sheep cannot be made until the domestic sheep allotments are removed from the Black Canyon-Gunnison Gorge area. Limited suitable habitat and domestic sheep allotments argues against any augmentation of the Lake Fork herd.

Twenty-one bighorn sheep from the Rampart herd in Colorado Springs were translocated to three restoration sites in the Dillon range on 23 January 1996. The translocations were made in cooperation with the National Park Service, the U.S. Forest Service, the U.S. Bureau of Land Management, and the Colorado Division of Wildlife. Nine sheep were released in the Dry Gulch, 10 sheep mile 1.6 km west of the Dry Creek, and 2 sheep in a parking lot (unintentional release site) in the Dillon Pinnacles. The total group consisted of 9 ewes (all ewes were radio collared), 3 rams (2 were radio-collared), 6 female lambs, and 3 male lambs. One female lamb sustained a

Table 4.8. GIS assessment of bighorn sheep habitat in Curecanti National Recreation Area and Black Canyon of the Gunnison National Monument, Colorado, 1995. This was an independent assessment by staff of the Curecanti National Recreation Area and did not include mapping of the proximity to domestic sheep. Dense vegetation obscures horizontal visibility and limits the suitability of some areas as bighorn sheep habitat. Domestic sheep also limit suitable habitat (Sweanor et al. 1995).

	Restoration Site[a]									MVP[b] requirements
	1–3	4	5	6–7	8	9	10	11	12	(Smith et al. 1991)
Priority for restoration	a	a	a	a	1	a	a	a	a	
Evaluated land area (km^2)	251	149	15	121	762	168	100	173	39	ND
Suitable habitat (km^2)	80	25	3	32	264	35	28	52	13	17.0
Summer range (km^2)	45	24	2	27	185	27	22	41	11	9.7
Winter range (km^2)	36	14	1	21	115	20	13	23	6	6.5
Lambing range (km^2)	21.0	0.7	0.4	3.3	46.0	6.0	3.6	7.0	1.0	3.6
Distance from domestic sheep (km)	<16	<16	>16	>16	<16	<16	<16	<16	<16	>16[c]
Estimated carrying capacity[a]	>125	24	14	114	>125	>125	>125	>125	31	125
Estimated number of bighorn sheep, 1995	<40	0	0	0	<50	0	>30	0	0	
Number of translocated bighorn sheep, 1995–97	0	0	0	0	21	0	0	0	0	
Estimated number of translocated bighorn sheep/population, 1997	/<40	0	0	0	18/55	0	/<30	0	0	
Survey type	aerial & ground	aerial & ground	aerial & ground	aerial & ground	aerial & ground	aerial & ground	aerial & ground	aerial & ground	aerial & ground	
Estimated land area inhabited by bighorn sheep, 1996 (km^2)	37	0	0	0	48	0	3	0	0	
Estimated land area available for bighorn sheep, 1996[e] (km^2)	0 (43)	0 (25)	3 (3)	32 (32)	216 (216)	0 (35)	0 (25)	0 (52)	0 (13)	

[a]Restoration Sites 1, 2, and 3 were combined for management because the distribution of the Gunnison River Gorge herd extends throughout the area. Restoration Sites 6 and 7 were combined because of size and proximity. None of these sites were recommended for restoration at this time.
[b]Minimum viable population.
[c]Not referenced in Smith et al. (1991) but identified in Singer et al. (1998a).
[d]Carrying capacity based on biomass production of forage that support 1 bighorn sheep/13 ha of suitable habitat.
[e]The number in parentheses denotes the available area for bighorn sheep if grazing allotments for domestic sheep are discontinued.

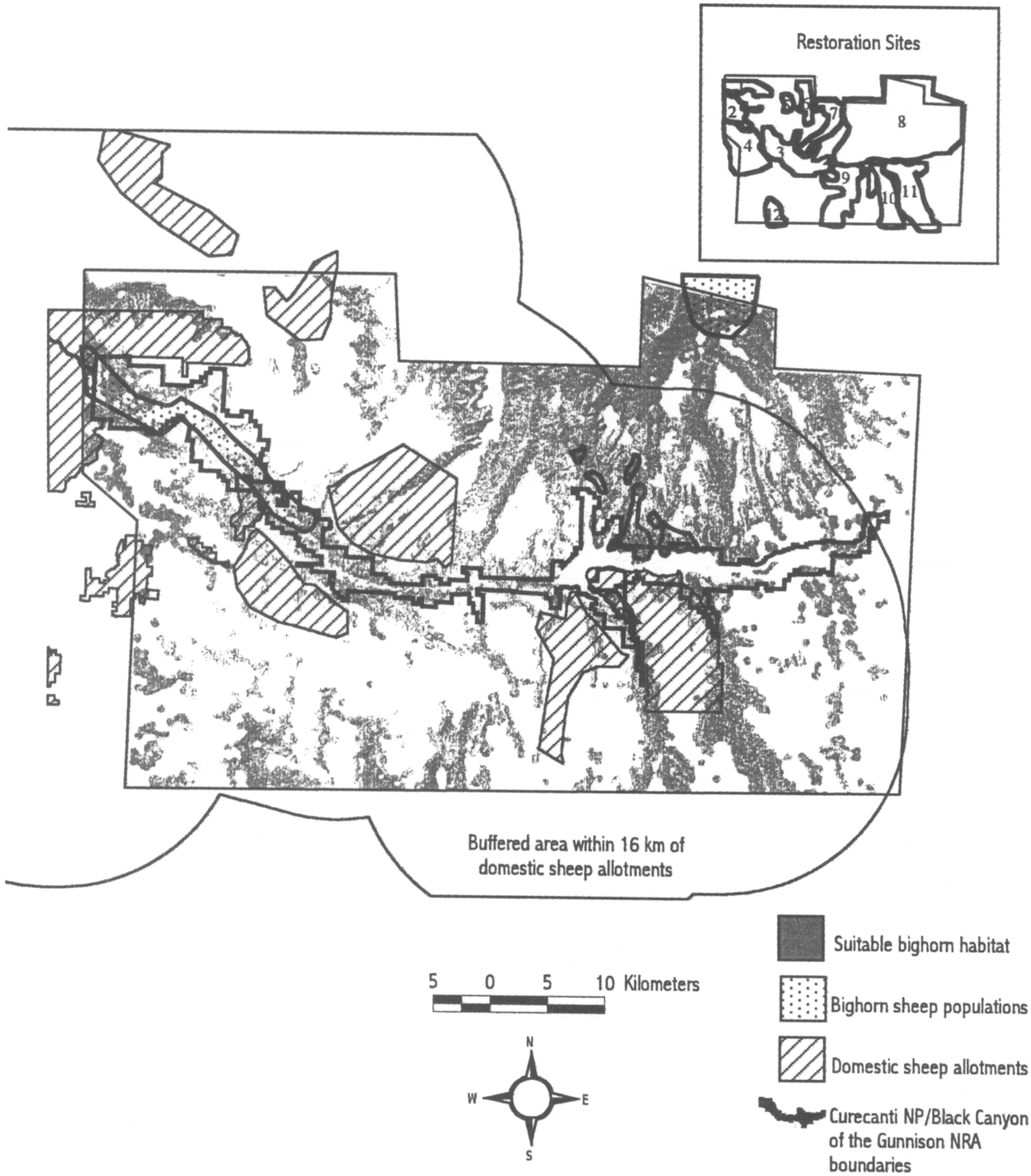


Figure 4.6. Suitable bighorn sheep habitat in Curecanti National Recreation Area and Black Canyon of the Gunnison National Monument, Colorado, and surrounding areas.

broken leg and died at the veterinary office in Gunnison. The Colorado Division of Wildlife plans to expand the Dillon herd as far as Beaver Creek to the east on the north side of the Blue Mesa Reservoir with augmentations.

The biological panel recommended prescribed natural fire and the retirement of domestic sheep allotments on the south side of Blue Mesa Reservoir for enhancing the overall success of restoration. Because much of the terrain on the northern side of Blue Mesa is land of the U.S. Bureau of Land Management, prescribed burning must be done in cooperation with that agency and possibly also with the National Forest Service. The principal domestic sheep allotments are on the southern side of the reservoir. The park is interested in purchasing (outright or through easement) the private land adjacent to the park boundary at the Black Canyon from a willing seller. In cooperation with the National Forest Service and the U.S. Bureau of Land Management, the park may also acquire a section of private land north of the Blue Mesa Reservoir that has been identified as suitable for bighorn sheep.

Dinosaur National Monument

All native herds in the area were extirpated. By 1991, seven different bighorn sheep herds were introduced to the Dinosaur National Monument-Green River area. The seven herds were the Lodore Canyon herd, Whirlpool Canyon herd, Cross Mountain herd, Beaver Creek herd, Sheep Creek herd, Bear Mountain herd, and Hole-in-the-Rock herd. The Lodore Canyon herd was reestablished in 1952 with 32 animals (3 males and 12 females from the Tarryall range; 5 males and 12 females from Rifle, Colorado) that quickly expanded to both sides of the river in the Lodore Canyon. Small groups extended 5–6 km east on the north side of the Yampa River and 5–6 km west on the north side of Whirlpool Canyon. In response to burns in the 1980s that removed high, dense vegetation, sheep began to reoccupy the edges of historic summer ranges above the canyon rims in the early 1990s. The herd consists of an estimated 150 to 200 animals. The estimated range size of the Lodore Canyon herd of about 11 km^2 in the 1950s has expanded to an estimated 14 km^2.

The Whirlpool Canyon herd was reintroduced in 1984 from the Never Summer range (13 adult females, 3 female lambs, 2 male lambs, and 1 2-year-old male). The herd stayed along the east face of Harper's Corner for 2 years. Then most of the sheep moved into the Whirlpool Canyon, from Echo Park to Island Park downstream from Jones Hole Creek. In the early 1990s, this population dispersed farther downstream to Split Mountain Canyon. The estimated size of the population was 75 in 1991. The herd seemingly intermingled with the Lodore Canyon herd in the Whirlpool Canyon. Their estimated range encompasses about 72 km^2.

