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COLORADO BIGHORN SHEEP MANAGEMENT PLAN 2009–2019

J. L. George, R. Kahn, M. W. Miller, B. Watkins

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COLORADO DIVISION OF WILDLIFE
TERRESTRIAL RESOURCES

COLORADO BIGHORN SHEEP MANAGEMENT PLAN

2009–2019

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FOREWORD

The Colorado Bighorn Sheep Management Plan is the culmination of months of work by Division of Wildlife biologists, managers and staff personnel. It is designed to provide overall guidance and direction on the conservation and restoration of statewide bighorn resources in the coming decade for Colorado's wildlife managers, and to be a reference document that summarizes and synthesizes bighorn sheep information from Colorado and elsewhere. This management plan is intended to compliment annual Division of Wildlife work plans, annual budgets, Long Range Plans, and Director and Commission guidance. It is not intended to supersede any specific Statutes, Commission Policies, Regulations, or Administrative Directives regarding bighorn sheep or their management in Colorado.

Thomas E. Remington, Director
Colorado Division of Wildlife

Cover photo credits: Rocky Mountain bighorn sheep near Georgetown (S32). Photo by John Legnard.

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Rocky Mountain bighorn ewes and lambs in the Rampart herd (S34).
Photo by Matthew P. Johnston.

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COLORADO BIGHORN SHEEP MANAGEMENT PLAN

EXECUTIVE SUMMARY

Bighorn sheep (*Ovis canadensis*) are likely the most iconic of Colorado's wildlife species. Bighorn sheep are the Colorado state mammal and are also the symbol of the Division of Wildlife (DOW). Today, Rocky Mountain bighorn sheep (*O. canadensis canadensis*) and desert bighorn sheep (*O. c. nelsoni* or *O. c. mexicana*) provide hunting recreation for approximately 300 hunters annually and are among the most sought after watchable wildlife species in the state. Given this high level of interest and status it is imperative that the DOW develop policies, guidelines and procedures that are designed to maintain and, to the extent possible, increase Colorado's bighorn populations.

HISTORY

It is difficult to estimate how many wild sheep were present in Colorado in pre-settlement times. Journals of explorers indicate great numbers of sheep in both the mountainous areas and along the Front Range. Since the late 1800s the general trend of wild sheep populations in Colorado and throughout the west has been downward. Historical statewide estimates of 7,230 bighorn sheep in 1915, 3,200 in 1958 and 2,200 in 1970 reflect this trend; there were an estimated 6,045 bighorns in Colorado in 1988, and in 2007 there were an estimated 7,040 bighorn sheep statewide.

One reason for the apparent increase in Colorado's bighorn populations is a longstanding effort to trap and translocate wild sheep to establish new populations or supplement existing populations. From 1945–2007, there were 147 releases of bighorn sheep in Colorado resulting in the translocation of 2,424 animals (excluding bighorns moved to research facilities). The majority of these transplants occurred during the 1980s. In 2007, translocated herds accounted for 54% of the total herds in Colorado and 48% of the total statewide bighorn population. Most transplant herds (78%) had less than 100 sheep in 2007 and relatively few of these herds have shown the sustained growth needed for long-term viability. Extant herds that have been supplemented with translocated sheep accounted for 24% of the total herds and 30% of the total statewide bighorn population in 2007.

Disease has often been implicated in periodic "all-age" die-offs and sustained bouts of poor lamb survival in Colorado bighorns. In the late 1800s, die-offs were reported in bighorn sheep in the Tarryall Mountains and elsewhere, and in 1933 a die-off extirpated bighorns in what is now Dinosaur National Monument. In 1953, the state's largest bighorn population residing in the Tarryall and Kenosha Mountains experienced a die-off caused by pneumonia that reduced the population from an estimated 1,000 animals (some observers have said 2,000) to 30 within two years; the Tarryall-Kenosha epidemic likely extended from a 1952 outbreak on Pikes Peak. The causes of these early die-offs are hard to verify retrospectively, but contact with domestic livestock that led to the introduction of exotic diseases and parasites seems the most logical explanation. Agents of disease suspected to be responsible for historical epidemics have included "scabies" (also called "scab" or "mange", and caused by mite infestations), "nasal bots" (parasitic fly larvae), "hemorrhagic septicemia" (later termed "pasteurellosis", a bacterial infection), and lungworms (a natural parasite of bighorns).

Other problems such as unregulated harvest, overgrazing, competition with other livestock, plant community succession and forestation of native ranges, and increasing human development of winter ranges have been identified as contributing to bighorn sheep declines either historically or presently.

In the 1970s, the DOW embarked on a series of research and management programs to reduce lungworm in the state's bighorn herds to see if this could have a positive effect on populations by increasing lamb survival. About 20% of the state's herds were treated with various drugs; some herds were treated annually and others more sporadically. In some cases the treatments were just administered as part of trap and transplant operations. Comparisons of treated versus untreated herds from the 1970s and 1980s and found no difference in population trends among herds. Similarly, a field experiment in the 1990s examined treated and untreated herds in the Southeast Region using a crossover design and also found no relationship between drug treatment for lungworm and changes in ewe/lamb ratios. As a result of this body of work, the practice of baiting and treating of sheep has been greatly reduced around the state since the late 1990s.

Bighorn sheep managers generally agree that bacterial pneumonia (also called "pasteurellosis") is the main reason for Rocky Mountain bighorn sheep population declines across much of the west in recent decades. Pasteurellosis is caused by several closely-related species of bacteria in the *Pasteurellaceae* family (e.g., *Mannheimia haemolytica*, *Bibersteinia trehalosi*, and *Pasteurella multocida*), and infections can sometimes be facilitated or exacerbated by other bacteria, viruses, or parasites. There are a number of strains of *Pasteurellaceae* commonly carried by domestic sheep and goats that are highly pathogenic to bighorns, and introduction of a pathogenic strain or another novel pathogen into populations can cause all-age die-offs and lead to low lamb recruitment. In some instances, this syndrome of low lamb survival can last for a decade or more. Once introduced, pathogenic bacterial strains apparently can sometimes persist in survivors of the initial epidemic, and thus infected bighorns may also serve as a source of infection for other herds and populations through natural movements and translocations. In addition, there appear to be situations where carriers of pathogenic *Pasteurellaceae* or other agents are responsible for lamb pneumonia in the absence of all-age epidemics.

Based on a substantial volume of literature, one of the most important aspects of wild sheep management is to keep these species separated from domestic sheep and goats. There are a number of bighorn herds in the state that are in close proximity to active or vacant domestic sheep allotments, particularly on the Western Slope. An extensive set of recommendations has been developed for managing bighorn and domestic sheep on shared ranges to help minimize the risk of epidemics in bighorns.

Interspecies competition with other wild ruminants, particularly mountain goats (*Oreamnos americanus*), also may affect bighorn population performance. In 1998, a committee was convened to develop a statewide plan and strategy for both bighorn sheep and mountain goats. Key elements of that strategy have been practiced in most parts of the state.

RECENT WORK (2003–2007)

The estimated statewide number of Rocky Mountain and desert bighorn sheep has declined slightly over the past seven years from about 8,000 in 2001 to 7,400 in 2007. It should be noted that bighorn herd and population estimates in Colorado come from a variety of sources including mark-resight inventories, helicopter surveys, coordinated ground counts and general observations by DOW personnel, sheep hunters and the public. Population estimation for bighorn sheep generally is difficult and tends to be less precise than what we have for other big game species. This is due to two factors: bighorns tend to hide when they encounter aircraft (helicopter and fixed-wing) and this makes them much more difficult to detect than deer or elk; and bighorn habitat is typically rougher and more difficult and dangerous to survey from the air.

Statewide Projects: Between 2005 and 2007, a total of 25 bighorn sheep "unit summaries" were written by biologists with assistance from regional staff. These summaries brought together known information on distribution, population, hunting seasons, inventory methods and management concerns. Pending the result of some of the population estimation projects noted below, spreadsheet models are in development for certain populations for future use as tools to aid in setting license numbers.

In September 2005, the DOW and the Colorado Woolgrowers Association began meeting to discuss interactions between domestic and bighorn sheep and mutually acceptable approaches for minimizing conflict. A series of subsequent meetings on this topic included participants from the Colorado Department of Agriculture, Colorado Woolgrowers Association, Rocky Mountain Bighorn Society, US Forest Service (USFS) and Bureau of Land Management (BLM), as well as DOW. The goal of this forum was to develop strategies for safeguarding both Colorado's bighorn sheep resources and the domestic sheep industry. Efforts within Colorado have been complimented by a broader effort undertaken in 2007 by the Western Association of Fish and Wildlife Agencies on this topic.

Several other projects have been initiated to learn about ways to improve bighorn herd health. An ongoing study by the DOW to characterize and compare *Pasteurellaceae* strains within and among Colorado bighorn populations was funded in 2006. Better data on the occurrence and distribution of pathogenic strains will assist in making informed decisions about translocations and may lead to strategies for recovering herds after all-age die-offs. A study looking at supplementing bighorn sheep with trace minerals, specifically selenium, was conducted between 2001 and 2005 in the Tarryall and Kenosha Mountains, St. Vrain, Collegiate Peaks and Arkansas River bighorn sheep herds. Other opportunistic field trials evaluating the utility of long-acting antibiotics and vaccines in improving lamb survival also have been undertaken more recently.

Bighorn sheep management and research has benefited from recent changes in rules governing the use of special "Auction and Raffle" (A&R) license revenues. In 2005, the Colorado General Assembly passed changes in the A&R process that allow more flexibility in spending these funds for bighorn sheep research and management. Since that time, auction and raffle funds have been an increasingly important source of funding for bighorn projects statewide.

DOW staff members met extensively during 2005–2006 to try and develop and reach consensus on a Trap and Transplant Directive that would give more clear direction and process to the trapping and movement of all species in the state, including bighorn sheep. As part of this effort, Terrestrial staff developed "Bighorn Sheep Capture and Translocation Guidelines" summarizing information on bighorn capture and making recommendations for trapping and transplanting. These guidelines are being used by the Terrestrial biologists in bighorn management planning.

STATEWIDE BIGHORN SHEEP MANAGEMENT PLANNING & MANAGEMENT GOALS

The DOW will strive to manage Colorado's bighorn sheep resources to maintain or increase the size of existing herds and populations with emphasis given to the larger herd complexes ("core populations") that represent groups of interconnected herds within a mountain range. As a framework for management planning, DOW will establish or modify bighorn sheep Game Management Units (GMUs) for all herds in the state and then establish bighorn sheep Data Analysis Units (DAUs) representing larger interconnected herd complexes that are regarded as populations. Once bighorn DAUs have been defined, work will begin to designate primary ("Tier 1") and secondary ("Tier 2") core populations, and to determine metapopulation (i.e., connectivity between populations) and range extension potential within and among DAUs. Whereas management emphasis will be placed on Tier 1 and Tier 2 populations, this categorization will not preclude management of smaller herds of local importance. Management planning will include establishing provisional objectives, developing and implementing inventory and monitoring protocols, developing and maintaining a centralized, statewide database of bighorn sheep data, and developing formal bighorn sheep DAU management plans. The DOW will collaborate with the US Forest Service, the Bureau of Land Management, the National Park Service, and private land owners to develop bighorn sheep DAU plans in those places where bighorn ranges include the lands managed by these entities.

In addition to establishing bighorn population management plans, the ***DOW will seek to improve specific aspects of bighorn sheep management in Colorado and to address specific factors identified as potential obstacles to achieving management goals*** as follows:

Inventory & Population Estimation: The DOW will strive to regularly survey all bighorn sheep DAUs with frequency and intensity dependent on their prioritization.

Population & Harvest Management: The DOW will strive to manage bighorn sheep herds and populations to be healthy and self-sustaining while providing hunting and wildlife viewing opportunities. Bighorn populations (= DAUs) will be managed using a management by objective process that includes formulation of population and sex ratio objectives for each DAU. The DOW will establish ram hunting harvest objectives to provide quality hunting experiences and will manage ewe harvest via hunting and translocation to control population numbers to meet DAU objectives while minimizing impacts on social structure and "legacy" movement patterns. Hunting seasons will be timed to provide quality hunting experiences while protecting natural biological processes and minimizing conflicts with other wildlife recreation activities.

Capture & Translocation for Restoration & Augmentation: The DOW will strive to capture or acquire bighorn sheep to gather biological information or to translocate individuals for reintroduction into historic or suitable habitat or to augment existing populations using established guidelines. The DOW will use translocation as a tool to increase numbers, extend range, and/or increase genetic diversity as feasible while minimizing the introduction of disease or increasing the risk of disease exposure or otherwise harming source or recipient populations.

Habitat Management: The DOW will strive to protect all bighorn habitat that is currently in good condition and to take advantage of opportunities to improve habitats in fair or poor condition or where other factors are limiting the potential for bighorn populations to thrive. The DOW also will work with public land management agencies and private land managers to use natural and prescribed fires and mechanical treatments to restore degraded habitats to a higher quality, and to influence development of new roads and trails, improvements of existing roads and trails, and uses of all-terrain vehicles to minimize exposure of bighorns to excessive activities of people and associated domestic animals (e.g., dogs and pack goats).

Health Monitoring & Management: The DOW will strive to prevent epidemics of introduced and endemic diseases that adversely impact bighorn population performance and viability, and to recover bighorn populations from the effects of epidemic and endemic diseases that have sustained effects on bighorn survival and recruitment.

Bighorn Sheep–Domestic Livestock Disease Interactions: The DOW will strive to prevent introductions of infectious or parasitic diseases from domestic livestock that could adversely impact bighorn population performance and viability. The DOW will work cooperatively with the USFS and BLM and private landowners to minimize the potential for bighorn sheep to contact domestic livestock whenever practicable.

Bighorn Sheep–Mountain Goat Interactions: The DOW will strive to manage mountain goat populations and distribution via the DAU planning process to limit their expansion into Tier 1 and Tier 2 bighorn sheep DAUs. The DOW will establish mountain goat DAUs for all existing or anticipated mountain goat populations in the state that do not present concerns to the viability of Tier 1 and Tier 2 bighorn sheep populations. To better understand and manage mountain goats, the DOW will develop and implement standard inventory and monitoring protocols for mountain goats that are sustainable on a consistent and long term basis, and will determine survival rates, recruitment rates, and population densities for selected mountain goat populations in Colorado.

Predation: The DOW will strive to prevent predation from severely impacting or extirpating introduced or established bighorn populations, but also will allow natural predation on unhealthy individuals to aid bighorn populations in recovering from epidemics.

Chapter 1

HISTORICAL TRENDS, STATUS, & LIMITING FACTORS: AN OVERVIEW

Bighorn sheep (*Ovis canadensis*) are likely the most iconic of Colorado's wildlife species. Bighorn sheep are the Colorado state mammal and also are the symbol of the Colorado Division of Wildlife (DOW). Today, Rocky Mountain bighorn sheep (*O. c. canadensis*) and desert bighorn sheep (*O. c. nelsoni* or *O. c. mexicana*) provide hunting recreation for approximately 300 hunters annually and are among the most sought after watchable wildlife species in the state. Colorado is fortunate to have the largest estimated number of Rocky Mountain bighorn sheep in the United States (Beecham and Reynolds 2007). The estimated 2007 statewide, posthunt Rocky Mountain and desert bighorn populations were 7,040 in 79 herds and 325 in 4 herds, respectively (Table 1). In 2008, there were 66 Rocky Mountain bighorn sheep units and 4 desert bighorn sheep units in Colorado (Fig. 1). Given the high level of interest in bighorn sheep and their status, it is imperative that the DOW develop policies, guidelines and procedures that are designed to maintain and, to the extent possible, increase bighorn populations in Colorado.

History

Based on early accounts by trappers and explorers, Rocky Mountain bighorn sheep were common in Colorado prior to settlement in the mid-1800s (Moser 1962). Available evidence indicates Rocky Mountain bighorns were widely distributed and occupied suitable habitat across a range of elevations throughout the state. With increased settlement and mining booms, bighorn numbers declined rapidly in the late 1800s, likely as a result of subsistence and market hunting, habitat fragmentation and conversion, and the introduction of domestic livestock and their diseases. Concerns about declining bighorn populations resulted in bighorn sheep becoming a protected species in Colorado in 1885 (Barrows and Holmes 1990). By the early 1900s, bighorn sheep in Colorado only existed in isolated, remnant populations.

There is no documented evidence that desert bighorn sheep occurred in Colorado when European settlers first arrived. However, archeological evidence, the close proximity of historic desert bighorn populations in Utah, and suitable desert bighorn habitat in southwestern Colorado make it likely that desert bighorns (likely *O. c. nelsoni*) did historically occur in southwestern Colorado in at least small numbers (Bureau of Land Management [BLM] and DOW 1989).