In 1977, the Cross Mountain herd was reintroduced with 20 animals (3 male lambs, 2 female lambs, 12 adult females, 3 yearling males) from Mt. Evans. The sheep occasionally entered the eastern portion of the monument. The herd is now regarded as extirpated. The estimated size of the range the animals occupied was about 61 km^2.

In 1983, the Beaver Creek herd was translocated about 19 km upstream from Dinosaur National Monument in the Beaver Creek Canyon and adjacent areas in Browns Park. The release included 21 animals (9 yearling and adult females, 4 yearling and adult males, 5 female lambs, 3 male lambs) from Basalt, Colorado. The remnants of this herd were removed in 1997. They were a sedentary herd with a range of only about 28 km^2.

In 1989, the Sheep Creek herd was reintroduced into National Forest Service lands several kilometers west of the monument. The release consisted of 21 animals (13 yearling and adult females, 3 yearling and adult males, 3 female lambs, 2 male lambs) from the Torray Creek herd in Dubois, Wyoming. The herd developed a migratory tendency.

The Bear Mountain herd inhabits National Forest Service lands on the eastern side of the Flaming Gorge Reservoir, several kilometers from the monument. This herd was established with animals from Whisky Mountain, Wyoming. Nineteen animals were translocated in 1983 (10 yearling and adult females, 5 yearling and adult males, 3 female lambs, 1 male lamb), and 17 in 1984 (13 yearling and adult females, 2 adult males, 1 female lamb, 1 male lamb).

In 1989, the Hole-in-the-Rock herd was reintroduced in an area about 113 km west-northwest of the monument. The herd consisted of 22 total animals (11 adult females, 3 adult males, 4 female lambs, 4 male lambs) from Dubois, Wyoming.

Most of the surviving herds are currently increasing. After a significant population decline in the late 1970s and early 1980s, the Lodore Canyon herd increased to an estimated 150–175 animals. The Whirlpool Canyon herd increased to an estimated 100–125 animals. The Cross Mountain herd is probably now extirpated. In 1991, the Beaver Creek herd experienced an outbreak of a respiratory disease and only 10 sheep had survived by 1993. Because of a lack of lamb recruitment since 1990 and concerns about disease transmission to other proposed founder stocks, this remnant population was eliminated in February 1997. In 1994, the Sheep Creek herd numbered 75–100 animals and the Bear Mountain herd numbered 45–55 animals. Both herds were considered stable. The Hole-in-the-Rock herd consisted of 60 animals in 1994 and was increasing.

Animals from the Lodore Canyon herd and the Whirlpool Canyon herd dispersed to other areas. The Lodore Canyon herd expanded to both sides of the Lodore Canyon, primarily in areas that were burned since the mid-1980s. The expansion was initiated by ram groups and was followed by ewe-lamb groups. The Whirlpool Canyon herd occupied almost all of the Whirlpool Canyon. In the early 1990s, the population rapidly expanded its range to most of the Split Mountain Canyon.

Habitat assessment with GIS revealed four restoration sites (Table 4.9, Figure 4.7). However, two of the areas were already occupied by previously translocated sheep. Two translocations into Dinosaur National Monument were proposed. The Utah Division of Wildlife is proposing two additional translocations north and west of the park in the interagency Green River Corridor. Twenty-one animals (10 adult females, 2 yearling females, 3 adult males, and 6 yearling males) from the Dome Rock herd, Colorado, were translocated into Tanks Peak in early 1997. Another translocation is scheduled into the Yampa River Corridor in the Big Joe area in winter 1998–99. Translocations into the Green River Corridor were conducted in cooperation with the Colorado Division of Wildlife, Utah Division of Wildlife Resources, U.S. Bureau of Land Management, and the National Forest Service.

Glen Canyon National Recreation Area

All or nearly all the native desert bighorn sheep in the area were extirpated. By 1991, six different bighorn sheep herds were reintroduced into Glen Canyon National Recreation Area: the North San Juan, South San Juan, Dirty Devil, Escalante-Moody Canyon, Kaiparowits Plateau, and Paria herds. The North San Juan herd ranged east of the Colorado River, south of Canyonlands National Park, and north of the Dark Canyon and Utah Highway 95. The size of the herd steadily declined from approximately 225 in 1976 to about 30 in 1990. The South San Juan herd ranges east of the Colorado River and south of the North San Juan herd, extending to the San Juan River. The herd declined due to a disease epizootic from a high of 140 in 1987 to a low of less than 30 in 1990. The 1993 census indicated a population size of 80.

The Dirty Devil herd inhabits an area east of the Dirty Devil River in Sams Mesa, approximately 10 km north of Glen Canyon National Recreation Area. The herd's range is approximately 93 km^2 and is bounded by the Dirty Devil River on the west, by the Happy Canyon on the south, and by the No Mans Canyon to the north. The herd was reintroduced with 22 sheep (15 females, 7 males) from the north San Rafael Swell herd.

The Escalante-Moody Canyon herd was established with translocations in 1975 (1 male, 3 females), 1976 (3 males, 9 females), 1978 (2 males, 5 females), 1984 (6 males, 15 females), and 1985 (10). Surveys from aircraft since 1975 indicate that the herd is moving into all canyons of the Escalante River

Table 4.9. GIS assessment of bighorn sheep in Dinosaur National Monument. Three scenarios were analyzed. The results are based on the third scenario, assuming that grazing by domestic sheep is eliminated within a 16-km radius of suitable habitat and pinyon juniper habitat is not considered to have adequate horizontal visibility. In this scenario, only horizontal visibility may be a limiting factor for routine movement and occupation of habitat by bighorn sheep (Sweanor et al. 1994).

	Restoration Site				MVP[b] requirements (Smith et al. 1991)
	1	2	3	4	
Priority for restoration	2	1	[a]	[a]	
Evaluated land area (km^2)	2,025	836	890	887	ND
Suitable habitat (km^2)	333	390	136	270	17.0
Summer range (km^2)	258	325	98	207	9.7
Winter range (km^2)	60	77	26	64	6.5
Lambing range (km^2)	7	26	20	33	3.6
Distance from domestic sheep (km)	>16	>16	>16	<16	>16[c]
Estimated carrying capacity[d]	>125	>125	>125	>125	125
Estimated number of bighorn sheep, 1995	60 in Restoration Sites 1 and 3 combined	100 in Restoration Sites 2 and 4 combined	60 in Restoration Sites 1 and 3 combined	100 in Restoration Sites 2 and 4 combined	
Number of translocated bighorn sheep, 1997	21	ND	ND	ND	
Estimated number of translocated bighorn sheep/total population	19/80	0/80	0/40	0/100	
Survey type	aerial	reported sightings	reported sightings	reported sightings	
Estimated land area inhabited by bighorn sheep, 1996 (km^2)	>59	>76	<1	>59	
Estimated land area available for bighorn sheep, 1996(km^2)	273[e]	254[e]	0[f]	0[f]	

[a] Already occupied.
[b] Minimum viable population.
[c] Not referenced in Smith et al. (1991) but identified in Singer et al. (1998a).
[d] Carrying capacity based on biomass production of forage that support 1 bighorn sheep/8 ha of suitable habitat.
[e] Management is in the process of retiring domestic-sheep grazing allotments, or converting to cattle.
[f] Reduced to zero because of concerns about poaching and plans of reintroducing other ungulates into the area.

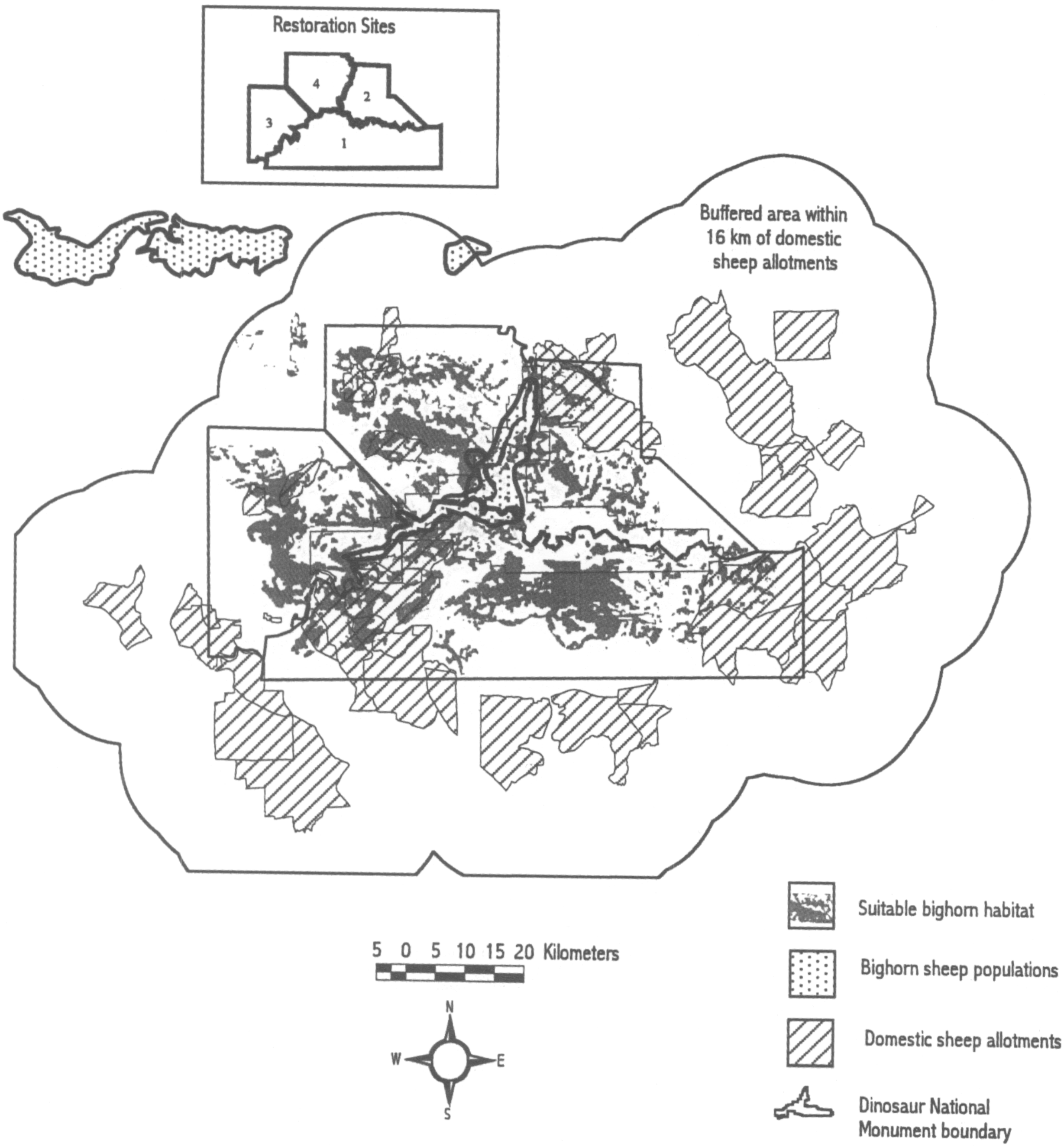


Figure 4.7. Suitable bighorn sheep habitat in Dinosaur National Monument, Colorado and Utah, and surrounding areas.

(approximately 259 km^2) and that the size of the population is increasing.

The Kaiparowits Plateau herd ranges north of Glen Canyon National Recreation Area on the Kaiparowits Plateau, south of Coyote Gulch on and near the Fifty Mile Bench and the Straight Cliffs. The herd was created in 1980 (20 sheep) and augmented in 1982 (12 sheep) and 1993 (13 sheep). The range encompasses an area of approximately 337 km^2. Aerial surveys since 1980 indicate that the population is established and increasing.

The Paria Wilderness herd was established with 37 sheep in 1984 and augmented with 15 sheep in 1985. The herd ranges over 207 km^2 north of Glen Canyon National Recreation Area in the Paria Canyon drainage. Aerial surveys since 1984 suggest the population has increased to an estimated 170 animals.

Habitat assessment with GIS revealed 13 restoration sites (Table 4.10, Figure 4.8). Ten were ready for translocation, and the herds on the remaining three sites do not require augmentation. One translocation was made in 1995 and two in 1996. Between 1995 and 1996, three translocations were made: 17 sheep were introduced to Rogers Canyon, 21 sheep from the Escalante herd were translocated to Browns-Long Canyon, 21 sheep were translocated to North Wash, and 6 into Cow Canyon. The three herds were monitored annually by the Utah Division of Wildlife Resources. The recreation area in cooperation with the Utah Division of Wildlife Resources and the National Park Service proposed translocations to the following sites: Andy Miller, Cow Canyon, Gunsight, Silver Falls Canyon, Horseshoe Canyon, and Smokey Mountain.

The biological panel recommended: (1) minimizing contact with livestock (especially domestic sheep); (2) protecting the genetic integrity of herds on either side of the Colorado River; (3) using bighorn sheep from Nevada for transplants as a last resort; and (4) using only Escalante herd as source stock for Cow Canyon and Silver Falls translocations. Utah Wildlife Resources agreed to complete the remaining translocations as source stocks and funding becomes available, and monitor the populations with aerial surveys and an annual census.

Herd	1994	1995
South San Juan	150	150
North San Juan	30	30
Escalante	300	300
Kaiparowits	150	150
Paria	158	142

Grand Teton National Park

Historically, the Teton Range bighorn sheep population was part of a complex of several native herds that inhabited the nearby mountain ranges and probably mingled. Several of the native herds were extirpated. Development in Jackson Hole cut off routes to wintering areas where populations mingled. Consequently, the herd is now isolated and does not use former low-elevation winter ranges. Domestic sheep are still grazed in parts of the Tetons, and use by domestic sheep is even heavier in adjacent mountain ranges.

The herd is confined to the Teton range, and exists of northern and southern subpopulations. Sheep occur occasionally in the area that separates the two subpopulations, but radio-telemetry data has failed to demonstrate mingling of sheep between the two subpopulations. The Teton Range herd is a native herd that has not been manipulated. The best available information suggests that the size of the herd may be slowly declining. No immigration or emigration has been documented. However, infrequent observations of sheep outside of sheep habitat, for example, in the Jackson Hole valley floor and in areas between the Teton herd range and the next closest population, the Gros Ventre herd, suggest some mingling of young males, adult females, and lambs between the two subpopulations.

Table 4.10. GIS assessment of bighorn sheep in Glen Canyon National Recreation Area, Utah, 1994. The assessment was prepared independently by park staff and did not include determination of the seasonal ranges, assessment of the area by restoration site, and estimation of the carrying capacity. Resource management prioritized sites for restorations.

	Restoration site[a]	MVP[b] requirements (Smith et al. 1991)
Evaluated land area (km^2)	5,058	ND
Suitable habitat (km^2)	2,154	17.0
Summer range (km^2)	ND	9.7
Winter range (km^2)	ND	6.5
Lambing range (km^2)	ND	3.6
Distance from domestic sheep (km)	ND	>16[c]
Estimated carrying capacity	ND	125
Estimated number of bighorn sheep, 1995	770	
Estimated number of bighorn sheep:		
1995	17	
1996	21	
1996	21	
Estimated number of translocated bighorn sheep/population, 1997	ND	
Survey type	aerial	
Estimated land area inhabited by bighorn sheep, 1996 (km^2)	311	
Estimated land area available for bighorn sheep, 1996 (km^2)	1,843	

[a]Translocations in order of site priority: (1) Rogers Canyon (completed); (2) Brown-Long Canyon (completed); (3) North Wash (completed); (4) Cow Canyon; (5) Silver Falls Canyon; (6) Andy Miller; (7) Smokey Mountain Area (north of Padre); (8) Horseshoe Canyon.
[b]Minimum viable population.
[c]Not referenced in Smith et al. (1991) but identified in Singer et al. (1998a).

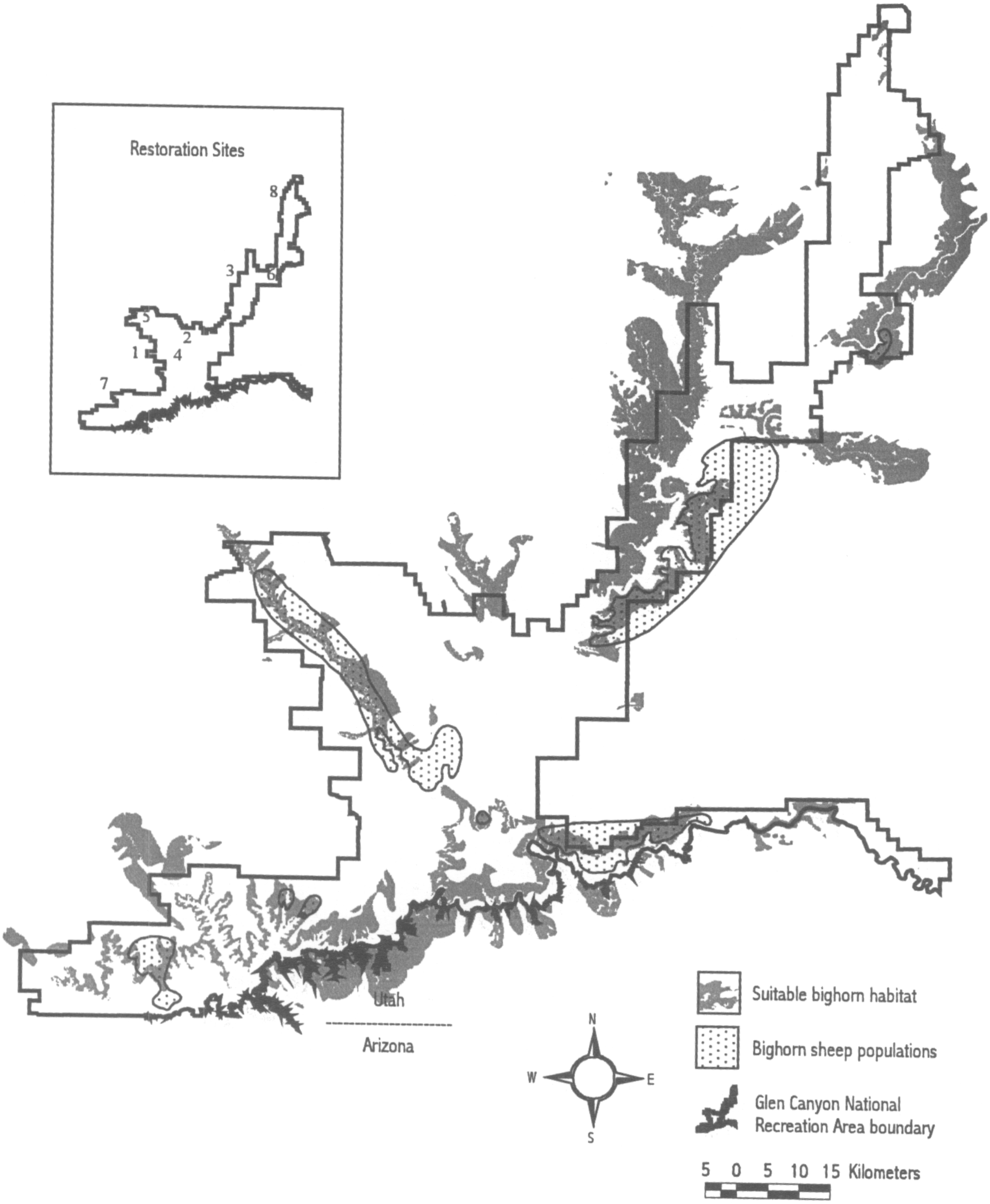


Figure 4.8. Suitable bighorn sheep habitat in Glen Canyon National Recreation Area, Utah, and surrounding areas.