Disease has been a major limiting factor for Rocky Mountain bighorn sheep in Colorado since at least the late 1800s, when novel pathogens and parasites apparently were introduced by domestic livestock (Warren 1910). Major disease-related die-offs of bighorn sheep were reported in some locations (e.g., Tarryall Mountains, Sapinero Creek, Green River, northern Front Range near Estes Park) in the late 1800s and early 1900s, and during the winter of 1923–24 (Warren 1910, Moser 1962). Undoubtedly, many early disease-related die-offs went undetected or unreported. The first well-documented all-age, disease-related die-offs occurred in 1952–1953 in the Pikes Peak (S6) and Tarryall (S27)/Kenosha Mountains (S23) bighorn populations (Moser 1962, Bear and Jones 1973). Subsequent major all-age die offs have been reported in Waterton Canyon, Alamosa Canyon (S29), Big Thompson Canyon (S57), Trickle Mountain (S10), and several other areas; most recently, die-offs were documented in the Greenland (S72) and Fossil Ridge (S70) herds in 2008. Prior to the 1970s, disease related die-offs were attributed to causes such as "hemorrhagic septicemia" (a form of pasteurellosis), scabies, and verminous pneumonia caused by lungworms (Warren 1910, Moser 1962). In more recent years, it has become increasingly evident that pasteurellosis probably has been the ultimate cause of most all-age disease-related die-offs in Colorado, with other factors such as other bacteria, viruses, lungworm, and environmental stressors including weather and nutrition being possible contributing factors in some cases. In addition to initial all-age die-offs, pasteurellosis can result in reduced lamb survival and recruitment for many years after a herd is infected; in some situations, lamb pneumonia also can

TABLE 1. Colorado bighorn sheep units and population estimates by unit or herd, 2007.

Unit	Name	Region	Origin	2007
ROCKY MOUNTAIN BIGHORN SHEEP HERDS BY UNIT				
S1	Poudre River	NE	Trans	55
S2	Gore-Eagle's Nest	NW	Suppl	100
S3	Mount Evans	NE	Native	90
S4	Grant	NE	Trans	90
S5	Beaver Creek	SE	Native	30
S6	Pike'sPeak	SE	Native	140
S7	Arkansas River	SE	Suppl	85
S8	Huerfano	SW	Trans	65
S9	Sangre de Cristo	SE, SW	Suppl	325
S10	Trickle Mountain	SW	Trans	45
S11	Collegiate, North	SE	Native	160
S12	Buffalo Peaks	SE	Suppl	200
S13	Snowmass, East	NW	Native	110
S14	Clinetop Mesa	NW	Suppl	5
S15	Sheep Mountain	SW	Native	100
S16	Cimarrona Peak	SW	Native	90
S17	Collegiate, South	SE	Native	100
S18	Rawah	NE	Trans	15
S19	Never Summer Range	NW, NE	Native	25
S20	Marshall Pass	SE	Native	75
S21	Cow Creek	SW	Suppl	125
S22	San Luis Peak	SW	Suppl	85
S23	Kenosha	NE	Native	6
S24	Battlement Mesa	NW	Suppl	30
S25	Snowmass, West	NW	Suppl	75
S26	Taylor River	SW	Suppl	70
S27	Tarryall	NE, SE	Native	100
S28	Vallecito	SW	Suppl	125
S29	Alamosa Canyon	SW	Trans	35
S30	Conejos River	SW	Suppl	75
S31	Blanco River	SW	Native	100
S32	Georgetown	NE	Suppl	400
S33	Lake Fork/Pole Mountain	SW	Suppl	90
S34	Rampart Range	SE	Trans	75
S35	Greenhorn	SE	Trans	70
S36	BellowsCreek	SW	Suppl	45
S37	St. Vrain	NE	Trans	50
S38	Apishipa	SE	Trans	70
S40	Lone Pine	NE	Trans	25
S44	Basalt	NW	Trans	100
S45	Cross Mountain	NW	Trans	0
S46	Dome Rock	SE	Native	35
S47	Brown's Canyon	SE	Trans	150
S48	Carrizo Canyon	SE	Trans	55
S49	Grape Creek	SE	Trans	225
S50	Mt. Maestas	SE	Trans	125
S51	Spanish Peaks, Culebra	SE	Trans	250
S52	Rock Creek	SW	Trans	25
S53	Bristol Head	SW	Trans	110
S54	West Elk-Dillon Mesa	SW	Suppl	100
S55	Natural Arch, Carnero Creek	SW	Trans	20
S57	Big Thompson Canyon	NE	Suppl	85
S58	Lower Poudre River	NE	Trans	20
S59	DerbyCreek	NW	Suppl	90
S60	Shelf Road	SE	Trans	150
S61	Purgatorie Canyon	SE	Trans	240
S65	Costilla	SW	Trans	400
S66	Mt. Elbert	SE	Native	125
S67	White River, South Fork	NW	Trans	40
S68	Cotopaxi	SE	Trans	60
S69	Lower Cochetopa Canyon	SW	Trans	50
S70	Fossil Ridge	SW	Trans	50
S71	West Needles	SW	Trans	75
S72	Greenland	NE	Expan	40
S73	Mount Zirkel	NW	Trans	50
S74	Glenwood Canyon	NW	Trans	35

Unit	Name	Region	Origin	2007
ROCKY MOUNTAIN BIGHORN SHEEP HERDS WITHOUT UNITS				
None	Black Canyon	SW	Trans	30
None	DeBeque Canyon	NW	Trans	40
None	DNM - *Harper's Corner*	NW	Trans	40
None	DNM - *Ladore Canyon*	NW	Trans	90
None	DNM - *Yampa River*	NW	Trans	35
None	Lower Lake Fork	SW	Suppl	10
None	Mesa Verde	SW	Trans	20
None	Mount Silverheels	NE	Trans	25
None	Rifle Hogback	NW	Trans	0
None	Pueblo Reservoir	SE	Trans	15
None	RMNP - *East Side*	NE	Suppl	75
None	RMNP - *Continental Divide*	NE,NW	Native	100
None	RMNP - *Never Summer*	NE,NW	Native	200
None	Sawpit	SW	Trans	20
None	Waterton Canyon	NE	Native	25

DNM = Dinosaur National Monument

RMNP = Rocky Mountain National Park

Unit	Name	Region	Origin	2007
DESERT BIGHORN SHEEP HERDS BY UNIT				
S56	Black Ridge	NW	Trans	75
S62	Uncompahgre (Dominguez)	SW	Trans	150
S63	Middle Dolores River	SW	Trans	30
S64	Upper Dolores River	SW	Trans	70

KEY

REGIONS:
- NE = Northeast
- NW = Northwest
- SE = Southeast
- SW = Southwest

ORIGIN:
- Native = No history of translocations.
- Suppl = Native herd that has been supplemented.
- Trans = Herd resulting primarily from translocation.
- Expan = Herd resulting from expansion of existing herd.

Pop. Est. 2007 = 2007 Posthunt population estimate:

Underline = Closed to hunting in 2008

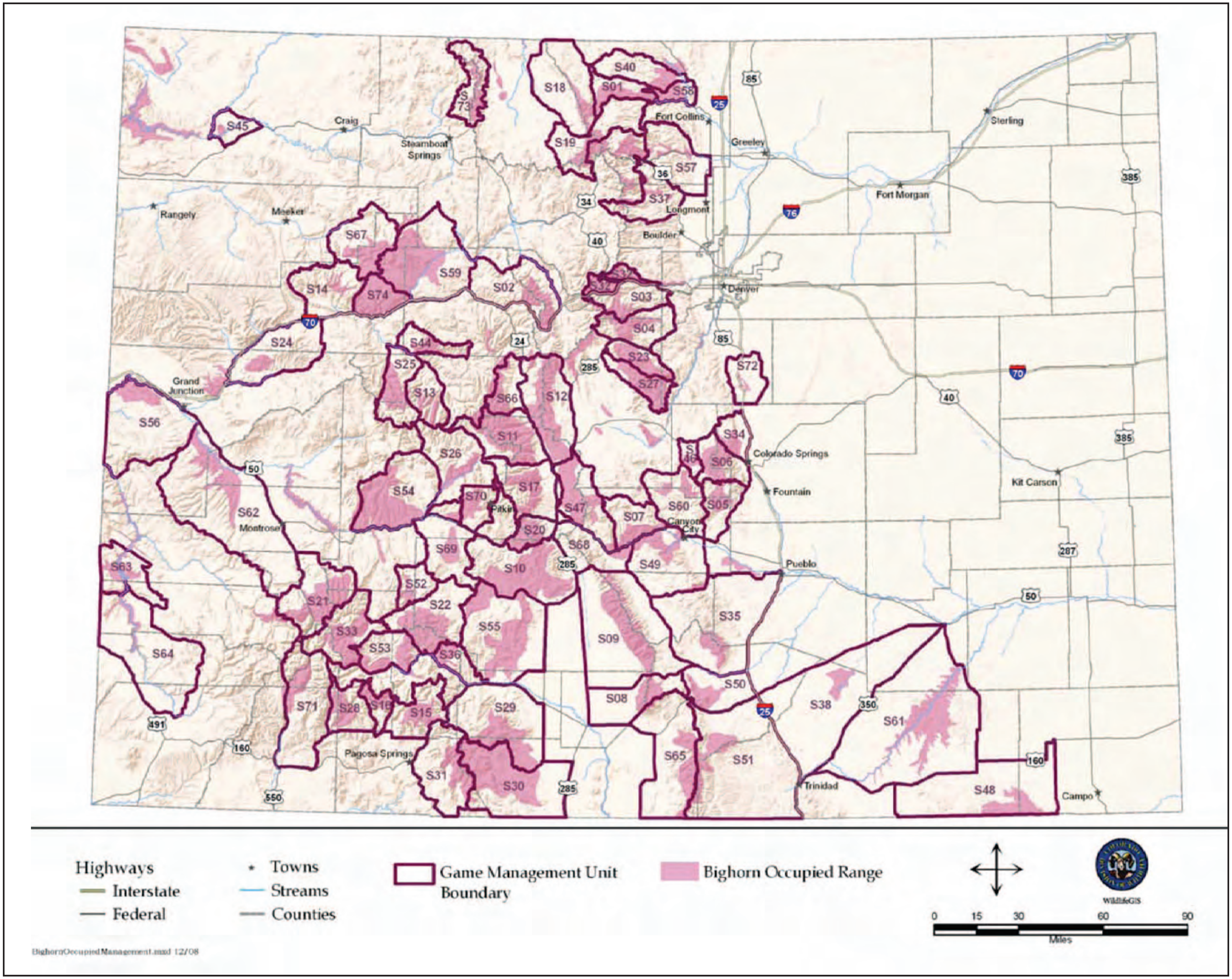

FIGURE 1. Bighorn sheep game management units and occupied bighorn sheep range in Colorado 2008.

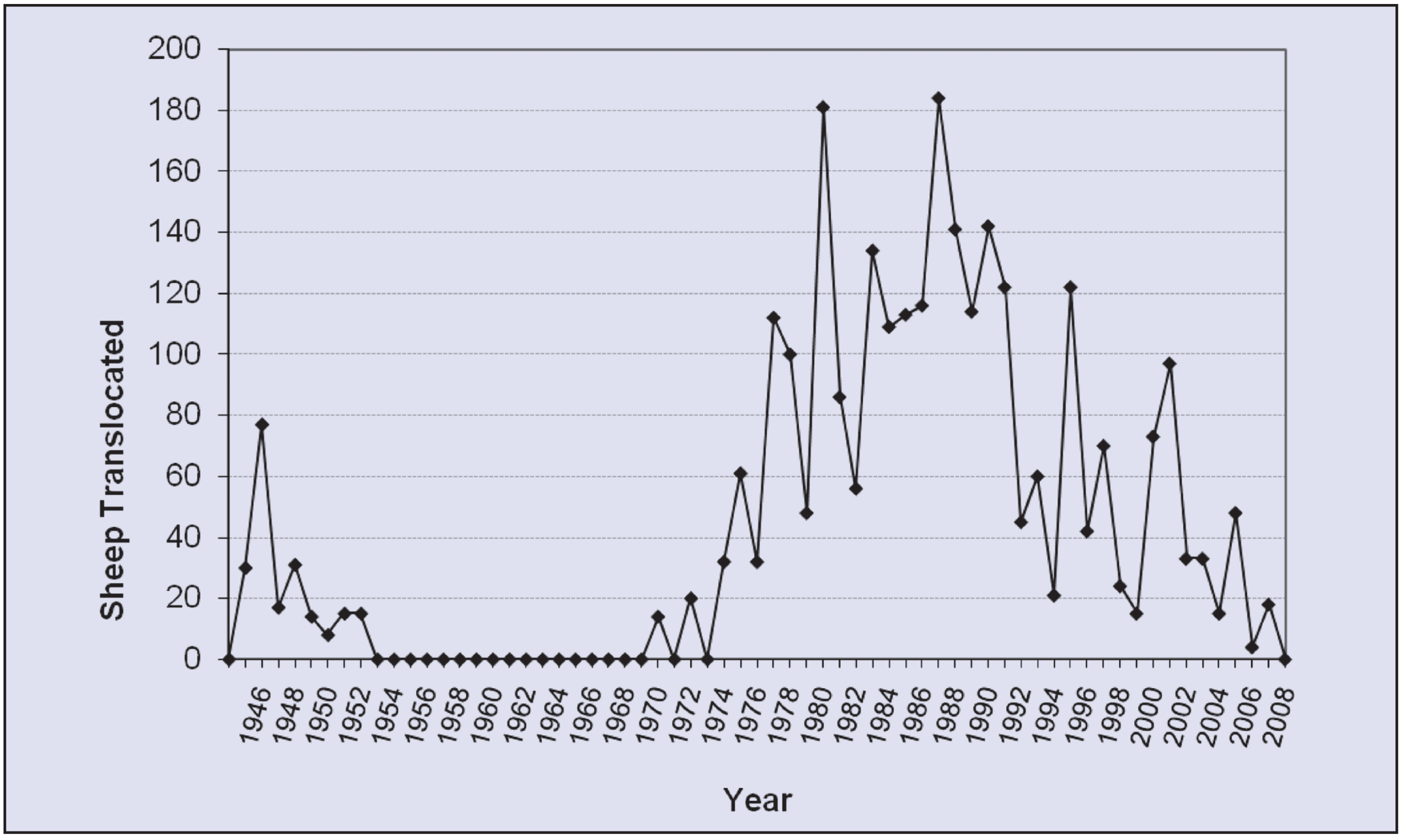

FIGURE 2. Number of bighorn sheep translocated in Colorado by year, 1946-2007.

occur in the apparent absence of an all-age epidemic. *See Health Monitoring & Management, Ch. 7.*

The first official hunting season for Rocky Mountain bighorn sheep in Colorado began in 1953 with 169 ram licenses and 58 rams harvested (Moser 1962). The following year, ewe licenses were also issued. The primary reason for opening sheep seasons was to disperse sheep to try and reduce disease transmission after the onset of a large all-age die off in the Tarryall and Kenosha herds. Sheep licenses have been issued in Colorado since 1953, and Colorado has been one of the few states and provinces to allow regular ewe harvest. From 1990-2007, an average of 126 rams (range 110 - 145) and 31 ewes (range 18 - 56) have been harvested on an annual basis. The average annual harvest rate for Rocky Mountain bighorn sheep from 1990 to 2007 was 2.5% (2% for rams; 0.5% for ewes) of the estimated posthunt population available for hunting. The first season for desert bighorn sheep opened in 1988 with an average of 5 rams harvested annually (range 2-9) from 1990-2007. No desert bighorn ewe licenses have been issued. The average annual harvest rate for desert bighorn sheep from 1990 to 2007 was 1.9% of the estimated posthunt population available for hunting. *See Population & Harvest Management, Ch. 4.*

Trapping and translocation of bighorn sheep in Colorado began in 1944 (Moser 1962). From 1944–2007, at least 2,592 bighorn sheep have been translocated from Colorado herds and 2,492 bighorns have been released in Colorado. The height of bighorn trap and translocation operations occurred in the 1980s (Fig. 2). A total of 252 sheep that originated from outside Colorado have been released in the state (mostly desert bighorns) and 352 Rocky Mountain bighorns from Colorado have been translocated to other states. In addition, 59 sheep from Colorado have been moved to DOW and Colorado State University research facilities. There have only been two releases using Rocky Mountain bighorn sheep originating from outside Colorado; both releases occurred at the same site in S65 (2 days apart) using sheep from British Columbia (Note: Rocky Mountain bighorn sheep from Alberta were also introduced behind a high fence as a private herd in GMU 105 in the 1980s). Desert bighorn sheep were first released in Colorado in 1979. All translocations of desert bighorn sheep have used sheep originating from Nevada, Arizona, or Utah and represent both *O. c. nelsoni* and *O. c. mexicana* subspecies. *See Capture & Translocation for Restoration & Augmentation, Ch. 5.*