Because data are still being collected and analyzed, and results of genetic samples are still unavailable, a formal biological panel has not yet been assembled to address the Teton Range sheep. Management options of the Teton herd are still being evaluated. Two factors seem to be important for the conservation of this herd: burning of former low-elevation winter ranges on the west side of the Tetons by the U.S. Forest Service to restore historic habitat and control of recreation that displaces sheep. Fire suppression promoted overgrowth of the most productive, low elevation winter ranges. The sheep no longer use these ranges. Knowledge of these areas by bighorn sheep may have been lost. Habitat improvements on Forest Service lands and recreational disturbance are being addressed. If winter-range improvements are made, a translocation of sheep to these areas during winter should be considered. Knowledge of the genetic status of the herd and other local herds would be helpful for determining appropriate source stock for translocations.

The park is currently reviewing seasonal distribution data to determine recreation closures in areas that are important to sheep. The park, the working group, and the National Forest Service are addressing the elimination of domestic sheep grazing allotments and improvement of low-elevation winter ranges on the west side of the Tetons.

Winter mortality, primarily from falls off cliffs and from avalanches, is high.

Mesa Verde National Park

Native animals in the area were extirpated. The Soda Canyon herd in the southwestern corner of Mesa Verde National Park and Ute Mountain Reservation was reintroduced with 14 individuals from Spanish Peaks, Colorado, in 1946. The herd was surveyed on the ground from 1981 to 1990. Research indicates that the herd is not dispersing and that its size is decreasing (3 ewes and 1 ram in June 1997). The biological panel determined that suitable bighorn sheep habitats in Mesa Verde are patches that are too small for a viable population (Table 4.11, Figure 4.9). Therefore, no translocations will be made at this time. Nevertheless, if a series of large fires open up some of the densely vegetated areas, the park staff may decide to proceed with restoration.

Theodore Roosevelt National Park

The original bighorn sheep herds, the hypothesized Audubon's subspecies, were extirpated early this century in Theodore Roosevelt National Park. The present herds in the Little Missouri Badlands are descendants of translocated animals from British Columbia, Canada. Assessments with GIS revealed three restoration sites: the North Unit, the South Unit, and all the area surrounding the North and South Units (Table 4.12, Figure 4.10). All three of these areas are suitable habitat if sufficient gene flow by bighorn sheep through the fences is assured with breaks or crawl-unders to permit bighorn sheep passages.

Nineteen sheep (5 males, 14 females) from British Columbia were translocated into the North Unit in January 1996. The translocation was made in cooperation with the North Dakota Game and Fish Department and the Wildlife Branch of the British Columbia Environment. One ewe was injured during capture and was released at the capture site. Another ewe that had been collared died from capture myopathy within 1 hour of arriving at the park. The translocated sheep were monitored in 1996 and 1997. Since the translocation, three more sheep died. A ram died of liver malfunction, a dead ewe was found at the bottom of a 6-foot sink hole, and another ewe was killed by coyotes. Five of 8 lambs survived to the end of December 1996.

Zion National Park

Native animals in the area were extirpated. Twelve sheep were transplanted from Lake Mead in 1973 into a 32-ha (80-acre) holding pen in Zion and subsequently released. In 1991, a survey from a helicopter revealed 35 animals. The herd remains in the southeastern portion of the park that extends to the

Table 4.11. GIS assessment of bighorn sheep habitat in Mesa Verde National Park, Colorado, 1995. The assessment was not by study area. Dense vegetation obscures horizontal visibility and significantly reduces the value of the area as bighorn sheep habitat. Risk of contact with domestic sheep was high in many areas (Johnson et al. 1995; Gudorf 1996).

	Restoration Site			MVP[a] requirements (Smith et al. 1991)
	Long Mesa	Moccasin Mesa	Soda Canyon	
Evaluated land area (km^2)	total of 1800			ND
Suitable habitat (km^2)	4.36	3.14	7.92	17.0
Summer range (km^2)	3.47	2.81	6.79	9.7
Winter range (km^2)	1.78	1.73	2.8	6.5
Lambing range (km^2)	0	0	0	3.6
Distance from domestic sheep (km)	<16	1.42	<16	>16[c]
Estimated carrying capacity	ND	ND	ND	125
Estimated number of bighorn sheep in 1995	0	0	0	0
Estimated land area inhabited by bighorn sheep in 1996 (km^2)	0	0	0	
Estimated land area available for bighorn sheep, 1996 (km^2)	0 (4.36)	1.72 (3.14)	0 (7.92)	

[a]Minimum viable population.
[b]Not referenced in Smith et al. (1991) but identified in Singer et al. (1998a).
[c]The number in parentheses denotes the area available for bighorn sheep if grazing allotments for domestic sheep are discontinued.

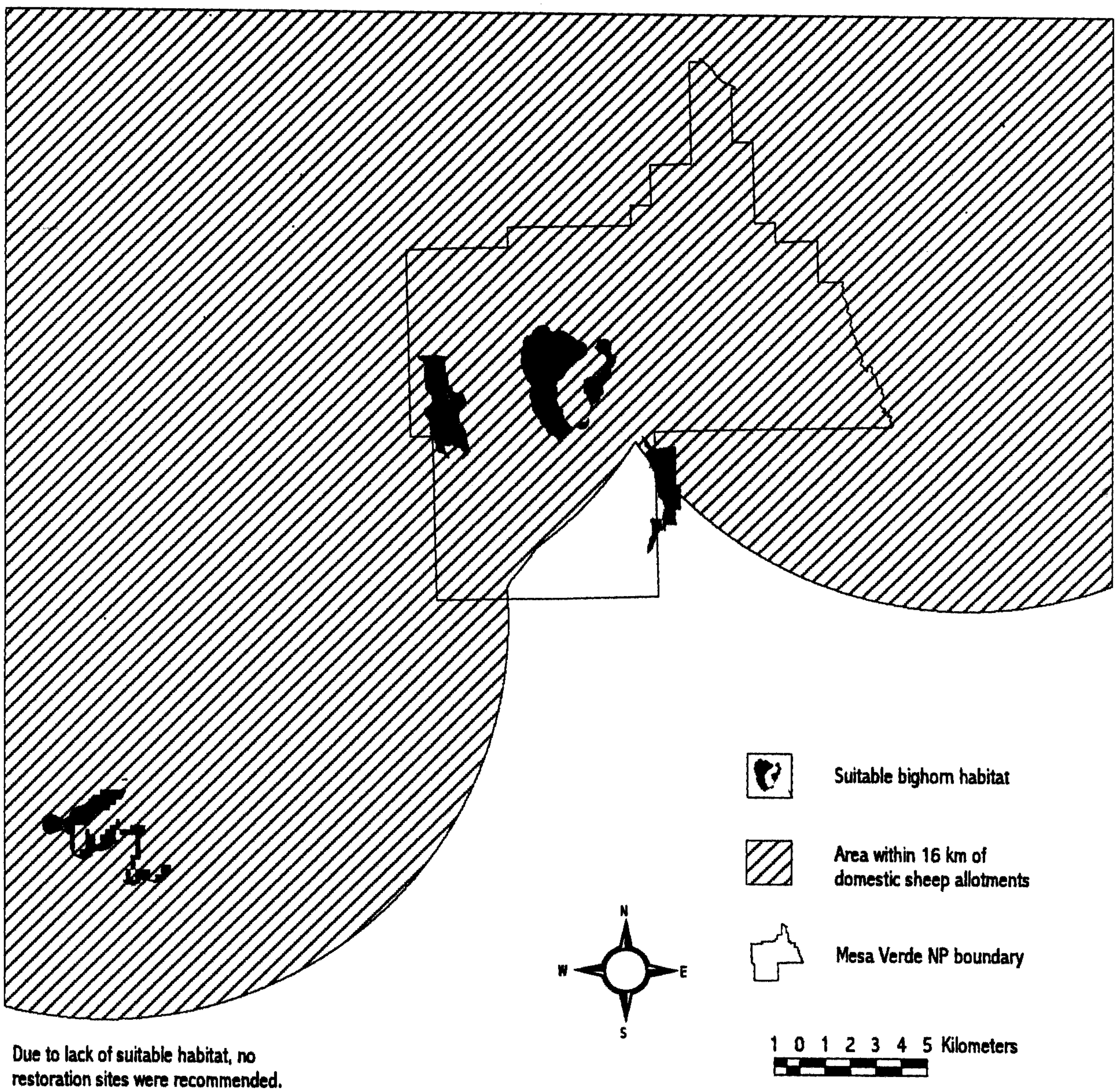


Figure 4.9. Suitable bighorn sheep habitat in Mesa Verde National Park, Colorado, and surrounding areas.

Table 4.12. GIS assessment of bighorn sheep habitat in Theodore Roosevelt National Park. In this area, the lambing range was the most limiting feature of bighorn sheep habitat. Risk of potential contact with domestic sheep was low in all restoration sites (Sweanor et al. 1994).

	Restoration Site			MVP[b] requirements (Smith et al. 1991)
	1	2	3	
Priority for restoration	1	2	a	
Evaluated land area (km^2)	97	188	3,209	ND
Suitable habitat (km^2)	26	19	291	17.0
Summer range (km^2)	25	18	286	9.7
Winter range (km^2)	12	7	101	6.5
Lambing range (km^2)	0.6	0.2	6.9	3.6
Distance from domestic sheep (km)	>16	>16	>16	>16[c]
Estimated carrying capacity[d]	20-38	6-13	230-435	125
Estimated number of bighorn sheep, 1995	2	6	130-140	
Translocated bighorn sheep, 1995-97	19	0	0	
Survey type	ground	ND	aerial	
Estimated number of translocated bighorn sheep/population, 1997	24	ND	ND	
Estimated land area inhabited by bighorn sheep, 1996 (km^2)	18	0	186	
Estimated land area available for bighorn sheep, 1996 (km^2)	7	19	105	

[a] Decision to restore bighorn sheep was defered to a later date.
[b] Minimum viable population.
[c] Not referenced in Smith et al. (1991) but identified in Singer et al. (1998a).
[d] Carrying capacity based on biomass production of forage that supports 1 bighorn sheep/13 ha of suitable habitat.