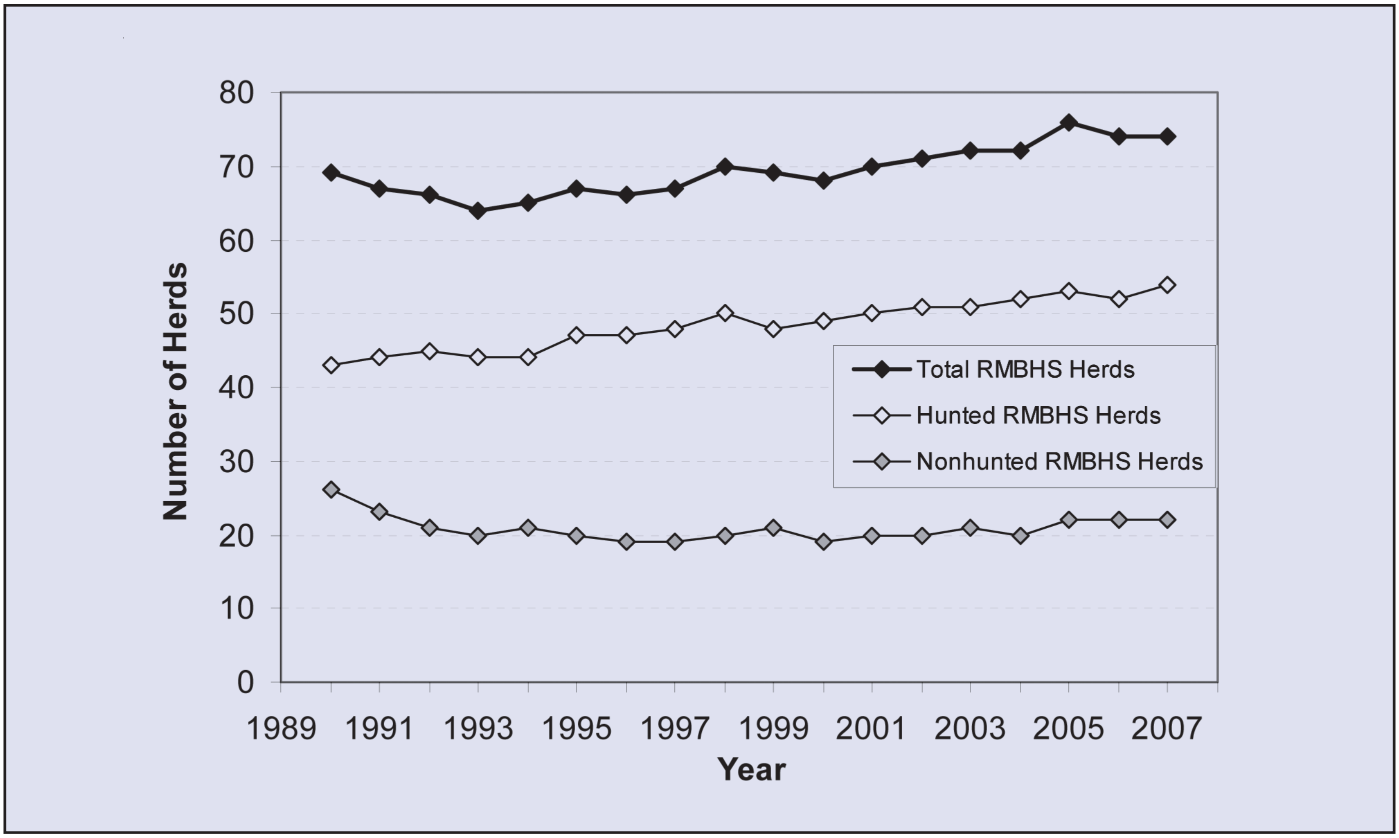

FIGURE 3. Number of Rocky Mountain bighorn sheep (RMBHS) herds in Colorado with ≥20 sheep, 1990-2007

Herd Trends

The number of bighorn sheep herds in Colorado has generally been increasing since translocations began in the 1940s. Moser (1962) reported 52 known major sheep herds in Colorado in 1956. Bear and Jones (1973) reported 33 herds in 1970 with only 25 of these herds having 20 or greater sheep. Part of the discrepancy between these herd numbers is explained by more herds being lumped together in 1970 which is more consistent with current herd designations. Bailey (1990) reported 67 RMBS herds in Colorado in 1988. From 1990–2007, the number of sheep herds with an estimated size of at least 20 individuals averaged 69 herds (range 64–76) with an average of 49 hunted herds (range 43–54; Fig. 3). During this period some sheep units were combined whereas others were divided, making year-to-year comparisons difficult. Generally, the number of hunted herds has increased over time as previously unhunted, and mostly translocated herds, became hunted. Estimated herd size for herds with 20 or greater sheep averaged 91 (average range 79–102) from 1990–2007 with a gradually decreasing trend in average herd size since 1993.

Population Trends

The DOW began making annual estimates of statewide, posthunt bighorn sheep populations in 1986 (Appendix I, Figs. 4-6). Since then, population estimates have been made for both hunted and unhunted populations. Prior to 1987, bighorn population estimates were sporadic and were often only made for hunted herds. One of the earliest, albeit dubious, statewide population estimates of 7,200 was made in 1922 (Seton 1929). Subsequent statewide Rocky Mountain bighorn sheep population estimates prior to 1986 (Moser 1962, Bear and Jones 1973, Denney 1976, Bailey 1990), indicate there was a substantial increase in the estimated statewide population in the 1980s. This increase corresponds with the increased translocation activity and an increased effort to obtain bighorn population estimates that occurred during the same period.

From 1990 to 2007, the estimated total statewide Rocky Mountain bighorn sheep population averaged 7,200 (range 6,500 to 7,600) with an average of 6,200 sheep in hunted populations (range 5,300 to 6,600) and 1,000 sheep in nonhunted populations (range 800 to 1,300). During this same period, the estimated statewide

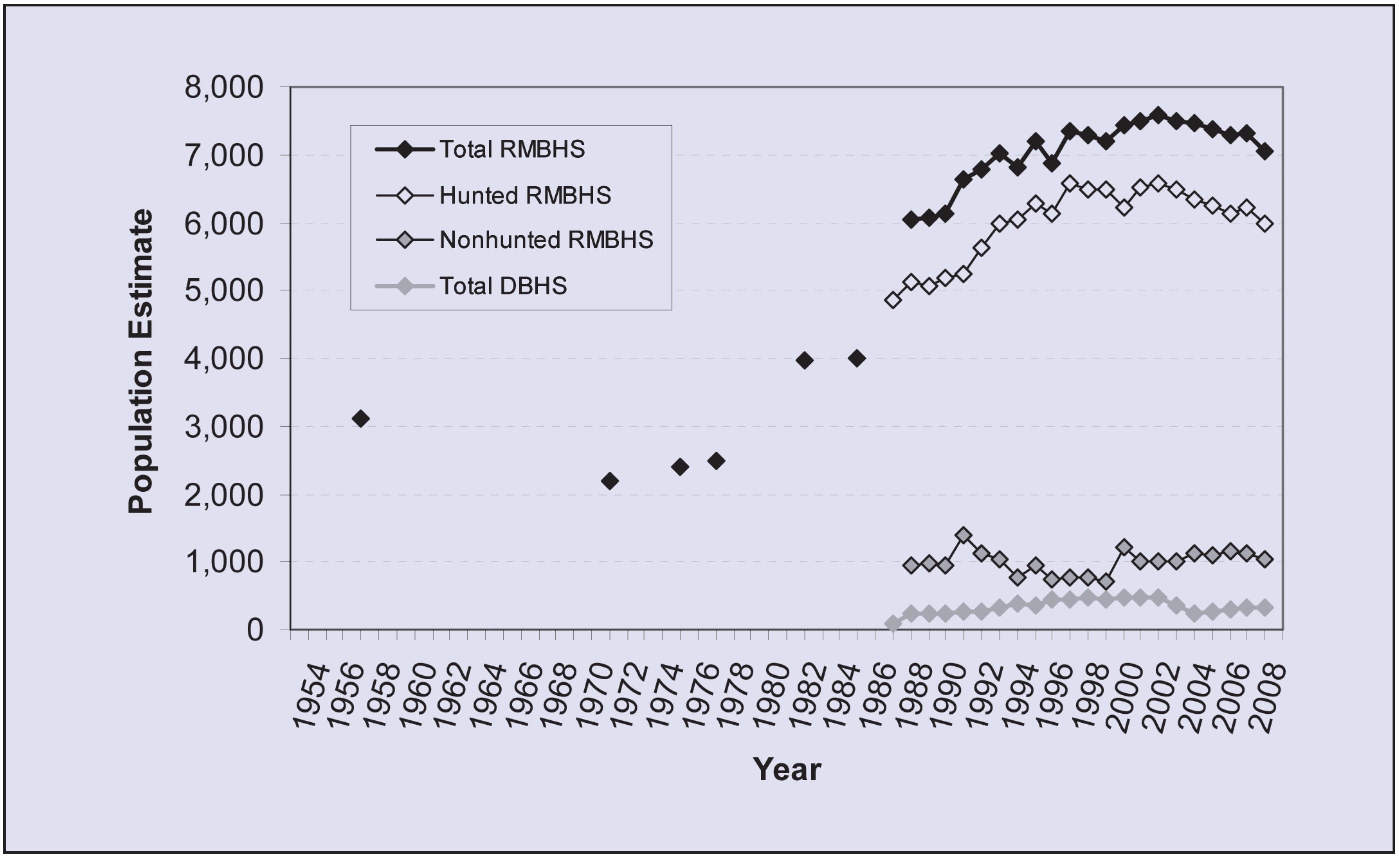

FIGURE 4. Statewide posthunt population estimates for total, hunted, and nonhunted Rocky Mountain (RMBHS) and total desert (DBHS) bighorn sheep populations in Colorado, 1953-2007.

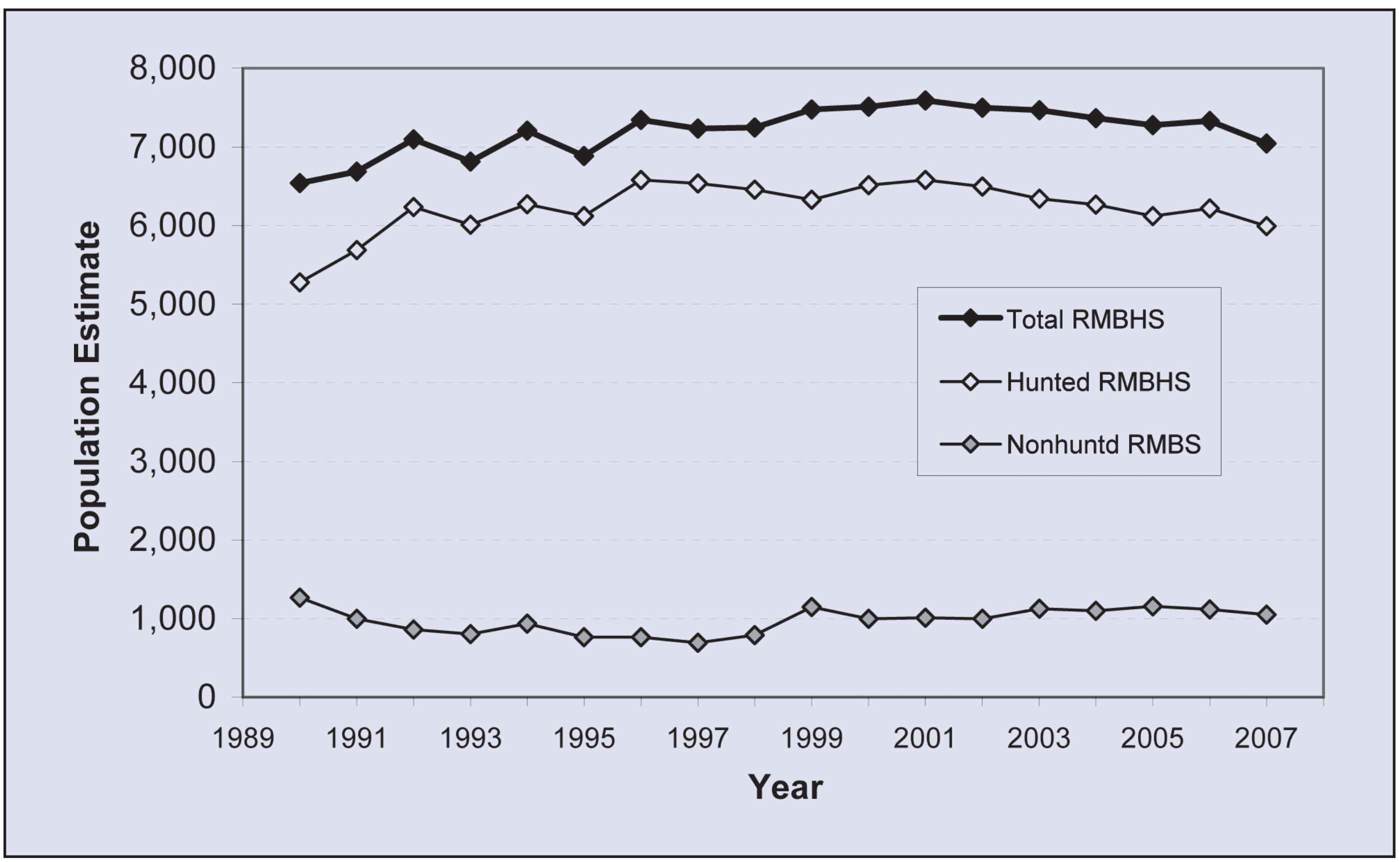

FIGURE 5. Statewide, posthunt population estimates for Rocky Mountain bighorn sheep (RMBHS) in Colorado, 1990–2007.

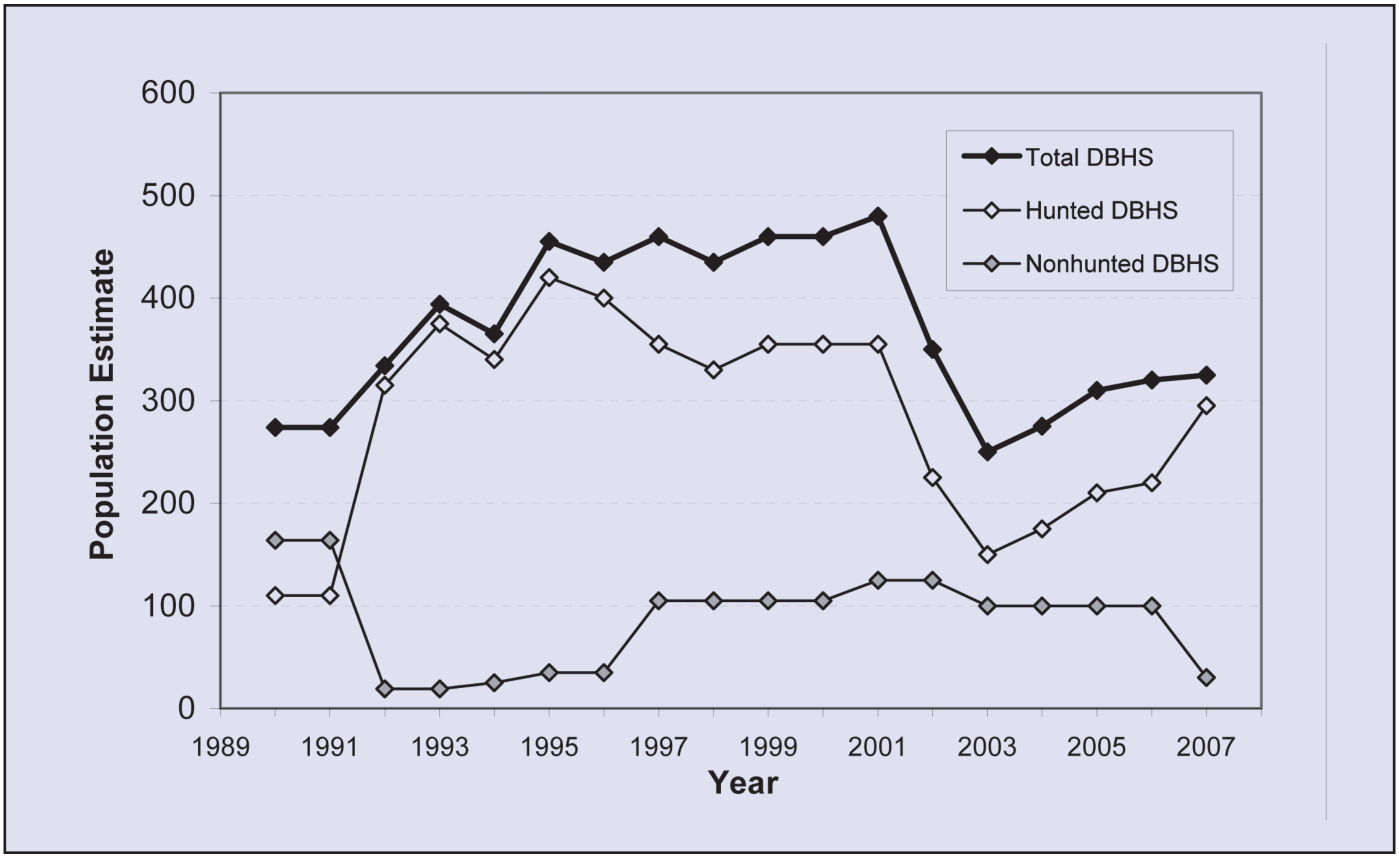

FIGURE 6. Statewide, posthunt population estimates for desert bighorn sheep (DBHS) in Colorado, 1990–2007.

desert bighorn sheep population averaged 370 (range 280 to 480) with an estimated average of 280 sheep in hunted populations (range 110 to 400) and 90 sheep in nonhunted populations (range 20 to 170).