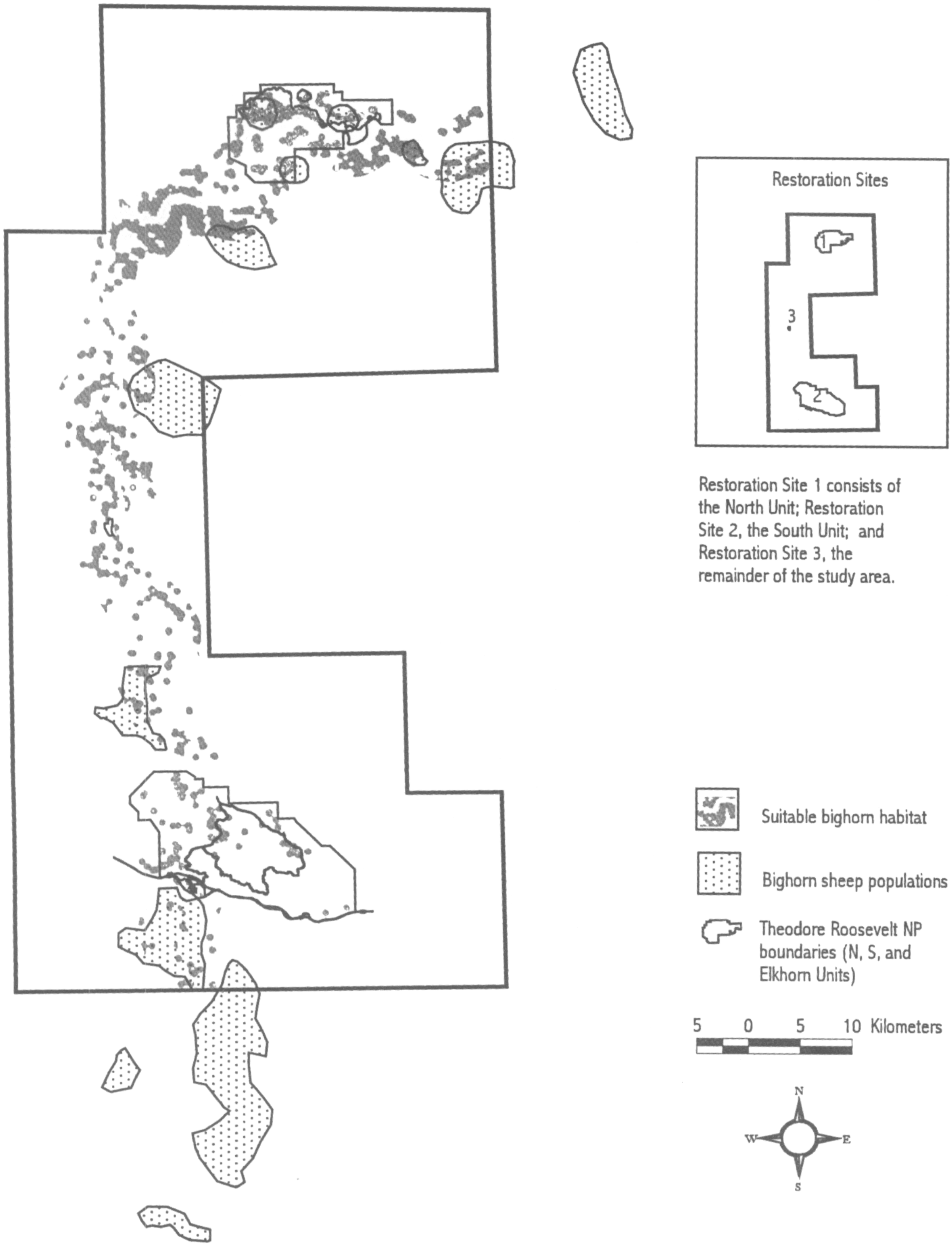


Figure 4.10. Suitable bighorn sheep habitat in Theodore Roosevelt National Park, North Dakota, and surrounding areas.

Canaan Mountain. The core habitat area is 80.14 km^2. Currently, the size of the herd seems to be increasing. The herd is gradually moving southward toward Colorado City, Arizona, and may be breaking up into different bands as suggested by breeding in several locations during 1995 and 1996.

Conservative estimates of population size with a Schnabel estimator revealed 74 sheep (±11 sheep) in Zion National Park. The lamb to ewe ratio is 48:100. The ram to ewe ratio in 1996 was 37:100. The lambing range has substantially expanded to the south. The most heavily used lambing area seems to be the Shunes Creek drainage. Anecdotal information suggests lambing outside the park in the Canaan Mountain area above Colorado City, Arizona. Sightings have also been reported from north of Highway 9 in the park, in the Deer Trap Mountain area above Zion Lodge, and around Twin Brothers and in Twin Canyon.

Habitat in the park is being assessed, and a biological panel will meet on completion of the assessment. No translocations were made between 1991 and 1996, and none is planned in the immediate future. Zion National Park selected the wait-and-see option for now.

Wind Cave National Park

The Black Hills area that includes Wind Cave National Park was an historic range of bighorn sheep. The species was extirpated from the Black Hills and all of South Dakota by the 1920s. The park was fenced in 1903, thus isolating the small area of potential habitat for bighorn sheep in the park. At least one animal, probably from restored populations in Custer State National Park crossed the fence into the park. The skull of this animal, a ram, was found on the northern Rankin Ridge in the park in the early 1960s.

Most of the park consists of rolling, open grassland and ponderosa pine (*Pinus ponderosa*) forest and only one small steep, rocky canyon might support bighorn sheep. The scientific committee that visited the park on 1 April 1991 estimated that the size of suitable bighorn sheep habitat in the park was only about 0.65 km^2 or only a tiny fraction the recommended smallest size of a restoration site. The very small area of suitable habitat within the park and fenced isolation from other herds to the north prompted the committee to recommend the area be eliminated from further consideration for restoration (Vyse et al. 1995). The park staff concurred with this suggestion.

CHAPTER FIVE

KEY RESEARCH FINDINGS AND MANAGEMENT IMPLICATIONS

The relative success of all prior restorations was evaluated in order to evaluate the factors that contributed to the highest success. First, the factors related to success or failure of all prior translocations of bighorn sheep on National Park Service land and elsewhere in the 6-state region were investigated. This investigation was the largest analysis of prior translocations of bighorn sheep (n = 100 prior translocations were analyzed). The analysis was based on a survey answered by managers of states, the U.S. Bureau of Land Management, National Park Service, U.S. Forest Service, and U.S. Fish and Wildlife Service.

The review indicated that the populations that were placed in desert habitats (almost all in southern Utah) were the most successful and grew at an annual average net increment of 10% ($\lambda = 1.10$).[6] The annual growth rate of new populations that were placed in Rocky Mountain habitats was only 2%. The annual growth rate of new populations that were placed in prairie badlands habitats was 4% (Figure 5.1). This pattern is not attributed to taxonomic differences but to the large, rugged and remote patches of habitat with few roads that are grazed by few domestic livestock that are found in the cold deserts of southern Utah. These cold deserts are the best

[6] λ is the net average growth gain or increment for a population. λ = Nt/Nt-1, where Nt = population size at year 5, Nt-1 = population size at year t-1.

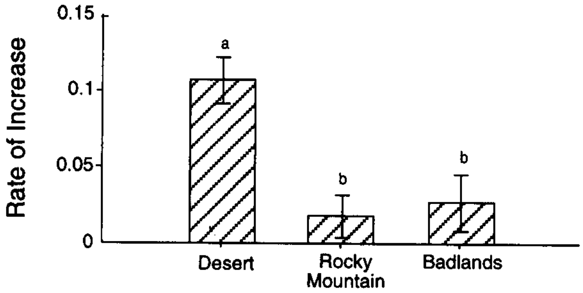


Figure 5.1. Growth rates of translocated bighorn sheep released into desert, Rocky Mountain, and prairie badlands habitats.

remaining restoration areas for bighorn sheep in the United States. Conversely, the smallest patches of suitable habitat were found in the prairie badlands of North and South Dakota.

Successful translocated populations were defined as 100 or more animals present at the end of the study in 1997, moderately successful as 30–99, and unsuccessful were those that were extirpated (n = 0) or fewer than 29 animals at the end of the study. Distance from domestic sheep was negatively correlated with the success of translocations (Singer et al. 1998a). The translocated populations were twice as successful when they were not placed near domestic sheep. Translocated populations on the same range with domestic sheep or 6 ± 2 km or less from domestic sheep were the least successful. The extent of migration affected the persistence of the translocated population. All of the fully migratory groups were successful; but only 81% of the partially migratory groups and 65% of the nonmigratory groups were successful. Grazing by domestic cattle was negatively correlated with success, although the effect on success was not as large by grazing cattle as by domestic sheep. Twenty-seven percent fewer translocated groups were successful when cattle grazed the area than when no cattle grazed the area.

Based on findings of this study, we conclude bighorn sheep should be translocated to large, undisturbed patches of habitat at a distance of more than 20 km from domestic sheep. Any proximity of less than 8 km of domestic sheep from occupied habitat of bighorn sheep should be strictly avoided. Distances of 8–12 km between domestic sheep and bighorn sheep apparently pose a moderate risk. Cattle should not graze the same range with bighorn sheep. Holding bighorn sheep in enclosures before release, i.e., soft releases, is not recommended and was discontinued years ago as a poor practice in most areas (Wilson and Douglas 1975, 1980; Desert Bighorn Council 1990). Too few such *soft releases* (only 3) were made to permit analysis. Also, in this study, the evidence for the effect of augmentations on success was equivocal.

The second approach to testing restoration success was an intense analysis of 31 translocations on or adjacent to National Park Service areas in the 6-state region prior to this restoration initiative. The second analysis, unlike the first, included a retrospective assessment of the area of suitable habitat in the patches where bighorn sheep were released (Singer et al. 1998b). Only 55% of these prior released groups grew steadily (only 39% numbered more than 100 in 1997), and 39% failed (extirpated or declined to remnant status, defined as less than 30). Population growth rates and largest population sizes (i.e., success) were correlated with larger N_e of the founder group, the number of different source populations represented in the founder group, and early contact with a second population. The probability of successful new colonizations of additional patches was greater when the released population increased rapidly, with more years since the release, when the released population was migratory, when few barriers (water, dense vegetation, developments) were present, and when the terrain between patches was rugged and broken.