Population Estimation

Most Rocky Mountain bighorn sheep population estimates have been based on general observation by DOW, United States Forest Service (USFS), and/or National Park Service (NPS) personnel and/or on reports by sheep hunters and interested publics. In some cases observations are simply opportunistic whereas in other cases they are based on an intentional inventory effort using ground and/or aerial surveys. Since the 1990s, estimated sizes for about 10 of the herds have been based on coordinated counts with multiple simultaneous routes that have typically been done on an annual basis. High counts at bait sites during trapping operations and during lungworm treatment have also been used for 4 or 5 herds on an annual or biennial basis. Mark-resight estimates using radio-collared sheep began in the mid-1990s and have increased in use. Mark-resight inventories using Bowden's estimator have been conducted in the Tarryall-Kenosha population (S23 and S27; George *et al.* 1996), in Rocky Mountain National Park (McClintock and White 2007), for the Upper and Lower Poudre herds (S1 and S58; Vieira 2005), the Georgetown population (S32; Huwer 2005), and the Pikes Peak population (S6; Dreher 2005), and for desert bighorns at Black Ridge (S56) (Duckett 2006). In 2006, primary methods used to estimate sizes of 79 herds were as follows: general agency and public observation – 43 herds; coordinated ground or ground + aerial counts – 15 herds; aerial counts – 11 herds; mark-resight inventories – 8 herds (note: some mark-resight inventories were done prior to 2006 and those data are still used for the 2006 estimate); and bait site observation – 2 herds.

Although population models are used on a regular basis to estimate other big game populations in Colorado, such models have received limited use for estimating bighorn sheep numbers. To be useful, population models must be based on unbiased estimates of sex and age structure, hunter harvest, and survival rates. Survival rates can sometimes be satisfactorily derived by fitting models to observed sex ratio data. Additional inputs include wounding loss. For most bighorn sheep herds in Colorado, sufficient information has not been available to reliably model populations. *See Inventory & Population Estimation, Ch. 3.*

Current Status

Colorado is fortunate to have the largest estimated number of Rocky Mountain bighorn sheep in the United States (Beecham and Reynolds 2007). The estimated 2007 statewide, posthunt Rocky Mountain and desert bighorn sheep populations were 7,040 in 79 herds and 325 in 4 herds, respectively. Rocky Mountain bighorn sheep herds were distributed by Region as follows (some herds extend across Regional boundaries but were only assigned to one Region): Northeast, 1,455 sheep in 17 herds; Southeast, 2,785 sheep in 23 herds; Southwest 1,960 sheep in 25 herds; and Northwest 840 sheep in 14 herds. Desert bighorn sheep herds were distributed as follows: Southwest, 250 sheep in 3 herds; Northwest, 75 sheep in one herd. In 2007, approximately half of the Rocky Mountain bighorn sheep herds were considered to be native or native with some supplementation whereas the remaining herds resulted directly from translocations. Based on available records, only 18 of the Rocky Mountain bighorn sheep herds existing in 2007 have not been established or supplemented by translocations at some point since 1945. All of the desert bighorn sheep herds have resulted from translocations.

Population Demographics

Population sex and age ratios have been collected for some herds. In most cases, classification is done on an irregular basis. Classification data have been collected in the summer or in the winter or in some cases during both periods. Winter classification during the breeding season is preferred because rams and ewes are less segregated and lamb survival through the first 6 months can be taken into account. Although summer classification data have some value for general information, these data have comparatively little value for modeling purposes because of potential bias in sex ratios and summer and fall mortality of lambs.

Game Management Units & Data Analysis Units, Herds & Populations

Contemporary big game management in Colorado is based on Game Management Units (GMUs) and Data Analysis Units (DAUs). Colorado has traditionally used DAUs as the basis for managing populations of deer (*Odocoileus* spp.), elk (*Cervus elaphus nelsoni*), pronghorn (*Antilocapra americana*), moose (*Alces alces*), bears (*Ursus americanus*), and mountain lions (*Puma concolor*) but not for managing bighorn sheep or mountain goats (*Oreamnos americanus*). GMUs allow localized management prescriptions for relatively distinct subpopulations of a species, whereas DAUs group GMUs to represent frequently interacting subpopulations that comprise a relatively discrete population.

Social and spatial organizational tendencies of bighorn sheep should serve as the basis for managing bighorn populations. Bighorn sheep organize themselves into matriarchal groups with seasonal segregation of ram and ewe-lamb bands and commingling of these bands into larger herds during part or all of the winter. Several relatively discrete herds within a mountain range are often interconnected, especially through movements and exchanges of rams, and thus likely represent a population with respect to genetic exchange and vulnerability to epidemics. For example, the Tarryall-Kenosha Mountains bighorn population is composed of three relatively discrete herds with separate winter ranges (Kenosha Mountains, Sugarloaf Mountain, and Twin Eagles). Within this population, there is little interchange of ewes among herds but considerable commingling and exchange of rams. In the context of bighorn social and spatial organization, GMUs should represent relatively discrete herds and DAUs should represent frequently interacting herd complexes.

Bighorn sheep and mountain goats historically have been managed on a GMU basis using bighorn sheep units (S-prefix GMUs) or mountain goat units (G-prefix GMUs). Bighorn sheep and mountain goat GMUs traditionally have been designated only for hunted herds (sometimes GMUs are subsequently closed to hunting but still retain their GMU designation). This has caused confusion because in 2008, 17 of the 26 unhunted sheep herds in the state were only identified by the name of a local geographical feature that could apply to multiple locations around the state (e.g., “Beaver Creek”, “Deep Creek”, “Brown’s Canyon”). In addition, historical records of several herds that no longer appear to exist only have been referenced by ambiguous place names. More specific records of these herds may exist, but are often buried in field office files.

Based on marked animals and telemetry data, it is well-established that there is movement and interaction between and among some bighorn sheep herds (and respective GMUs). In some cases, larger bighorn GMUs have been divided into smaller units to better control harvest and hunter distribution even though bighorns are known to regularly move between the smaller units (e.g., S23 and S27 each cover portions of the Tarryall-Kenosha Mountain population range). To be most effective and consistent, management plans and actions should consider the interaction between and among herd units (i.e., GMUs) and should focus on populations (i.e., DAUs) rather than individual herds because of the effect that management in one herd might have on another herd within the same population range.

In 2009, there were 66 designated Rocky Mountain bighorn sheep GMUs and 4 designated desert bighorn sheep GMUs (Fig. 1). Fifty-three Rocky Mountain bighorn sheep GMUs and 3 desert bighorn sheep GMUs were open to hunting in 2009. To date, no bighorn sheep DAUs have been formally identified or established; bighorn herds without designated GMUs could make the DOW's conventional DAU management approach problematic, and consequently GMUs will be established for all of Colorado's bighorn herds as part of the statewide management planning process.

Primary & Secondary Core Populations

Primary (Tier 1) core Rocky Mountain bighorn populations (to be designated as DAUs) are regarded as those large (i.e., ≥100 animals for ≥90% of the years since 1986), native populations comprised of one or more interconnected herds (in, or to be designated into, GMUs) that have received few (i.e., ≤50 animals total) if any supplemental releases of Rocky Mountain bighorn sheep in the past. In some cases, smaller (<100 animals) indigenous populations may be justifiably regarded as core populations when restoration to a larger size is deemed feasible. Performance potential in respect to factors such as habitat condition and trend, and proximity to and intensity of domestic sheep and domestic goats also should be considered. These populations likely represent those indigenous Rocky Mountain bighorn sheep populations that have maintained the greatest genetic diversity and their ranges represent habitats where bighorn populations have best been able to persist in sizable numbers despite various adversities. Examples of potential primary core populations include S6+S46+S34, S9, S11+S17+S66, S12, S22, S25+S13, S27+S23, S32, and Rocky Mountain National Park+S19+S57+S37. Primary core populations and the herds comprising those populations should be given the highest priority for inventory, habitat protection and improvement, disease prevention, and research.

Secondary core (Tier 2) bighorn populations are medium to large (i.e., ≥75 animals for ≥80% of the years since 1986 or since becoming fully established) populations comprised of one or more interconnected herds that are native or have resulted from translocations. These herds may represent indigenous or introduced bighorn sheep populations (and combinations thereof) that have less genetic diversity and more limited ranges that may or may not be able to persist in sizable numbers in the face of various adversities. Examples of potential secondary core populations include S1+S18+S40+S58, S3+S4, S7, S20, S26, S29+S30+S31, S47, S49, S50+S51+S65, S60, and S61. Secondary core populations should be given priority for inventory, habitat protection and improvement, and research over populations that are not considered primary core populations. The Commission-approved DAU process will determine which DAUs are considered to represent Tier 1 and Tier 2 populations. This categorization does not preclude management efforts directed at smaller populations of local importance.

Metapopulations, Connectivity, & Range Extensions

Given the extensive and often contiguous potential sheep habitat that existed in many parts of Colorado prior to settlement, it is very likely that most bighorn populations in the state existed as parts of large metapopulations that could have encompassed several contemporary populations (DAUs). Within these metapopulations, bighorns would have interacted over large areas and maintained high genetic diversity. It is also likely that the herds and populations comprising these historical metapopulations generally would have made greater movements between summer and winter ranges and exploited more habitat across a range of elevations than contemporary herds. With population bottlenecks resulting from disease die-offs, over-harvest, and increased human impacts on the landscape (e.g., roads, reservoirs, mines, towns, wildfire suppression, habitat conversion for domestic livestock, etc.), these metapopulations have fragmented into the relatively isolated herds that exist today with much more restricted movements.

Because of habitat conversion and fragmentation, it would be impossible in many parts of Colorado to recreate the metapopulations that likely existed historically. However, large areas of contiguous potential sheep habitat still do exist in some areas (e.g., San Juan Mountains, Collegiate and Sawatch Ranges, Sangre de Cristo and Culebra Ranges) and there is the potential in these ranges to increase connectivity between and among some herds and populations.

There are two schools of thought on increasing the connectivity of sheep herds and populations. One is that increased connectivity is beneficial from the standpoint of increased gene flow and heterozygosity. Increased connectivity could also potentially increase resilience to predation and other non-disease related mortality factors, better distribute use across suitable habitat, and foster greater mobility and exploration within occupied habitats. An opposing viewpoint is that connectivity increases the potential for introducing and spreading infectious diseases, and this risk may negate any potential benefits derived from increased connectivity. With connectivity among herds, the likelihood of a disease epidemic in one herd affecting another is greatly increased (see George *et al.* 2008 for a recent example). The increased risk of epidemics associated with connectivity may be especially large in areas where increased connectivity could increase the potential for any of the interacting subpopulations to come into contact with domestic sheep or goats as ranges expand. It follows that the connectivity of populations into metapopulations would carry similar inherent risks with potential consequences over a larger geographic area

Creating metapopulation complexes to facilitate gene flow should be a continuing goal. However, this management strategy should be tempered with the need to minimize the risk of disease introduction and spread. Although there are several areas in the state where available habitat would likely avail itself to a metapopulation management approach, there are currently few areas where such management would not greatly increase disease risks. Bighorn populations in the Sangre de Cristo and Culebra mountain ranges (i.e., S8, S9, S50, S51, S65) probably have the greatest potential to be managed as a large metapopulation, but the uncertain future of domestic sheep grazing resulting from historic land grant grazing rights in S65 make even this possibility a high risk. Alternative strategies for preventing or controlling epidemics and their aftermath would afford greater flexibility in bighorn metapopulation management.

In addition to the direct effects of habitat changes and disease outbreaks in restricting bighorn ranges and fostering fragmented and relatively sedentary herds, the loss of herd knowledge or institutional memory of migration routes and seasonal ranges has also likely occurred in many areas. This is especially likely in translocated herds where indigenous sheep populations were extirpated. Even in extant herds, herd knowledge can be lost over time as populations shrink and key adults are removed through epidemics, translocation, harvest, or natural attrition. Using translocations to extend ranges and use of available habitat by relatively sedentary bighorn herds has met with mixed results (Bailey 1990) and further work assessing and refining this management approach is needed.

Range extensions can be potentially beneficial to bighorn herds and populations, but again the benefits must be weighed not only against the possibility of increased potential for domestic sheep contact but also the possibility that a novel pathogen could be exchanged by commingling bighorns from different populations. To minimize risks of pathogen introduction, range extensions in Colorado should be done using bighorns from the general vicinity of the release area whenever possible with the intent of expanding herd ranges or populations rather than establishing metapopulation connectivity. Additional research on tools for eliminating potential pathogens from translocated bighorns may help further reduce risks associated with range extension and other translocations.

Population Limiting Factors

A number of factors may work individually or additively to limit bighorn population performance, stability, and viability. Future plans and actions for managing bighorns in Colorado will need to consider and, where relevant and feasible, address various combinations of these factors on a population-by-population basis.

Infectious Disease

The susceptibility of bighorn sheep to diseases originally introduced by domestic livestock is considered by the DOW to be the primary factor limiting Rocky Mountain bighorn sheep populations in Colorado (Hobbs and Miller 1992, George *et al.* 2008). By far the most important of these diseases is pasteurellosis caused by infections with bacteria presently classified in the genera *Mannheimia*, *Bibersteinia*, and *Pasteurella* (collectively called *Pasteurellaceae*). These infections can sometimes be exacerbated by other bacteria, viruses, or parasites. In addition to initial all-age die offs, pasteurellosis epidemics in bighorn sheep can cause long-term reductions in lamb survival and recruitment resulting in stagnant or declining populations over many years. Large areas of historic Rocky Mountain bighorn sheep habitat, particularly in the Southwest Region and to a lesser extent in the Northwest Region, remain unoccupied by Rocky Mountain bighorn sheep, most likely because of the presence of domestic sheep and frequent reintroduction of respiratory pathogens. Young Rocky Mountain bighorn sheep rams can wander long distances and are often the most likely to come into contact with domestic sheep and transmit diseases back to other herd members. Some more benign pathogens such as bovine respiratory syncytial virus (BRSV), parainfluenza-3 (PI-3), and *Mycoplasma* spp. may facilitate or increase bighorn susceptibility to pasteurellosis.

Other pathogens of concern in bighorn sheep in Colorado include bluetongue and epizootic hemorrhagic disease viruses (BTV and EHDV, respectively). These vector-borne diseases can cause some mortality in bighorns but are generally not considered limiting except possibly for small, struggling populations. In addition, contagious ecthyma, infectious keratoconjunctivitis, and paratuberculosis ("Johne's disease") occasionally occur in bighorn sheep in Colorado but these diseases are usually infrequent or are localized, and do not appear to cause large-scale losses that limit population size or productivity. *See Health Monitoring & Management, Ch. 7.*

Parasitism

Lungworm (*Protostrongylus stilesi* and *P. rushi*) and "scabies" (or "mange") mites (probably *Psoroptes* spp.) are the only parasites that have been suspected to limit Rocky Mountain bighorn sheep populations in Colorado. Verminous pneumonia caused by lungworm infestation has been considered a possible limiting factor in Colorado since the 1950s (Moser 1962). However, it has become increasingly evident that the primary effect of lungworm infection is probably to increase susceptibility to pasteurellosis rather than to cause "verminous pneumonia" per se. Lungworms are natural parasites of bighorn sheep and do not appear to compromise the overall health of bighorn sheep at typical levels of infection. Greater dispersal of Rocky Mountain bighorn sheep across available habitat can help reduce lungworm loads by reducing "hot-spot" areas where the intermediate snail host can become highly infected. The value of prophylactic lungworm treatment using anthelmintics is inconclusive (Miller *et al.* 2000) and is under further investigation (Dreher 2005).

Scabies has been implicated in some early Rocky Mountain bighorn sheep die-offs in Colorado and other western states (Warren 1910, Moser 1962). Scabies does not appear to be endemic in any of Colorado's contemporary bighorn herds, and in the future is only likely to occur via introductions of bighorns from out-of-state or in areas where bighorns come into contact with scabies-infected domestic sheep; the latter seems relatively unlikely because at present scabies appears to have been essentially eradicated from domestic sheep in Colorado. Although scabies can cause bighorn die-offs, it appears likely that historical scabies outbreaks were concurrent with infectious disease epidemics. *See Health Monitoring & Management, Ch. 7.*

Habitat Quantity and Quality

Carrying capacity of available habitat will ultimately limit any bighorn population that is not otherwise limited by other factors. Moreover, all other biological limiting factors except perhaps novel diseases are likely to be a function of habitat quantity and quality to some degree. Adequate forage and rugged escape terrain in areas with good visibility are probably the most important habitat components for bighorn sheep. Overall spatial distribution, especially as it relates to infectious disease transmission, also can be important. In general, most Rocky Mountain bighorn sheep populations in Colorado do not appear to be obviously limited by availability of suitable habitat. However, many bighorn sheep herds and populations in Colorado do not appear to fully use the suitable habitat available to them for reasons that are not clear. Small herds often become sedentary, and their continued, concentrated use of small patches of available habitat could result in paradoxical density-dependent effects wherein habitat actually does become limiting despite an apparent abundance of potentially suitable habitat being available.

Winter habitat is most likely to be limiting for Rocky Mountain bighorn sheep in Colorado. During winter, bighorns often are forced to concentrate on windswept ridges or move to lower elevations where human impacts on historic sheep habitat are more pronounced. Bighorn sheep die-offs that appeared to be due to malnutrition unrelated to disease have seldom been reported in Colorado, but extreme winter conditions may help to precipitate all-age mortality (e.g., Feuerstein *et al.* 1980). It is much more likely that the effects of inadequate forage resources would be manifested as reduced lamb recruitment or increased susceptibility to disease rather than overt all-age mortality from malnutrition; however, the poor lamb recruitment that typically follows pneumonia epidemics does not appear to be a result of ewe malnutrition.

Rocky Mountain bighorn sheep prefer open habitat with good visibility in proximity to escape terrain to avoid predators. Advanced vegetative succession in the absence of fire probably has affected some Rocky Mountain bighorn sheep populations as maturing forests and shrublands increasingly restrict the availability of preferred ranges (Wakelyn 1987).

Trace mineral deficiencies, particularly selenium deficiency, have been suggested as a possible limiting factor for Rocky Mountain bighorn sheep (Carpenter and Ramey 2007). Most bighorn sheep populations exist and have evolved in granitic and often glaciated environments that are characteristically low in Se, I, Cu, Na and other elements. Historically, movements to lower elevations may have afforded some bighorn populations an opportunity to consume higher levels of trace nutrients than their contemporary counterparts that tend to remain at higher elevations. It also has been suggested that increases in acid rain during the 20th century may have decreased availability of some minerals (Hnilicka *et al.* 2002). At this time, evidence that trace mineral deficiency is limiting Rocky Mountain bighorn sheep populations in Colorado or surrounding states is equivocal and mostly anecdotal, and research studies have been inconclusive (Carpenter and Ramey 2007).

There is little doubt that habitat loss and fragmentation by roads, recreation areas, residential developments, domestic sheep allotments, etc. has had and will continue to have major impacts on Rocky Mountain bighorn sheep populations. These impacts are often insidious and may manifest themselves through other limiting factors. *See Habitat Management, Ch. 6.*

Predation

Predators of adult bighorn sheep in Colorado include mountain lions, coyotes (*Canis latrans*), black bears, and domestic dogs. Additional predators of lambs include bobcats (*Lynx rufus*), golden eagles (*Aquila chrysaetos*), and red foxes (*Vulpes vulpes*). Predation is usually considered much less of a limiting factor for Rocky Mountain bighorn sheep populations than disease and habitat. However, in some cases mountain lion predation in particular can be a significant local mortality factor. Lion predation is primarily a concern with small, isolated bighorn herds where alternate prey (e.g., deer and elk) are limited and in populations already suffering from poor recruitment from other causes such as disease. For most Rocky Mountain bighorn sheep herds in Colorado, there is little evidence that lion predation is limiting sheep numbers. It is likely that abundant numbers of deer and elk act to help buffer mountain lion predation on most Rocky Mountain bighorn sheep herds. However, lion predation has been found to be a significant source of Rocky Mountain bighorn sheep mortality in some field studies (Vieira 2005) and in some cases numerous losses may be attributable to a single lion. Several studies have shown that lion predation is more likely to be a limiting factor for desert bighorn sheep than Rocky Mountain bighorn sheep populations (Rominger *et al.* 2004, Kamler *et al.* 2002, McKinney *et al.* 2006). Based on cause-specific mortality of radio-collared sheep, lion predation is considered to be the primary factor limiting desert bighorn sheep populations in S56 and S63 and is likely a significant cause of mortality in S62 and S64 (Creeden and Graham 1997, Banulis 2005, Wait 2005, Watkins 2005).

Reduced Genetic Diversity and Heterozygosity

Because many of Colorado's Rocky Mountain bighorn sheep herds exist as small, isolated bands, often arising from translocations using only a few founder animals, genetic diversity has been a concern for bighorn managers. Reduced heterozygosity and genetic drift are more likely to occur in small, isolated populations and could result in inbreeding depression and increased susceptibility to disease. The number of founders could influence the genetic diversity of translocated Rocky Mountain bighorn sheep herds, as could the selection of source stock from indigenous herds versus herds established using previously translocated source stock (Singer *et al.* 2000). Selective harvest of large rams also may cause drift in genes that influence horn size (Fitzsimmons *et al.* 1995).

Because of these concerns, many bighorn translocations have been done to supplement existing herds for the purpose of increasing genetic diversity even in the absence of conclusive information on negative effects of low genetic diversity. Unfortunately, the inherent risks of disease transmission associated with supplemental translocations of bighorn sheep have been demonstrated in Colorado, and those consequences appear far more severe than the ostensible effects of diminished genetic diversity. Disease screening to identify herds with similar exposure to pathogens is necessary to lessen the likelihood of disease outbreaks in the recipient or translocated sheep; however, additional data are needed to improve the effectiveness and interpretation of existing approaches.

As a means of limiting further compromise in the genetic integrity of Colorado's bighorn populations, it may be useful to estimate genetic variation within and among primary core populations and develop strategies for maintaining maximum genetic diversity to the extent feasible based on the genetic distance between populations (i.e., populations with the greatest genetic distance should receive management priority). However, any planning done to achieve and maintain genetic diversity in primary core populations also should consider the potential for introducing or spreading pathogens among bighorn herds and populations with disparate exposure histories. Comparing genetic variation of bighorn sheep may be accomplished using loci from nuclear DNA (e.g., allozymes and microsatellites) or mitochondrial DNA (Luikart and Allendorf 1996, Fitzsimmons *et al.* 1997, Gutierrez-Espeleta *et al.* 2000).

Environmental Stress

Bighorn sheep often appear to habituate fairly well to human activity. However, under some circumstances it is possible that bighorns may be adversely affected by chronic exposure to stressors as has been reported for a variety of other mammalian species. Stress-induced responses might increase susceptibility to diseases such as pasteurellosis in individual bighorns and thus could contribute the onset of epidemics in some situations (Spraker *et al.* 1984, Kraabel and Miller 1997).

Interspecies Competition

Competitive interaction between bighorn sheep and other wild ungulates can result from dietary overlap and from displacement from preferred habitat. Bighorn sheep, mountain goats, mule deer (*O. hemionus*), and elk all show some degree of dietary overlap that can vary by location and season. Mountain goats and bighorns have similar habitat requirements and can be direct competitors in some cases. Based on observations of interactions between mountain goats and Rocky Mountain bighorn sheep, mountain goats are often the more aggressive and dominant species and appear to be capable of displacing bighorns (e.g., Carpenter and Ramey 2007. Also see photos pp.74.) The DOW has therefore managed mountain goat populations and distribution to limit the expansion of mountain goats into areas occupied by Rocky Mountain bighorn sheep.

Competition with mule deer can potentially have negative impacts on bighorns primarily because mule deer are much more common than sheep. However, except during periods of extreme food shortage, there is little evidence that competition with mule deer is a significant limiting factor for bighorn sheep. It is more likely that competition with elk would have a greater negative effect because elk are much larger, they are capable of having broader dietary overlap with bighorn sheep, and large herds of elk can gather in alpine areas traditionally used by bighorns.

Exotic sheep species such as mouflon (*Ovis musimon*) and aoudads (or Barbary sheep; *Ammotragus lervia*) can potentially compete with bighorn sheep and introduce infectious diseases; mouflon also can readily interbreed with bighorns. Consequently, all exotic, wild species of *Caprinae* are prohibited in Colorado by Wildlife Commission regulations. Escapes of exotic sheep and goats have occurred in the past in the Battlement Mesa area, in the Black Canyon of the Gunnison River, and near Pikes Peak.

Harvest & Translocation Off-take

Harvest rates in Colorado are low enough in most herds (e.g., <3% of the estimated post hunt herd size in most cases and mostly rams) that it is unlikely that harvest has had much direct effect on limiting herds or populations in most cases. In some units with substantial ewe harvest (e.g., S6, S9, S32) and/or translocation removals (S32, S34), off-take rates can approach or exceed 10% of the post hunt population. In such cases, off-take likely does limit or reduce population size and this effect may persist for several years in less productive high elevation herds (Stevens and Goodson 1993). High off-take rates are primarily used to reduce the potential for disease epidemics and to manage populations toward population and sex ratio objectives. *See Population & Harvest Management, Ch. 4.*

Other Factors

Other known sources of mortality in bighorn sheep include vehicle accidents, train accidents, lightning, avalanches and snow slides, falls, drowning, and fires. In robust populations these additional mortality factors would seldom be expected to have much population effect. However, in small populations where every individual is at a premium, such stochastic-type events can contribute to extirpation. Areas with substantial highway mortality of Rocky Mountain bighorn sheep include I-70 (S32), Hwy 550 (S21), and Hwy 50 (S54).

Future Status

Few areas of suitable habitat are left in Colorado where new populations of Rocky Mountain bighorn sheep could potentially be established without some likelihood of interactions with domestic sheep that may result in disease transmission. There are several areas where small herds that might have watchable wildlife value could potentially be established but such herds would have little value in terms of an overall goal of maintaining viable populations with high genetic diversity. To maintain Rocky Mountain bighorn sheep numbers in the future, emphasis will need to be placed on management of existing populations rather than trying to establish new herds. It is especially important that the emphasis be placed on core populations and the largest native herd complexes with goals of increasing abundance and distribution within the ranges of those herd complexes.

Southwestern Colorado appears to offer considerable potential habitat for desert bighorn sheep. The Colorado Desert Bighorn Sheep Management Plan (BLM and CDOW 1989) set a population objective of 1,200 desert bighorn sheep by the early 21st century. The estimated statewide population of 325 desert bighorn sheep in 2007 fell well short of this mark. Available evidence indicates that the failure to even approach the statewide goal has resulted from different factors for different herds. In the case of the S62 population, currently the largest desert bighorn sheep herd in the state, respiratory disease, likely due to the presence of several domestic sheep allotments in and around occupied S62 desert bighorn sheep range, has probably been the primary limiting factor (Watkins 2005). In the case of S56 and S63, herd size appears to be limited primarily by mountain lion predation (Creeden and Graham 1997, Banulis 2005). In the case of S64, disease, mountain lion predation, and habitat have all been possible limiting factors (Wait 2005). With its large areas of ostensibly suitable habitat, remoteness, and absence of domestic sheep allotments, S63 appears to hold the greatest potential for substantially increasing desert bighorn sheep numbers in Colorado in the future. However, it is unlikely that the S63 population will increase without additional desert bighorn sheep transplants and mountain lion control.

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Chapter 2

STATEWIDE OBJECTIVES & PLANNING

Continued restoration of bighorn sheep (*Ovis canadensis*) in Colorado will require considerable investment in time and money and the cooperation of a variety of entities (e.g., US Forest Service, Bureau of Land Management, National Park Service, bighorn sheep advocates, domestic sheep industry, private landowners, and other publics). The Division of Wildlife believes that greater attention to population- and metapopulation-level management will be the most effective long-term approach to bighorn sheep management in Colorado. To this end, bighorn management planning will be revised in the near future to establish bighorn sheep Data Analysis Units and subsequent goals and plans for their management to better direct and monitor progress in DOW efforts to restore and conserve statewide bighorn resources.

Statewide Bighorn Management Goals & Strategies

The DOW will strive to manage Colorado's bighorn sheep resources to maintain or increase the size of existing herds and populations with emphasis given to the larger herd complexes ("core populations", as described previously). This will not preclude management of smaller populations of local importance.

Objectives & Timelines

All products listed below from the Senior Biologists, the Big Game Coordinator, the Big Game Data Analyst, and the Terrestrial Biometrician should be submitted to the Terrestrial Wildlife Manager. In cases where Game Management Units, DAUs, or metapopulation complexes extend across Regional boundaries, the respective Senior Biologists should designate one Senior to take the lead.

1. **Establish or modify bighorn sheep units (GMUs) for all herds in the state.**

   Strategy: Determine geographical boundaries that encompass bighorn sheep herds that are not currently in established sheep ("S") units. New sheep GMUs should take into account available movement information, suitable habitat in the vicinity, spatial distribution relative to other sheep units, and management concerns. Boundaries of existing GMUs used for cervids and pronghorn (*Antilocapra americana*) should be used whenever applicable.
   2009 - Senior Biologists submit a list of new sheep GMUs for their Regions with boundary descriptions.

   Strategy: In cases where movement and distribution data are available that indicate existing sheep GMU boundaries do not effectively represent herd distribution and management concerns, boundaries should be adjusted accordingly taking into account potential ramifications for data continuity.
   2009 - Senior Biologists submit a list of adjusted sheep GMUs for their Region (if any), including justification and boundary descriptions.

   Strategy: Determine areas where potential future bighorn translocations might occur outside of existing or pending new GMUs with consideration given to possible DAU implications and the potential for interaction with domestic sheep.
   2009 - Senior Biologists submit an initial list of potential future bighorn sheep translocation sites and an assessment of potential domestic sheep interactions. This list will serve as the starting point for subsequent discussions about translocations to establish new herds.

   Strategy: Recommend that new and adjusted bighorn sheep unit boundaries and designations be approved by the Wildlife Commission and incorporated into regulations.
   2009 - The Terrestrial Wildlife Manager submits bighorn sheep unit recommendations for Regulation Review.

2. Establish bighorn sheep Data Analysis Units.

Strategy: Combine bighorn sheep herds (GMUs) into DAUs as appropriate to represent interacting bighorn herds that should be managed collectively as a population. A bighorn DAU may include both hunted and nonhunted bighorn GMUs, as well as anticipated ranges of proposed translocation herds.
2009 – Senior Biologists submit a list of DAUs and their assigned GMUs for their Regions with a brief justification.

3. Designate core populations (DAUs).

Strategy: Develop a list and map ranges of primary (Tier 1) and secondary (Tier 2) core DAUs within Colorado (see Ch. 1, pp. 13 for definitions). Identifying core populations will allow needs and priorities for DAU planning, inventory, habitat projects and protection, disease prevention, and research to be identified and established.
2009 - Senior Biologists submit a prioritized list of primary and secondary core populations for their Region with a descriptive narrative.

Strategy: Opportunistically collect blood, tissue, and fecal samples (e.g., from hunter harvested animals, captured animals, mortalities) from primary and secondary core bighorn populations to determine and compare DNA characteristics and relatedness to better define and distinguish populations and metapopulations.
Ongoing sample collection.

4. Determine metapopulation and range extension potential within and among DAUs.

Strategy: Develop protocols for creating and recognizing metapopulation complexes by increasing connectivity within and among DAUs while considering the potential for increased disease transmission, especially as related to domestic sheep distribution and mixing of different herds or populations that have or may have different pathogen exposure histories.
2009 – Big Game Coordinator with input from the Senior Biologists submits metapopulation protocols.

Strategy: Develop a prioritized list of potential metapopulation complexes (including both connectivity between herds and range extension of existing herds) based on the protocols.
2009 - Senior Biologists submit a list of potential metapopulation complexes with a descriptive narrative.