The initial predictions of Griffith et al. (1989) were supported. Success was greater when founder sizes were large (Griffith et al. 1989) and when animals were from mixed sources. Placement of founder groups into clusters of large habitat patches that favored migration between subpopulations were recommended. Founders should be released into habitat patches that are 10 km or farther apart. Early contact with another population correlated with rapid population growth and high dispersal of translocated populations (Singer et al. 1998a). When the distances between two founder populations were only a few kilometers, the last released group sometimes abandoned its release site immediately to join the other animals, thus negating the restoration into the release site. Establishment of residency for 2–3 or more years prior to contact with another released population seemed to be ideal.

The effect of metapopulation spatial structures on persistence is complex. The cluster or metapopulation structure promoted early contacts between subpopulations that in turn promoted rapid population growth and rapid dispersal rates. Given the same fixed area of habitat and in contrast to the original expectations, modeled persistence was longer in a single large patch than in several small habitat patches that equaled the same total area (Gross et al. 1998a). Managers do not have the option of arbitrarily breaking apart patches of habitat. If managers of large landscapes have the option of restoring a single large patch of suitable habitat rather than restoring a complex of five habitat patches that combined are as large as the area of the large patch, restoration of the single large patch is preferable. Modeling demonstrated that persistence was greater when bighorn sheep were translocated into several (3 or more) patches than when populations were translocated into only one patch (Gross et al. 1998b). Managers should promote or protect connections and interchanges between the patches through removal of barriers, prohibition of development (canals, super highways, impoundments), and the prevention of encroaching dense cover.

Each translocation of a new founder group posed disease risk because a novel pathogen may be introduced into any new group. To reduce this risk, the founder animals should come from the same source over a short period, so that the disease background of the founder group is consistent. However, the source population's disease history could change over a long period of time and later present a risk if augmentations were to occur into the new restoration sites.

No panacea or absolute guarantees exist for restoration. For example, mixing source stocks may promote population growth rates and success of founder groups, but taking animals from only one source stock may reduce the risk of introducing a novel pathogen. Deciding between mixing stocks versus using only one stock may present a dilemma for managers.

The results from this study did not reveal any one single unequivocal minimum viable numbers of bighorn sheep. The results support any manager who seeks 300 or more animals because populations of fewer than 300 animals may lose genetic heterozygosity (Fitzsimmons et al. 1995) and their persistence may be threatened by severe or moderate epizootics (Gross et al. 1998a,b). The size of a target population depends on the expected severity and frequency of disease. If disease is not an issue, a population size of 100 may be a reasonable goal. Restoration into patches of at least 500 km^2 ($\pm$90) of suitable habitat increased the success rate of restorations (Singer et al. 1998a) and restorations into patches of this size or larger are recommended. Restoration to a single, small patch of habitat of less than 30–40 km^2 of suitable habitat lowered the success rates of restorations and should be discouraged.

TAXONOMICS

Morphometric analysis indicated that the Audubon's or Badlands subspecies of bighorn sheep that Cowan (1940) proposed was based on limited sample sizes and was not well supported. Museum specimens from this now extirpated population demonstrated differences no greater than differences that occur within the Rocky Mountain subspecies (Ramey and Wehausen 1995). The researchers recommended the two groups be synonomized. Whether or not the extirpated population was uniquely adapted to the prairie badland environment will never be known. Localized populations should be preserved whenever possible under the assumption that they may possess unique adaptations.

A cold desert group of bighorn sheep was identified from the Great Basin and southern Utah. The cold desert animals justified a separate race or perhaps a separate subspecies (Ramey and Wehausen 1995, 1998). The implications for managers is that only native, indigenous populations to southeastern Utah (i.e., only the Canyonlands and North San Juan populations or secondary or tertiary translocated populations from these stocks) should be used as source stocks for restoration into southern Utah.

DISEASES

This research supported the original contention (Foreyt and Jessup 1982; Godson 1982; Foreyt 1989; Callan et al. 1991; and others) that disease is the most profound cause of failure of bighorn sheep translocations and that seemingly, disease is usually transmitted from domestic sheep (Gross 1998a,b; Singer et al. 1998a,b,c). One of the six intensively studied populations, the Beaver Creek herd, near Dinosaur National Monument, was subjected to an epizootic introduced to the group by one of the radio-collared rams in fall 1993. During a foray the ram probably came in close contact with a herd of domestic sheep. About half of the population died during winter 1993–94, although ram .311 that introduced the pathogen survived the epizootic. A second population, the Needles herd of Canyonlands National Park, is in the thirteenth year of chronically low lamb mortality from a pathogen. The pathogen or pathogens responsible for either the initial die-off (1984–85) or the chronic lamb mortality since then have not been identified (Williams et al. 1995; Singer et al. 1998c), although domestic sheep first grazed the apparent source site of the epizootic in 1984. Bluetongue, PI-3, and Pasteurella titers were higher in the Needles herd than in nearby other herds, and one or more of these pathogens may be responsible. The agent targets only young animals, because adult survivorship has not differed between this herd and nearby healthy herds in recent years (Singer et al. 1998c).

The epidemic of infectious keratoconjunctivitis (IKC) in mule deer (*Odocoileus hemionus*) in Zion National Park was also investigated (Dubay 1997). The IKC outbreak seemed to have run its course by 1994–96. The *Moraxella ovis* that contributed to the outbreak in mule deer was probably not transmitted to bighorn sheep. IKC was not observed in 12 examined bighorn sheep in the park.

VISITOR DISTURBANCES

Desert bighorn sheep may habituate more to road traffic (vehicles and mountain bicycles) along the heavily used White Rim and Shafer trails of Canyonlands National Park than in more remote areas (Papouchis et al. 1998). Desert bighorn sheep responded less to vehicles and mountain bikes with a flight response in the more heavily used area. But there was no evidence of habituation to hikers. Bighorn sheep fled twice as far from a hiker than from a vehicle. A hiker elicited flight by desert bighorn sheep in 60% of encounters, but vehicles elicited flight in only 20% of encounters. Bighorn sheep took flight at a mean distance of 116 m from the road. The animals generally ignored road traffic when they were farther than 792 m from the road. Desert bighorn sheep kept at an average distance of about 136 m farther from the road in the heavily used area than in more remote areas.

CONSERVATION BIOLOGY

In accord with the original expectations, dispersal rates and successful new colonizations were greater when founder groups were placed into landscapes with few barriers to travel between patches, i.e., into areas with open habitats, few impoundments or large rivers, few or no highways, and few or no large human developments between the patches (Singer et al. 1998a). Dispersal and (initial) colonization rates were higher than suggested by the literature and indicated that under the proper conditions, bighorn sheep can and do disperse.

Modeling suggested dispersal rates (i.e., connectedness) between habitat patches affected persistence less than other parameters (Gross et al. 1997). The elimination of dispersal between patches, however, such as occurs when encroaching conifer cover, a water impoundment, or a highway totally blocks travel across the intervening corridor, reduced persistence and gene flow.

Seasonal migration patterns in translocated populations, unlike sedentariness or year-round residency on the same range, induced faster population growth rates and higher dispersal rates. Any management that effects seasonal migrations is strongly recommended and may include the removal of barriers to potential travel, easements, prescribed burning, and the placement of animals in restoration sites with several seasonal ranges.

Alternate breeding strategies by the study populations in Beaver Creek, Canyonlands and Badlands National Parks, and Waterton Canyon were observed and were consistent with the observations of Hogg (1984, 1987). Such breeding by subdominant males increases the ratio of the genetically effective number to total population size (N_e:N) and thus reduces the goals for minimum viable populations for genetic purposes. But the research also supported the extreme polygyny model of Geist (1971) and lower N_e:N ratios only for a northern climates study area in Denali National Park, Alaska. This research suggested that reproductive strategies by rams are related to area and probably climate differences (Singer et al. 1998a).

Two investigations of genetic heterozygosity were conducted (Buskirk and Johnson 1994; Fitzsimmons et al. 1995, 1997; Ramey 1998). Heterozygosity was positively related to genetically effective number (N_e) in eight bighorn sheep herds in Wyoming (Fitzsimmons et al. 1995, 1997). The heterozygosity of smaller populations and of populations less than 300 individuals was lower (Fitzsimmons et al. 1995). But there was no evidence of extreme inbreeding or of any extensive loss of heterozygosity in two populations that passed through population bottlenecks for about two decades (Ramey et al. 1998). As in most bighorn sheep in deserts, heterozygosity was low in the bighorn sheep population in Zion National Park. Heterozygosity was also low in the population in Grand Teton National Park. This population may be inbred. Ramey et al. (1998) concluded there was little immediate danger of inbreeding in any of the other park populations. The maintenance of high heterozygosity was the consequence of the brevity of bottlenecks of only two to four generations and selection that favored heterozygosity (Ramey et al. 1998).

Genetic heterozygosity positively correlated with horn growth in rams that were older than 8 years (Fitzsimmons et al. 1995), which is the age at which rams are more likely to breed. Because total horn size is closely associated with dominance and breeding success in bighorn sheep, higher individual genetic heterozygosity may influence male reproductive success in populations with diverse heterozygosity. Low genetic heterozygosity in the long-term can be expected to reduce the ability of the population to respond to changing conditions.

The studies of genetic heterozygosity and individual fitness in rams and ewes were inconclusive, mostly because of limited sample sizes (Singer and Zeigenfuss 1998). The animals in the Canyonlands study area were of limited use for testing the hypotheses because variation at the examined loci between individuals was low. The genetic diversity of the marked animals varied too little to obtain useful regressions. Rams also proved to be a difficult study subject because fitness is a relative term applicable only to that study population, thus greatly limiting the number of useable ram samples for correlations. The investigators recommend that additional necessary samples be gathered, preferably from populations such as in Badlands National Park where individuals varied in genetic heterozygosity (Singer and Zeigenfuss 1998).