5. Establish provisional DAU objectives.

Strategy: Establish internal DAU objective ranges for population size and rams/100 ewes in DAUs open for hunting or in DAUs that will potentially be used for translocation stock. In addition, establish any special provisional objectives or milestones.
2009 - Terrestrial Biologists, with input from their respective Areas, make internal DAU objective recommendations to the Senior Biologist.
2009 – Senior Biologists, with input from the Regional Manager, submits internal DAU objective recommendations.

6. Develop and implement inventory and monitoring protocols.

Strategy: Develop protocols for inventory and monitoring with emphasis on primary and secondary core DAUs. Whenever possible, consistent inventory methods should be used on a regular (but perhaps not annual) basis. Classification data should ideally be collected during the breeding season (December for Rocky Mountain bighorns and August-September for desert bighorns), if possible.
2009 – Senior Biologists submit inventory and monitoring protocols for primary and secondary core populations.

7. Develop and maintain a centralized, statewide database of bighorn sheep data.

Strategy: Biologists enter bighorn sheep classification data into the “Deer, Elk, Antelope Management” (DEAMAN) database program, calculate Kaplan-Meier survival rates (Kaplan-Meier 1958) using available radio-collar data, and submit available herd, population, demographic, spatial, translocation, disease, and treatment data

for inclusion in the statewide database.
2009 – Senior Biologists submit data and DEAMAN files to the Big Game Coordinator.

Strategy: Create a centralized, statewide database with all available bighorn sheep population, harvest, demographic, spatial, translocation, disease, and treatment data.
2009 – Big Game Coordinator and Big Game Data Analyst submit the completed database.

Strategy: Maintain and update the centralized, statewide database with available bighorn sheep population, harvest, and translocation data and incorporate the database into the Inventory Management Program.
Ongoing – Big Game Coordinator and Big Game Data Analyst.

8. Develop bighorn sheep DAU management plans.

Strategy: Develop a prioritized list of bighorn sheep DAU management plans with anticipated completion dates for each plan. DAUs with huntable populations should receive the highest priority in plan development scheduling. A minimum of four plans per year should be completed by each Region until all plans for the Region are completed.
2009 – Senior Biologists submit a prioritized list of DAU plans with a tentative completion timeline.

Strategy: Develop management plans for each bighorn DAU considering biological issues, habitat capability, and public and interagency input. Each plan should include the following:

1) DAU description (GMUs, boundaries, land ownership, general physiography)
2) History
   a. Historical occurrence and distribution
   b. Translocations (to and from the DAU)
   c. Population history and past inventory methods
   d. Hunting and harvest history
   e. Disease history
3) Distribution
   a. Current distribution and herd (subpopulation) descriptions including all commonly used herd names
   b. Interaction of herds (subpopulations) within the DAU
   c. Interaction with other DAUs (metapopulation or other)
   d. Summary of available movement and distribution data
   e. Delineation and use of available habitat
4) Current population estimate and proposed inventory methods
   a. Current population estimate and inventory methods
   b. Proposed future inventory methods
5) Management Issues
   a. Habitat quality, quality, and for potential improvement
   b. Development and fragmentation impacts
   c. Recreational impacts
   d. Diseases and parasites
   e. Predation
   f. Illegal kill
   g. Other
6) Management recommendations and future needs (subheadings below are examples)
   a. Use as a source herd for translocations
   b. Need for supplementation or range extension translocations
   c. Need for translocations to increase genetic diversity
   d. Habitat improvement recommendations
   e. Critical habitat protection
   f. Disease and parasite treatment
   g. Need for movement and distribution studies
7) Population objective range

In addition, plans for hunted DAUs should include:

8) Harvest objectives & management
   a. Rams/100 ewes ratio range (or proposed alternative parameters)
   b. Special objectives (e.g., proportion of post hunt rams ≥3/4 curl or class 3 or 4; proportion of ram harvest ≥6 yrs of age)
   c. Ewe harvest (including translocation removals)
   d. Methods of takee. Season structure and timing
   f. Closures and special restrictions
   g. Maximum allowable off-take (harvest and translocation)

In addition, plans for nonhunted DAUs should include:

8) Future Potential for Hunting
   a. Is there future potential for hunting?
   b. What conditions should be met before hunting is allowed (e.g., minimum sheep number, landowner participation, etc.)?
   c. What is being done or can be done to meet those conditions?
9) Off-take objectives
   a. Maximum allowable translocation off-take

Strategy: Submit bighorn DAU plans for approval by the Wildlife Commission.
Beginning 2009 – Senior Biologists will submit at least four bighorn DAU plans per year for their Regions. The Terrestrial Wildlife Manager will submit at least 16 DAU plans per year to Regulation Review in 2009 and 2010.

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Chapter 3

INVENTORY & POPULATION ESTIMATION

Reliable data on bighorn sheep (*Ovis canadensis*) herd composition, recruitment and population numbers are needed to develop and evaluate population management goals and objectives and to make informed management decisions. Estimates of these population parameters should be based on rigorously collected data with known levels of precision whenever possible. However, many of Colorado's bighorn sheep populations occur in remote, rugged areas with limited human access making this information expensive and time consuming to collect. Because it will not be possible to acquire precise estimates of these parameters for all herds, inventory methods need to be efficient and populations (and herds within populations) should be prioritized to best use available resources.

Management Goals & Strategies

Management Goal

All bighorn sheep Data Analysis Units should be regularly surveyed with frequency and intensity dependent on their prioritization.

Strategy: At a minimum, all bighorn sheep populations should be surveyed every two years by either helicopter or by coordinated ground surveys to obtain herd composition, minimum population numbers, status of individual herds, and population trends. Primary and secondary core (i.e., Tier 1 and Tier 2) (see Ch. 1, pp. 13 for definitions). DAUs and other populations used as source stock for translocations should be surveyed or modeled annually. Surveys of Rocky Mountain bighorn herds should be conducted during winter (Dec-Mar) whenever possible, with December being the preferred month in most DAUs. When summer surveys are necessary, efforts to collect winter lamb:ewe ratios of at least a subsample of the DAU are recommended, if possible. Surveys should not be conducted immediately prior to or during a bighorn sheep hunting season to avoid potential impacts to hunter experience.

Strategy: Population estimates using mark-resight or other statistically rigorous techniques should be conducted periodically (e.g., once every 10-15 years) in Tier 1 and Tier 2 DAUs (or representative herds within those DAUs) and in other populations of special interest dependent on funding, feasibility of marking an adequate sample, and access. During these studies, marked animals also should be used to estimate survival rates and document seasonal ranges and movements. Alternatively, more frequent inventory and monitoring of select herds within DAUs may be considered as a means of tracking bighorn population performance.

Strategy: Population modeling should be used to develop annual population projections and population trends in Tier 1 and 2 DAUs and in other populations or herds where mark-resight surveys have been conducted.

Background & Literature Review

Inventory

Bighorn sheep populations have been inventoried via ground, fixed wing and helicopter surveys. Data from these surveys have been used to estimate the size of bighorn populations using various methods including using count data without adjustments for sightability (Cook *et al.* 1990, Bodie *et al.* 1990, Karasek *et al.* 1992), with standard upward adjustments (15-40%) (Skjonsberg 1988, George *et al.* 1996, Utah Division of Wildlife unpubl. data 2007), in sightability models (Bodie *et al.* 1995, Bernatas and Nelson 2004), with double-count methods (Magnusson *et al.* 1978, Graham and Bell 1989), and with mark-resight methods (Neal *et al.* 1993, George *et al.* 1996, McClintock and White 2007). In some cases, population estimates have been used along with other parameter estimates in population models to project annual population numbers and trends.

Whether surveys are conducted via helicopter or on the ground depends on funding and habitat conditions. Helicopter surveys may provide more thorough coverage of an area than can be achieved using ground surveys and allow more efficient access to remote areas. One disadvantage of helicopter surveys compared to ground based surveys is a higher potential for misclassification, especially of yearlings, under some conditions (patchy snow, high wind, extremely rugged cliffs). Therefore, when helicopter surveys are used they should be conducted with fresh snow cover and in low to moderate winds. Many of Colorado bighorn sheep ranges contain power lines, persistent high winds, residences, and highways that preclude helicopter surveys. In these cases, ground counts are most suitable.

Helicopter surveys have resulted in mean ewe sighting probabilities of approximately 0.60 (0.58 in Neal *et al.* 1993 for Trickle Mountain, 0.57 in Bodie *et al.* 1995 in Idaho, and 0.61 in George *et al.* 1996 for the Tarryall Mountains). However, sighting probabilities may be much higher (0.95 in the Kenosha Mountains, George *et. al.* 1996) and variable (0.33-0.86 in Neal *et al.* 1993; 0.32-0.88 in George *et al.* 1996). Ground surveys in 3 herds in Rocky Mountain National Park resulted in mean ewe sighting probabilities of 0.450, SE = 0.082; 0.302, SE = 0.153; 0.413 SE = 0.030 (McClintock 2004).

Classification surveys for Rocky Mountain bighorns are best conducted during December when rams associate with ewes, and lambs have survived past the late summer time period when lamb pneumonia mortality frequently occurs in herds with a history of pneumonia epidemics. However, late winter helicopter surveys conducted in March may be considered because high sightability rates have been observed in some high elevation in alpine and timbered habitats (George *et al.* 1996). Winter classification surveys in Dec-Mar will provide lamb:ewe ratios representative of annual recruitment, but late winter surveys (Feb-Mar) may result in underestimated sex ratios. For desert bighorns, late summer (Aug-Sep) may be more appropriate for conducting classification surveys.

Summer surveys of some Rocky Mountain bighorn populations may be necessary in remote areas where winter conditions preclude access. Summer surveys should be conducted as late as possible waiting until September or October if conflicts with hunting seasons are not a concern. Postponing summer surveys is advised because parturition may occur as late as July in high elevation herds (Stevens and Stevens 1991, George 1997) and surveys done in mid-summer (Jun-Aug) may significantly underestimate lamb mortality caused by respiratory disease and other factors. In addition, sightability increases in August and September when ewes and lambs aggregate into larger groups and move into more open terrain (Huwer unpublished data, Dreher unpublished data).

During surveys, bighorn sheep should be classified in the following categories: lambs (<12 months old); yearling rams and ewes (12-23 months old); unclassified yearlings (12-23 months old); ewes; mature rams by horn curl (1/2, 5/8, 3/4, 7/8, full); and unclassified mature rams. Bighorn sheep that cannot be identified should be recorded as "unclassified". Each animal or group of animals observed should be recorded as one observation on standardized data sheets. Observations should be used to determine lamb:ewe, yearling:ewe, and ram:ewe ratios and age structure of the ram population.

Mark-resight surveys should follow methods and recommendations described by Neal *et al.* (1993), George *et al.* (1997), and McClintock and White (2007).

Modeling

Spreadsheet Models should be used to project population numbers and trends and to provide a basis for harvest recommendations. Survival rates from mark-resight and other radio telemetry studies should be used when available. For populations without survival rate data, see Table 2 on page 3 in McCarty and Miller (1998) for a review of survival rates. Bighorn sheep are typically long-lived with constant high survival rates. In the absence of disease epidemics or episodes of high lion predation, adult ram and ewe survival rates usually exceed 0.90 excluding harvest.

For Tier 1 and Tier 2 populations, population models should be built during years of intensive study when radiocollared animals are available for mark-resight population estimates and annual survival rate estimates. Modeling should continue in years between intensive study relying primarily on annual estimates of sex and age ratios and removals via hunter harvest and other methods (e.g., translocations) as annual inputs.

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POPULATION & HARVEST MANAGEMENT

Colorado's bighorn sheep (*Ovis canadensis*) herds should be managed to be healthy and self-sustaining while providing hunting and wildlife viewing opportunities. As with other big game species, bighorn sheep populations should be managed using a management by objective process which includes formulation of population and sex ratio objectives for each Data Analysis Unit. Population objectives should be determined through the DAU planning process and consider biological and habitat constraints as well as the public's desires for hunting and viewing opportunities. Because of potential density dependent effects, population objectives should not be overly optimistic and ewe removals via hunter harvest and translocation should be used to keep populations within objectives. Ram harvest will provide quality hunting opportunities and, to a lesser extent, contribute to population management.

Management Goals & Strategies

Evidence of density dependent decreases in ram horn growth rates and population performance on some ranges, combined with the demand for hunting opportunities that far exceeds supply, justify an integrated approach to population and hunting management.

Population Management

Management Goal

Bighorn sheep populations will be managed using a "management by objective" approach similar to other big game species in Colorado.

Strategy: All bighorn sheep populations, hunted and unhunted, will be placed in bighorn sheep DAUs. A bighorn DAU may contain both hunted and unhunted subpopulations and one or more hunt Game Management Units. *See Statewide Objectives & Planning, Ch. 2.*

Strategy: Population and sex ratio objectives will be determined for each bighorn sheep DAU using the DAU planning process. *See Statewide Objectives & Planning, Ch. 2.*

Strategy: Bighorn sheep harvest objectives and license number recommendations will be submitted annually on bighorn sheep DAU objective sheets.

Ram Hunting

Management Goal

Ram hunting harvest objectives will be managed to provide quality hunting experiences as defined by low hunter density and the opportunity to see and harvest mature rams. Ram harvest will also used to manage sex ratios and, to a lesser degree, population numbers toward DAU objectives.

Strategy: Licenses will remain limited in number. Three-year average hunter success rates will be used to calculate hunting license numbers necessary to meet harvest objectives. Ram harvest objectives will be based on population models in Tier 1 and Tier 2. (see Ch. 1, pp. 13 for definitions). DAUs. In other populations or herds, and as a check for modeled DAUs, ram harvest objectives should be 2-5% of the post hunt populations and/or 4-10% of total post hunt ram numbers. In DAUs exceeding sex ratio or population objectives, ram harvest may exceed 5% and 10% until objectives are met. Conversely, in DAUs below objective or with low (<20:100) winter lamb:ewe ratios, harvest rates may be reduced.

Strategy: The Division, in partnership with the Rocky Mountain Bighorn Society and other organizations, will continue to provide hunters with specialized training at an annual bighorn sheep and mountain goat hunter orientation. Guidance on identifying legal animals, judging ram horn size and age, hunting methods and ethics will be provided.

Strategy: Maintain the minimum 1/2 curl regulation or implement an "any ram" regulation that has proved successful in other states.

Strategy: Number of ram hunting licenses will be consistent with obtaining a statewide ram hunter success at or above 45% (as estimated from 3-year running average).

TABLE 2. Recommended ewe removal rates presented below include removals via hunting and translocation.

Estimated Population in Relationship To Objective	Observed Winter Lamb:Ewe Ratio	Ewe Removal Or Harvest Rate as a Percentage of Total Population	Comments
≥25% below	NA	No ewe removals	Exceptions allowed for disease management
<Objective, but within 25%	≥40:100	Up to 5% of total post hunt population ≥1 year old	Or up to12% of pre hunt ewe population
At Objective	≥40:100	5-10% of total post hunt population ≥1 year old	Or 12-24% of pre hunt ewe population
	20-39:100	<5% of total post hunt population ≥1 year old	Or <12% of pre hunt ewe population
	<20:100	No ewe removals	Exceptions allowed for disease management
Over Objective		≥10% of total post hunt population >1 year old	≥24% of pre hunt ewe population

Strategy: Ram harvest objectives will be consistent with obtaining average age of harvested rams at six years old based on number of horn annuli.

Strategy: Bighorn sheep DAUs may be divided into hunting units to improve hunter distribution, reduce crowding and to meet harvest objectives.

Ewe Harvest via Hunting and Translocation

Management Goal

The primary goal of ewe harvest will be to manage population numbers to meet DAU objectives. Further, ewe hunting provides quality recreational hunting opportunities for which demand is increasing. Ewes removed for translocations will be treated the same as hunter harvest in terms of population management. Translocation removals will be conducted in a manner that minimizes impacts on social structure and "legacy" movement patterns (i.e., traditional or unique movements that are likely learned through bighorn matriarchal social structure within bands and herds). *See Capture & Translocation for Restoration & Augmentation, Ch. 5.*

Strategy: Licenses will remain limited in number. Three-year average hunter success rates will be used to calculate hunting license numbers. Ewe harvest objectives will be based on population models in Tier 1 and Tier 2 DAUs. In other populations or herds, and as a check for modeled DAUs, harvest objectives should be based on recommended harvest rates (Table 2); these recommendations should be considered as starting points for adaptive management. If population monitoring indicates that removal rates are not producing the desired effect on population numbers, then rates should be adjusted. Removal rates should account for both hunter harvest and translocations. The rates in Table 2 are based on work by Jorgenson *et al.* (1993) and assume survival of >90% for ewes and >70% for rams, typical for herds not experiencing disease epidemics or unusually high adult mortality rates for other reasons.

Ewe harvest by hunting or translocation is not recommended for 5 or more years after a pneumonia epidemic unless used as part of a disease management strategy. However, ewe hunting may be needed in cases where harvest is needed to meet population or herd size objectives after an epidemic.

Hunting Season Timing and Duration

Management Goal

Hunting season timing will provide quality hunting experiences while protecting natural biological processes (migration, breeding and rearing of young) and minimizing conflicts with other wildlife recreation activities.

Strategy: Ram hunting seasons will occur no earlier than 1 August and no later than 31 December.

Strategy: The primary bighorn ram hunting seasons should occur in August-September and should not overlap regular deer and elk seasons in October and November.

Strategy: Ram hunting should not occur during the breeding season (generally October-December for Rocky Mountain bighorns and September-November for desert bighorns) except when that is the only time animals are accessible due to movements out of refuges or in low elevation herds in southern portions of the state where high early season ambient temperatures may negatively impact meat care and hunting success.

Strategy: As a general rule, ewe seasons should not begin prior to 1 September and end no later than 31 December for desert bighorns and 28 February for Rocky Mountain bighorns. The only published study of lamb survival in a hunted bighorn herd found that orphaning of lambs greater than 15 weeks old did not compromise lamb survival or growth rates (Alberta Fish and Wildlife Division 1993, Jorgenson *et al.* 1993). Since lambing occurs primarily in May in Colorado, most lambs would be 15 weeks of age by 1 September. However, lambing may occur later in herds that use alpine habitats year-round which would justify further delay in ewe season opening dates. Similarly, earlier lambing dates in herds residing year-round at lower elevations justify earlier ewe season closing dates.

Strategy: Seasons should be at least nine days long, but no longer than 35 days unless they are part of disease, distribution, or experimental management programs. Based on DOW mandatory check data, the average number of days hunted by ram and ewe hunters was eight and four, respectively. Exceptions may occur for auction and raffle licenses or for disease, distribution, or experimental management hunts.

Strategy: Longer seasons can be divided into two or more shorter seasons to reduce hunter crowding or increase hunter success rates.

Background & Literature Review

Population and harvest management of bighorn sheep should consider potential density-dependent effects. Bighorn sheep are susceptible to pneumonia and high population densities have been associated with disease outbreaks in some populations (Denny 1976, Festa-Bianchet 1988, Monello *et al.* 2001). In the absence of disease, bighorn sheep populations also have exhibited density-dependent responses to increasing population numbers more typical of other native ungulates. Jorgenson *et al.* (1993 and 1998) found that a three-fold increase in ewe numbers after the cessation of ewe hunting resulted in a decrease in ram horn size and the number of 2-year old ewes producing lambs. In these studies, stable population numbers were achieved by the removal or 12-24% of the total ewe population which equated to 5-10% of the total population.

Ram harvest provides quality hunting opportunities and, to a lesser extent, contributes to population management. Ram removal rates of 4-5% of total bighorn population, or 8-10% of ram numbers, are used by other agencies (Nevada Division of Wildlife 2001, Alberta Fish and Wildlife Division 1993). These ewe and ram removal rates are comparable to the intrinsic rate of increase of 0.26 that Buechner (1960) calculated for bighorn sheep and the observed average annual rate of increase of successful transplant herds in Colorado of 0.13 (McCarty and Miller 1998).

History of Bighorn Sheep Hunting

Unregulated market hunting, along with habitat losses and introduced diseases associated with livestock, contributed to reductions in bighorn numbers in the 1860s and 1870s. In response to declining bighorn populations, the Colorado legislature placed a moratorium on sheep hunting in 1885 which remained in effect for over 60 years.

Bighorn numbers did not increase consistently in the absence of hunting during the more than six decades of closed seasons and it became apparent that disease outbreaks were depressing population performance in many areas (Denny 1976, Hobbs and Miller 1992). After a pneumonia epidemic in the Pikes Peak and Tarryall and Kenosha Mountains herd complexes in the winter of 1952-53, a limited ram-

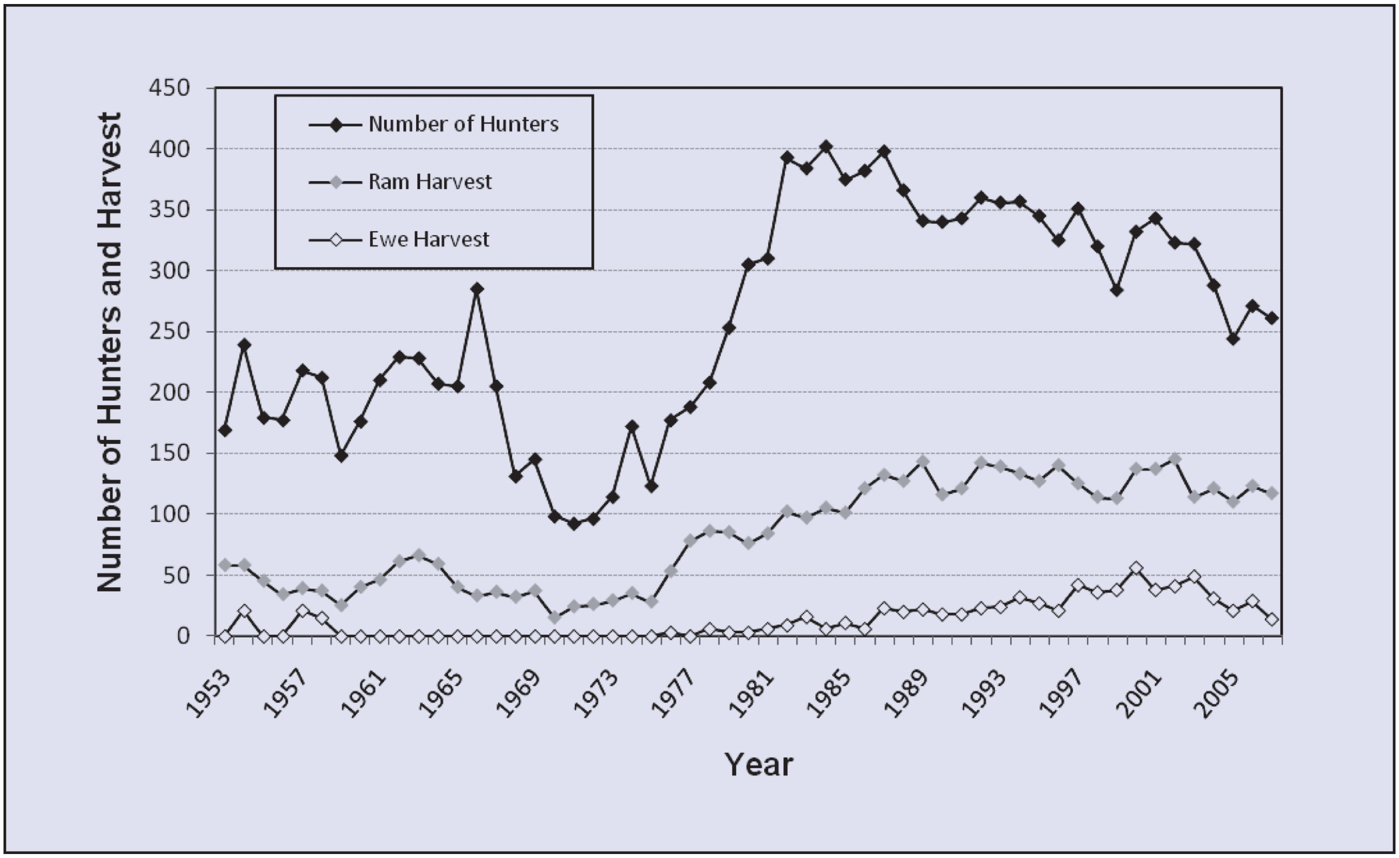

FIGURE 7. Number of Rocky Mountain bighorn sheep hunting licenses and harvest in Colorado, 1953-2007.

only hunting season was opened in the fall of 1953 with the goal of dispersing sedentary bighorn herds to reduce the likelihood of further disease outbreaks. One hundred and sixty-nine licenses were issued for 18 hunting units resulting in the harvest of 58 rams (Fig. 7). The following year, the first ewe harvest occurred in the Buffalo Peaks herd via either sex licenses for the purpose of collecting samples to access herd health. Ram hunting has continued every year since 1953, but ewe harvest was intermittent until 1976 when there was a ewe season on Pikes Peak. Since 1978, limited entry hunting of both rams and ewes has been allowed each year with the added goals of managing population numbers and providing quality hunting experiences.

As bighorn sheep numbers and distribution grew, hunting opportunities increased. In addition to rifle hunting seasons, archery-only hunting for Rocky Mountain bighorns began in 1972 with 20 licenses and increased to 60 the following year. The total number of rifle and archery licenses increased rapidly in the 1970s peaking in the mid-1980s at 400 licenses. Since 1990, license numbers have declined to around 250-300. In 2006, 51 units were open to hunting Rocky Mountain bighorn with a total of 224 ram and 79 ewe licenses resulting in the harvest of 123 rams and 29 ewes.

Although hunting license numbers peaked in the 1980s, harvest continued to increase until 2000 when 193 animals were harvested. The continued increase in harvest was due to increased hunter success rates and increases in ewe harvest.

Desert bighorn hunting began in 1988 with two ram licenses in a single unit. Since then, ram only hunting has continued with licenses numbers ranging from two to nine in three different units.

Nonresident hunting has been allowed for Rocky Mountain bighorn sheep beginning in 1984, but nonresident licenses are limited to no more than 10% of total licenses. Desert sheep licenses have been limited to residents only.

Recent Bighorn Sheep Harvest and Hunter Success

From 1987-2007, mandatory harvest checks have been conducted on over 2,500 Rocky Mountain bighorn rams (Table 3). The majority of these rams were 3/4 curl with an average age of 7 years, as estimated by number of horn annuli. Average circumference of

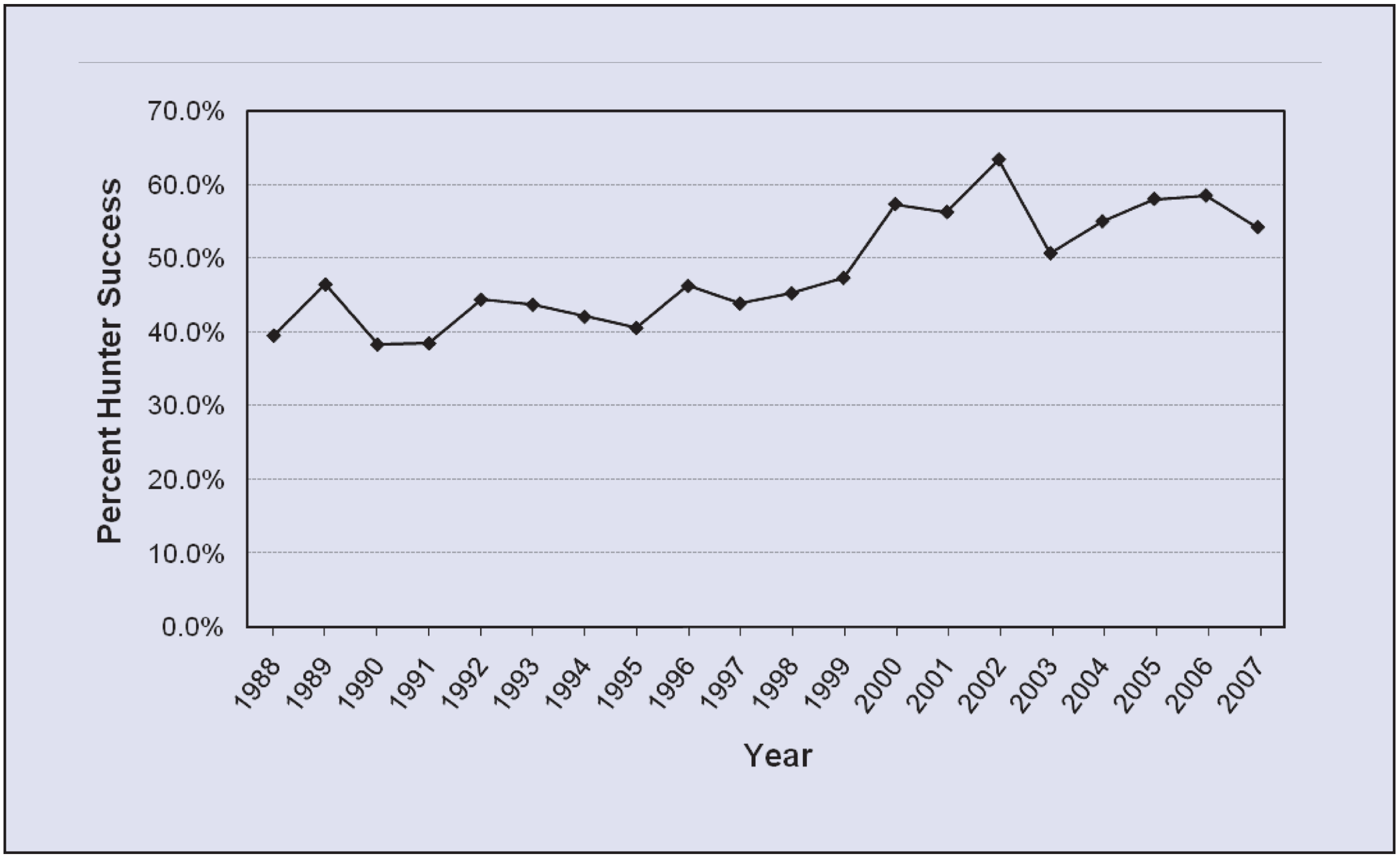

FIGURE 8. Ram hunter success rate for Rocky Mountain bighorn sheep in Colorado,1988-2007.

TABLE 3. Curl, average horn length, average basal horn circumference, and annular growth rings from mandatory harvest checks of Rocky Mountain bighorn sheep in Colorado, 1987-2007. SE = Standard error; N = Number of sheep checked.

Curl	Average Length (inches)			Average Circumference (inches)			Annular Growth Rings		
	Mean	SE	N	Mean	SE	N	Mean	SE	N
1/2	19.3	0.3	128	12.4	0.1	128	2.8	0.1	124
5/8	24.4	0.2	362	14.2	0.1	362	4.1	0.1	350
3/4	29.4	0.1	1058	15.0	0.1	1057	6.1	0.1	1039
7/8	32.2	0.1	753	15.1	0.0	751	7.5	0.1	743
Full	34.5	0.2	282	15.0	0.1	282	8.1	0.1	275

mature rams (>3/4) was 15 inches, but average horn length continued to increase with curl classification to 34.5 inches for full curl rams.

During the last 20 years (1988-2007), Rocky Mountain bighorn ram hunter success has increased along with the average age and horn size of harvested rams. Average ram hunter success increased from 40% for 1988-1997 to 55% for 1998-2007 (Fig. 8). From 1987-2007, the average age of harvested rams increased from five to seven year and the average horn length increased from 28 to 30 inches (Figs. 9 and 10). Although horn length has consistently increased during the last 20 years, the high variability within each year precludes statistical significance (Fig. 10). Furthermore, horn length and age are not independent variables with horn length peaking at between 10 and 11 years (Fig. 11). Basal horn circumference becomes asymptotic at 6 years of age (Fig. 12 and Table 3). Although age of harvested rams increased, the average age of harvested ewes has remained constant at between four and five years old. This may be the result of the difficulty of aging adult ewes by horn annuli (Geist 1966), but more likely it is due to lack of selective harvest based on horn size.