GIS-BASED HABITAT MODELS

The first retrospective test of the habitat model of Smith et al. (1991) was only 50% successful. The success of only four of eight translocations was predicted by the model (Johnson and Swift 1995). But these researchers then modified the original model with more realistic parameters. The modifications included a relaxation of horizontal visibility from 80% to 62%, and a relaxation of criteria of what constitutes dense vegetation and development barriers to bighorn sheep. The modifications (Johnson and Swift 1995), with the exception of the area change, were applied to the 15 assessments in parks conducted from 1994 through 1996. Further testing of the modified model is still in progress. Some initial data suggest 96% of all radio locations of desert bighorn sheep in a portion of Canyonlands National Park was in the area classified as suitable habitat by the model (Zeigenfuss et al. 1998).

A study was also conducted of the effect of resolution of GIS data on model estimates. The authors concluded that low resolution digital GIS maps (30 m and 3-arc-second DEMs) significantly underestimated escape terrain and thus estimates of suitable habitat for bighorn sheep (Sweanor et al. 1998). The biases were greater in certain habitats, for example, the badlands ecotype.

ACKNOWLEDGMENTS

This restoration would not have been possible without the efforts of Drs. Robert Schiller and Dan Huff of the Intermountain Region of the National Park Service. They wrote the first of two proposals for the Natural Resource Preservation Program (NRPP) funding. Robert Schiller served as the National Park Service project coordinator from 1990 to 1995, when he went to Grand Teton National Park. We also thank two park superintendents, Denny Huffman of Dinosaur National Monument and Irv Mortenson of Badlands National Park, for hosting the first science committees. Along with Walter Dabney of Canyonlands National Park, these superintendents provided the study approval and logistic support for several of the most significant studies to be conducted in their parks. Following the transfer of Robert Schiller, GIS specialist Michelle Gudorf served as regional National Park Service coordinator. The assistance of the restoration coordinators Steve Petersburg (Dinosaur National Monument), Craig Hauke (Canyonlands National Park), Bruce Bessken (Badlands National Park), Roger Andrasik (Theodore Roosevelt National Park), and Terry Peters (Bighorn Canyon National Recreation Area), and later Steve Cain (Grand Teton National Park) was greatly appreciated. Several park resource managers participated in the preparation of restoration plans, logistic support of research, and restoration. They included the already mentioned National Park Service coordinators and Tom Clark, Rick Harris, Rick Lasko, Jack Lindsay, Patrick Perrotti, Clive Pinnock, Bruce Rogers, William Sloan, and Leslie Spicer. Michelle Gudorf conducted all of the GIS-based analyses of habitat with assistance from park-based GIS specialists Eric Gdula, Lex Newcomb, Jennifer Norton, and Therese Johnson (resource specialist). Abby Miller, Deputy Associate Director of Natural Resource Stewardship and Science, and Robert Moon, Chief Natural Resources and Technology, Intermountain Region, of the National Park Service critically assisted with the preparation of this report.

Francis Singer of the U.S. Geological Survey (formerly National Biological Service) was the biological coordinator and advisor throughout the restoration, except for the restoration in Glen Canyon National Recreation Area and Zion National Park where Henry McCutcheon of the U.S. Geological Survey served as the biological coordinator. Francis supervised the research, wrote the second NRPP and the CANON, Inc., proposals and coordinated the scientific advisory committees, biological panels, and report preparations. Patricia Sweanor compiled the GIS and the biological panel's recommendations for each National Park System unit. Mike Moses of the U.S. Geological Survey coordinated the census model development and coordinated aspects of the field data collection by research crews. Kay McElwain of the Natural Resource Ecology Laboratory and Dora Medellin of the U.S. Geological Survey typed, formatted, and edited the report. The report was reviewed by Vern Bleich, Gillian Bowser, Ray Boyd, Charles Douglas, William Dunn, Henry McCutcheon, Patricia Sweanor, and John Wehausen. However, the authors take sole responsibility for all opinions expressed and any errors.

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Veterinarians Mike Miller, Colorado Division of Wildlife, Terry Spraker, Colorado State University, and Elizabeth Williams, Wyoming Fish and Game Department, sampled animals and made recommendations for disease considerations during restoration.

A large group of scientists and biologists provided time and effort to assist the National Park Service with the restoration of bighorn sheep. The early advisory committees helped shape the direction of the restoration. Foremost in this group of austere and world-renowned specialists was Peter Brussard (University of Nevada) who sat on the Badlands National Park committee. Peter helped with setting the tone for reviews and recommended many of the members for subsequent committees. Dennis Murphy (Stanford University) guided two of the committees, including the seminal Colorado Plateau group. Vern Bleich (California Department of Fish and Game) and Joel Berger (University of Nevada) were instrumental throughout the entire restoration. Other advisory committee members who contributed significantly to the end product included William Adrian (Colorado Division of Wildlife), Fred Allendorf (Montana State University), James Bailey (Colorado State University), Michael Bogan (U.S. Geological Survey), Steve Buskirk (University of Wyoming), Charles Douglas (University of Nevada, Las Vegas), N. Thompson Hobbs (Colorado Division of Wildlife), Thomas Smith (Brigham Young University), Dave Stevens (National Park Service), Charles Van Riper III (U.S. Geological Survey), Ernie Vyse (Montana State University), and Gary White (Colorado State University).

All biological panel members contributed greatly to the direction of restoration and to restoration plans in the parks. Particularly influential were Joel Berger, Vern Bleich, William Dunn (New Mexico Department of Fish and Game), Mike Miller, and Rob Ramey, II (University of Colorado), each of whom sat on two panels. Other panel members greatly contributed to the effort, including: Roger Andrasik, Susan Bellew, Ted Benzon, Bruce Bessken, John Bissonette, Ann Blankenship, Leon Bogedahl, Steve Buskirk, Judy Cordova, Steve Cordts, Joe Cresto, William De Vergie, Charles Douglas, William Dunn, Tom Easterly, John Ellenberger, John Emmerich, Charles Eustace, Rick Harris, Susan Hauke, Lynn Irby, Van Graham, John Gross, Michelle Gudorf, David Jaynes, Bert Jellison, Chip Jenkins, William Jensen, Therese Johnson, Robert Kissell, Laurie Lee, Jack Lindsay, E.J. Lowrey, Tom Lytle, Jeff Madison, Don Masden, Craig McCarty, Kathleen McKay, Norm McKee, Karen McKinlay-Jones, Mike Moses, Rick Nolan, Jennifer Norton, Matt Obradovich, James Olterman, Jay Parks, Patrick Perretti, Terry Peters, Steve Petersburg, Glenn Plumb, Dale Reed, Kim Reid, Mike Reynolds, Bruce Rogers, Robert Schiller, Richard Sherman, Linda Siebert, Francis Singer, William Sloan, Dr. Terry Spraker, D.V.M., Shawn Stewart, Patricia Sweanor, Kate Symonds, Tom Voss, Curtis Warrick, Elizabeth Williams, and Bob Woyewodziz.

We also thank the 46 biologists, specialists, and managers that met in Grand Junction in August 1995 to make recommendations to the National Park Service on source stocks and translocation procedures. We particularly thank Dave Jessup, D.V.M. (California Department of Fish and Game), for leading the workshop on diseases and source stocks; Joe Cresto (Bureau of Land Management), for leading the workshop on domestic livestock and bighorn restoration; Roger Andrasik for leading the session on national park needs; and Vern Bleich for leading the session on translocation procedures. Many biologists and biological technicians contributed to the field research. They included Susan Bellew, Steve Cordts, Kevin Fox, Scott Gamo, Therese Johnson, and William Sloan from the National Park Service; Peggy Anderson, Tony Arnold, David Barnett, Michelle Bourassa, Steve King, Mike Moses, Christopher Papouchis, and Francis Singer from the U.S. Geological Survey; and John Gross and Kate Symonds from the Natural Resource Ecology Laboratory at Colorado State University.

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Appendix A. Types of Assistance with Restoration of Bighorn Sheep Requested by 18 National Park System Units, 1 May 1991

NPS unit	Restoration and restoration protocol	Habitat assessments and habitat management	Diseases and livestock non-native caprids[a]	Population dynamics and population regulation	Genetic viability
Arches NP	x		x	x	
Badlands NP	x	x			x
Bighorn Canyon NP	x			x	x
Black Canyon of the Gunnison NM	x		x	x	
Canyonlands NP	x		x	x	
Capitol Reef NP	x				x
Colorado NM	x				x
Curecanti NRA	x		x	x	
Dinosaur NM	x	x		x	x
Glacier NP	x	x		x	x
Glen Canyon NRA	x	x	x		x
Grand Teton NP				x	x
Mesa Verde NP		x	x	x	
Rocky Mountain NP					
Theodore Roosevelt NP	x	x			x
Wind Cave NP	x	x			
Yellowstone NP			x	x	
Zion NP		x	x		

NPS unit	Limiting factors of population	Population persistence	Response to disturbance by visitors	Interspecific competition	Census	Predators
Arches NP			x			
Badlands NP	x			x	x	
Bighorn Canyon NP			x			
Black Canyon of the Gunnison NM						
Canyonlands NP			x	x		
Capitol Reef NP					x	
Colorado NM					x	
Curecanti NRA					x	
Dinosaur NM					x	
Glacier NP		x				
Glen Canyon NRA					x	
Grand Teton NP	x	x	x			
Mesa Verde NP						x
Rocky Mountain NP						
Theodore Roosevelt			x	x		
Wind Cave NP					x	
Yellowstone NP			x	x		
Zion NP						x

NM = National Monument; NP = National Park; NRA = National Recreation Area.
[a]Included escaped mouflon (*Ovis musimon*) in Black Canyon of the Gunnison NM and introduced non-native mountain goats in Grand Teton NP.

Appendix B. Reports Produced During This Restoration Initiative

Arches National Park:

Sloan, W.B. 1995. Herd history of the desert bighorn sheep of Arches National Park. Canyonlands National Park, Moab, Utah. 9 pp.

Sweanor, P.Y., M. Gudorf, F.J. Singer, S. Bellew, S. Buskirk, J. Cresto, B. Dunn, J. Gross, J. Guymon, C. Hauke, K. McCoy, N. Mckee, K. McKinlay-Jones, M. Moses, R. Nolan, S. Petersburg, R. Ramey II, B. Rodgers, B. Sloan, and B. Woyewodzic. 1995. Bighorn sheep habitat assessment of the Greater Canyonlands and Arches National Parks. National Park Service and National Biological Service cooperative report. Canyonlands National Park, Moab, Utah. 57pp.

Badlands National Park:

Sweanor, P.Y., M. Gudorf, F.J. Singer, T. Benzon, J. Berger, B. Bessken, S. Cordts, C. Douglas, M. Moses, G. Plumb, R. Sherman, and E. Williams. 1995. Bighorn sheep habitat assessment of the Greater Badlands National Park area. National Park Service and National Biological Service cooperative report. Badlands National Park, Interior, South Dakota. 66pp.

Plumb, G. 1996. Restoration plan: Rocky Mountain bighorn sheep at Cedar Pass, Badlands National Park. National Park Service Report. National Park Service and National Biological Service cooperative report. Badlands National Park, Interior, SD. 30pp.

Bighorn Canyon National Recreation Area:

Gudorf, M., P.Y. Sweanor, F.J. Singer, A. Blankenship, V. Bleich, T. Easterly, J. Emmerich, C. Eustace, L. Irby, D. Jaynes, B. Jellison, R. Kissell, J. Lindsay, J. Parks, T. Peters, K. Reid, S. Stewart, and T. Voss. 1996. Bighorn sheep habitat for the Greater Bighorn Canyon National Recreation Area. National Park Service and National Biological Service cooperative report. Bighorn Canyon National Recreation Area, Lovell, Wyo. 43pp.

Black Canyon of the Gunnison National Monument:

Bellew, S. 1995. A demographic study of bighorn sheep located in the Gunnison River Gorge, Colorado. 1937–1995. Curecanti National Recreation Area, Gunnison, Colo. 34pp.

Sweanor, P.Y., M. Reynolds, M. Gudorf, F.J. Singer, B. Dunn, R. Harris, C. Jenkins, D. Masden, C. McCarty, M. Miller, and D. Reed. 1995. Bighorn sheep habitat assessment of the Greater Curecanti National Recreation Area and Black Canyon of the Gunnison National Monument.

National Park Service and National Biological Service cooperative report. Curecanti National Recreation Area, Gunnison, Colo. 49pp.

Canyonlands National Park:

Sloan, W.B. 1995. Herd history of the desert bighorn sheep of Canyonlands National Park. Canyonlands National Park, Moab, Utah. 29pp.

Sweanor, P.Y., M. Gudorf, F.J. Singer, S. Bellew, S. Buskirk, J. Cresto, B. Dunn, J. Gross, J. Guymon, C. Hauke, K. McCoy, N. Mckee, K. McKinlay-Jones, M. Moses, R. Nolan, S. Petersburg, R. Ramey II, B. Rodgers, B. Sloan, and B. Woyewodzic. 1995. Bighorn sheep habitat assessment of the Greater Canyonlands/Arches National Park. National Park Service and National Biological Service cooperative report. Canyonlands National Park, Moab, Utah. 57pp.

Capitol Reef National Park:

Bellew, S. 1995. History and demographics of several desert bighorn sheep herds in and near Capitol Reef National Park. Capitol Reef National Park, Torrey, Utah. 19pp.

Norton, J., P.Y. Sweanor, M. Gudorf, F.J. Singer, L. Bogedahl, T. Cox, K. Duffy, C. Hauke, E.J. Lowrey, N. Mckee, R. Nolan, M. Obradovich, B. Sloan, T. Spraker, and C. Warrick. 1995. Bighorn sheep habitat assessment of the Greater Capitol Reef National Park area. Capitol Reef National Park, Torrey, Utah. 29pp. (preliminary report).

Sloan, W. 1996. A study and restoration plan: Desert bighorn sheep, Capitol Reef National Park. Capitol Reef National Park, Torrey, Utah. 5pp.

Colorado National Monument:

Graham, V. 1995. Colorado Bighorn Sheep Restoration Management Plan: Colorado National Monument – Black Ridge herd unit update. Colorado National Monument, Fruita. 12pp.

Gudorf, M., P.Y. Sweanor, F.J. Singer, V. Bleich, J. Cordova, C. Hauke, L. Lee, T. Lytle, P. Perrotti, S. Petersburg, and B. Sloan. 1995. Bighorn sheep habitat assessment of the Greater Colorado National Monument area. National Park Service and National Biological Service cooperative report. Colorado National Monument, Fruita. 52pp.

Sloan, W. 1995. A herd history of the bighorn sheep of the Colorado National Monument and the Black Ridge Colorado. Colorado National Monument, Fruita. 16pp.

Graham, V., and P. Perrotti. 1996. Interagency restoration of desert bighorn sheep in and around the Colorado National Monument. Colorado National Monument, Fruita, Colo. 5pp.

Curecanti National Recreation Area:

Bellew, S. 1994. Dillon Pinnacles bighorn sheep, herd history. Curecanti National Recreation Area, Gunnison, Colo. 9pp.

Sweanor, P.Y., M. Reynolds, M. Gudorf, F.J. Singer, B. Dunn, R. Harris, C. Jenkins, D. Masden, C. McCarty, M. Miller, and D. Reed. 1995. Bighorn sheep habitat assessment of the Greater Curecanti National Recreation Area and Black Canyon of the Gunnison National Monument. National Park Service and National Biological Service cooperative report. Curecanti National Recreation Area, Gunnison, Colo. 49pp.

Dinosaur National Park:

Bellew, S. 1994. Bighorn sheep herds of the Green River corridor. Dinosaur National Monument, Colo. 45pp.

Bellew, S. 1994. Bighorn summary report: Dinosaur National Monument, Colo. 18pp.

Sweanor, P.Y., M. Gudorf, S. Chambers, F.J. Singer, J. Bissonette, J. Ellenberger, T. Johnson, S. Petersburg, R. Schiller, and K. Symonds. 1994. Bighorn sheep habitat assessment of the Greater Dinosaur National Monument area. National Park

Service and National Biological Service cooperative report. Dinosaur National Monument, Colo. 65pp.

Bellew, S., J. Ellenberger, B. deVergie. 1995. Interagency bighorn sheep restoration plan Green River Corridor group: 1995. Dinosaur National Monument, Colo. 16pp.

Glen Canyon National Recreation Area:

The park staff prepared the habitat assessment independently and utilize the information in management of bighorn populations. However, a formal report has not been prepared.

Grand Teton National Park:

Park managers have chosen to prepare the habitat assessment independently following additional surveys and research on existing populations, including studies of mortality rates and genetics.

Mesa Verde National Park:

Bellew, S. 1995. Mesa Verde bighorn sheep. Mesa Verde National Park, Mesa Verde, Colo. 10pp.

Johnson, T.L., M. Gudorf, F.J. Singer, R. Schiller, C. McCarty, T. Lytle, D. Reed, and W. Dunn. 1995. Bighorn sheep habitat assessment of the Greater Mesa Verde National Park area. National Park Service report. 25pp.

Gudorf, M. 1997. Reassessment for the 1996 Chapin Mesa burned area: Bighorn sheep habitat assessment of the Greater Mesa Verde National Park Area. Mesa Verde National Park, Colo. 6pp.

Gudorf, M. 1997. Reassessment of bighorn sheep habitat in areas of the 1996 Chapin Mesa fire. Mesa Verde National Park Service report. 6pp.

Sloan, W. 1997. The status of bighorn sheep within Mesa Verde National Park, Colorado. 5pp.

Theodore Roosevelt National Park:

Andrascik, R. 1996. Restoration plan: California bighorn sheep. Theodore Roosevelt National Park. North Unit, 1996. Theodore Roosevelt National Park, Medora, ND. 31 pp.

Sweanor, P.Y., M. Gudorf, F.J. Singer, R. Andrascik, W.F. Jensen, C.W. McCarty, M. Miller, D. Reed, and R. Schiller. 1994. Bighorn sheep habitat assessment of the Greater Theodore Roosevelt National Park area. National Park Service and National Biological Service cooperative report. Theodore Roosevelt National Park, Medora, ND. 55pp.

Zion National Park:

Smith, T.S. 1991. Preliminary evaluation of desert bighorn sheep habitat in Zion National Park, Utah. National Park Service report. 26pp.

McCutcheon, H.E. 1994. An interim report on the status of desert bighorns in Zion National Park, Utah. 17pp.

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Six reports prepared by five scientific advisory committees on overall project design and by one scientific interagency committee on restoration procedures:

Berger, J., P. Brussard, and E. Vyse. 1995. Badlands National Park. Pages 2–4 *in* Bighorn sheep in the

Rocky Mountain Region. Reports of the five scientific advisory committees. National Biological Service, report to the National Park Service. Ft. Collins, Colo.

Hobbs, N.T., F. Singer, T. Smith, and D. Stevens. 1995. National parks in Colorado. Pages 5–18 *in* Bighorn sheep in the Rocky Mountain region. Reports of the five scientific advisory committees. National Biological Service, report to the National Park Service, Ft. Collins, Colo.

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The observation of bighorn sheep in their natural settings in the canyons, slick rock, badlands and rocky ledges of the national parks of the Intermountain Region stir the imaginations of the U.S. public. The restoration of this decimated and fragmented species to its former vast range in the parks has been a formidable task that is being undertaken by the National Park Service and U.S. Geological Survey. This book summarizes the many assessments, biological advise by experts, planning, research, and restorations that were conducted from 1990 through 1997 in the Intermountain U.S. West.

It is our most sincere hope that this volume will also be useful to other land and resource managers who aim to restore bighorn sheep or other similar depleted vertebrates.

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