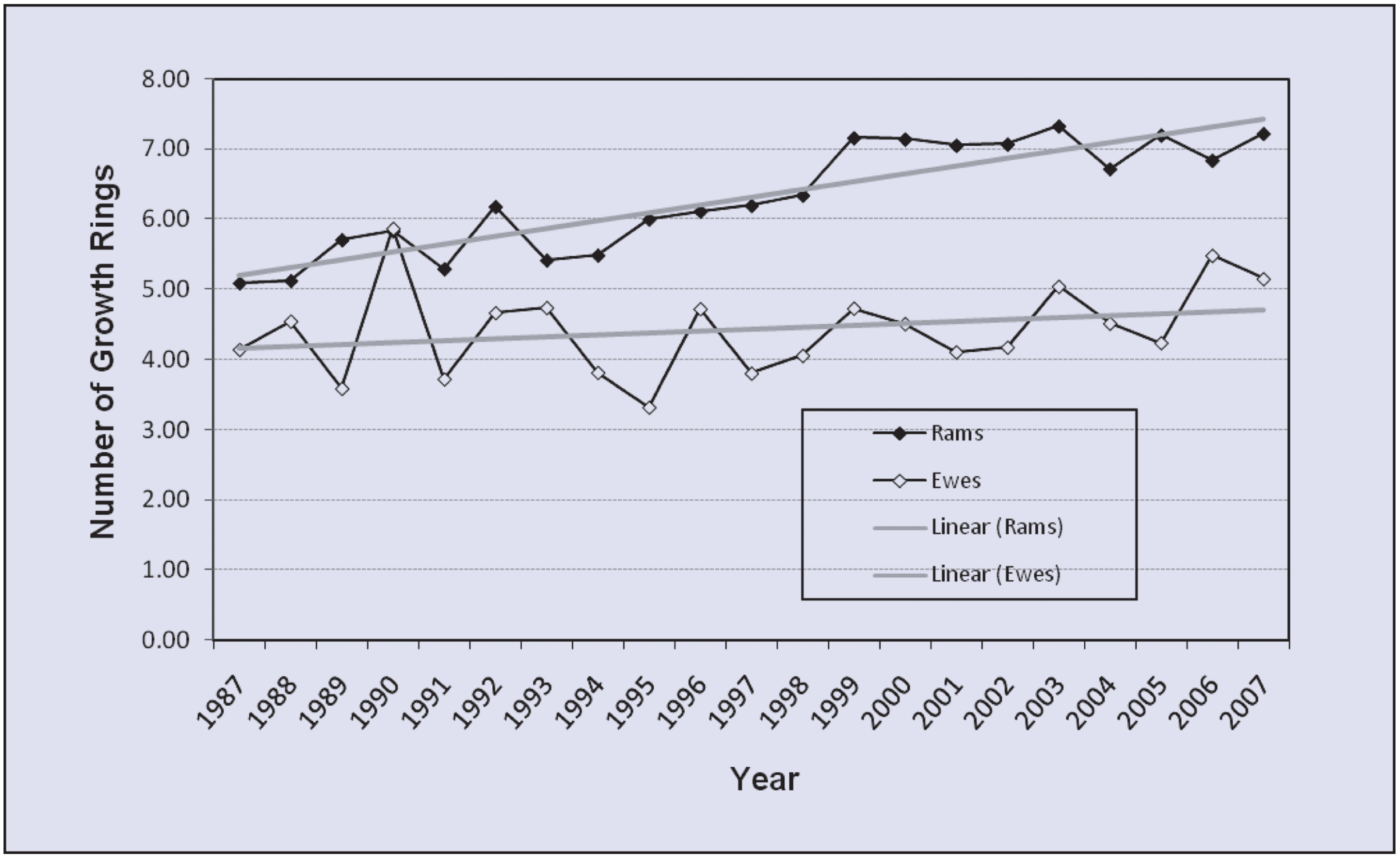

FIGURE 9. Average age of harvested ram and ewe bighorn sheep in Colorado, 1987-2007. Age based on number of growth rings.

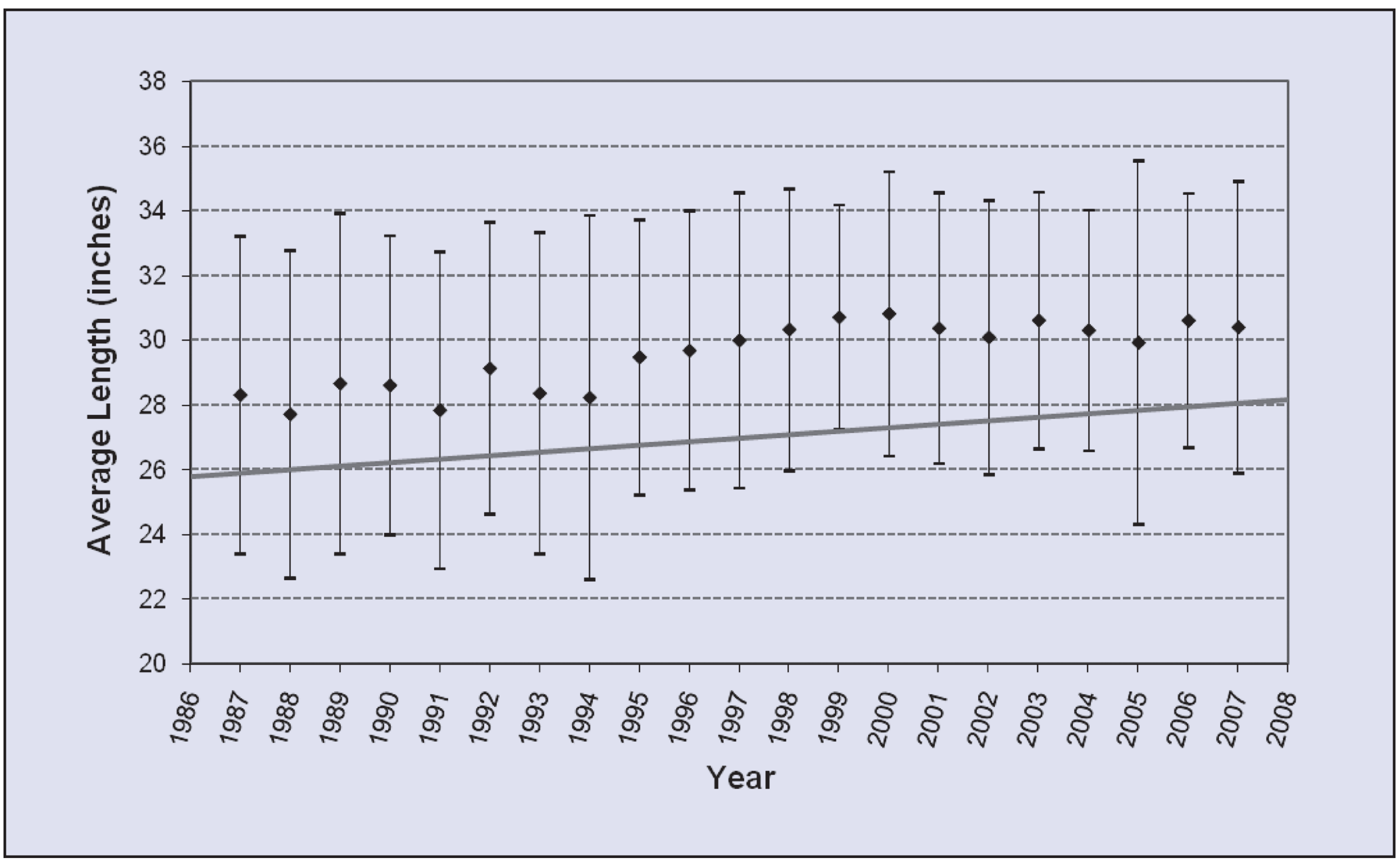

FIGURE 10. Average horn length (inches) versus year of harvest of 2621 Rocky Mountain bighorn sheep checked in Colorado from 1987-2007. Bars represent one standard deviation.

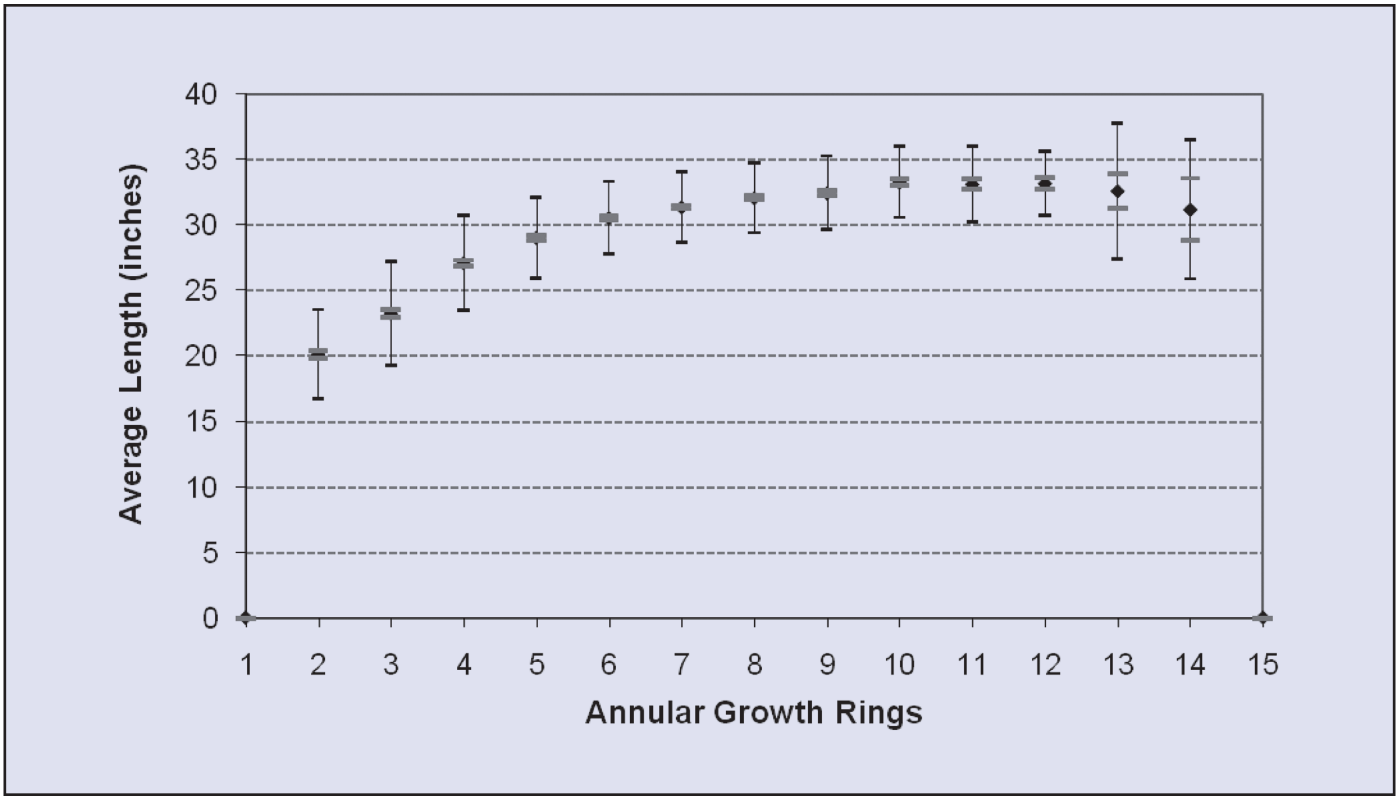

FIGURE 11. Average horn length (inches) versus annular growth rings (age in years equals the number of rings +1) of 2,532 Rocky Mountain bighorn sheep checked in Colorado from 1987-2007. Outer (black) bars represent one standard deviation and inner (grey) bars represent one standard error of the mean.

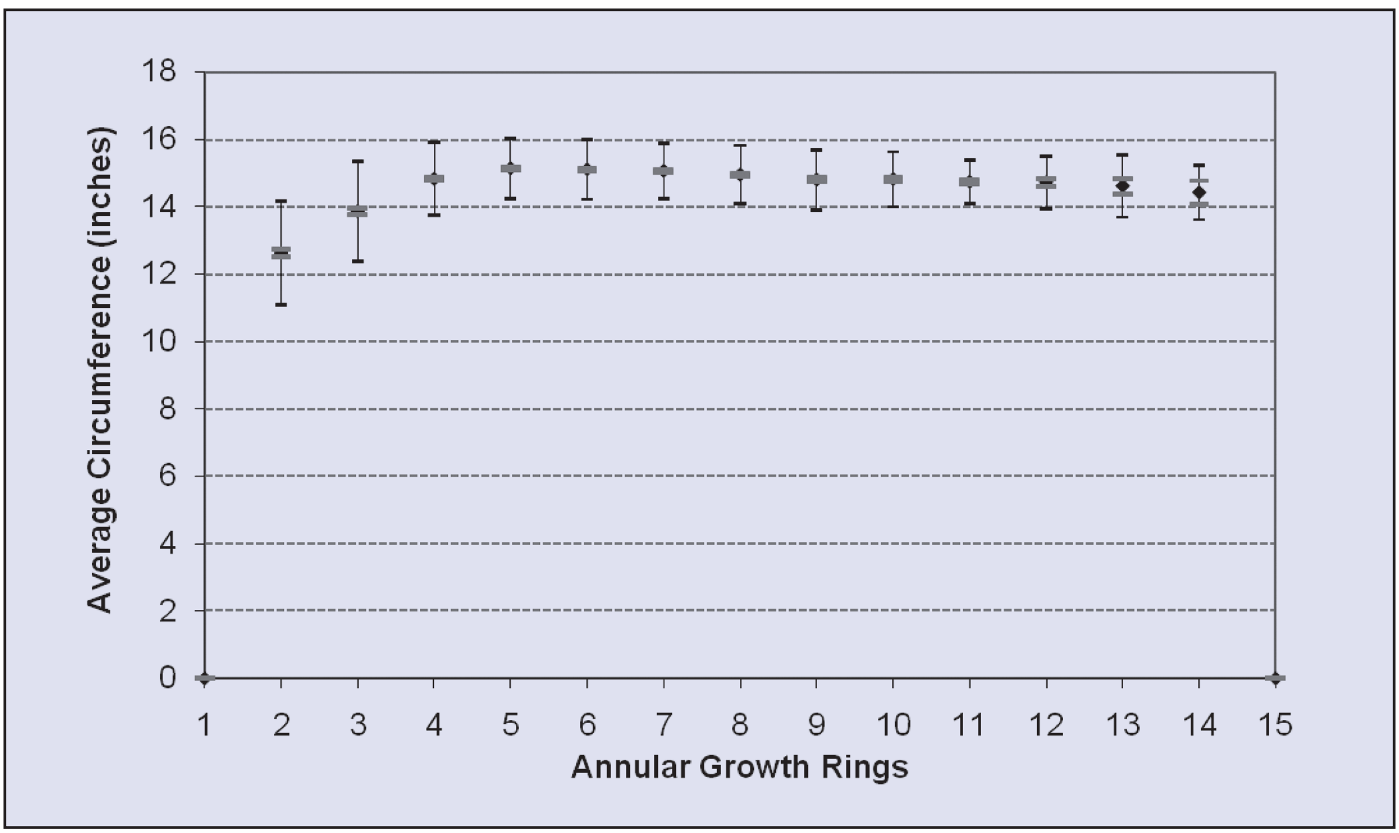

FIGURE 12. Average basal horn circumference (inches) versus annular growth rings (age in years equals the number of rings +1) of 2529 Rocky Mountain bighorn sheep checked in Colorado from 1987-2007. Outer (black) bars represent one standard deviation and inner (grey) bars represent one standard error of the mean.

TABLE 4. Minimum curl restrictions for bighorn ram hunting in Colorado 1953-2007 (Denny 1976, Hobbs and Miller 1992).

Years	Minimum Curl	Comments
1953-1957	1/2 Statewide	Either-sex licenses in Buffalo Peaks in 1954 & 1957
1958-1959	3/4 Statewide	Either-sex licenses in Buffalo Peaks in 1958
1960-1964	1/2 Statewide	
1965-1969	1/2 and 3/4	Varied by unit and year – primarily 3/4 Either-sex licenses in Georgetown in 1966 & 1968
1970	Full and 3/4	13 units with full curl and 3 units with 3/4
1971-1973	3/4 Statewide	
1974-1981	3/4 and 1/2	3/4 in East Slope herds and 1/2 in West Slope herds Either-sex in 1976 on Pikes Peak.
1981-present	1/2 Statewide	A few “any sheep”, “any ram” or “slot” ram licenses

The apparent increase in hunter success and size of harvested rams during the last 20 years was not due to greater effort by hunters because the average number of days hunted remained constant at eight days for ram hunters and four days for ewe hunters. The combination of increasing trends in hunter success and horn size of harvested rams occurring during a time of stable to slight reductions in bighorn sheep numbers (Chapter 1, Figs. 4 and 5) and licenses, but consistent hunter effort, indicates a shift towards more limited opportunity, but higher quality bighorn sheep ram hunting experiences in Colorado.

Hunter success for desert bighorn rams has remained high at 100% in all but 2 years since the first season in 1988. The exceptions were 83% (5 of 6 hunters) in 1995 and 67% (2 of 3 hunters) in 2005.

Curl Restrictions

Colorado and other wildlife agencies have tested minimum curl restrictions as a means to direct ram harvest to older age classes and found restrictions >1/2 curl unnecessary for limited entry seasons. Colorado implemented a 1/2 curl minimum when hunting reopened in 1953 which continued until 1958. Throughout the 1960s and 1970s, restrictions varied by unit and year alternating between 1/2 and 3/4 curl minimums with a single year of a full curl minimum in 1970, and then came full circle back to a 1/2 curl minimum. The 1/2 curl regulation has been in place statewide since 1981 with a few exceptions for special management hunts (Table 4).

Most states have dropped minimum curl regulations in favor of allowing the harvest of “any ram.” Arizona was the first to adopt an “any ram” regulation in 1985, followed by Oregon in 1990. Subsequently, Nevada, Idaho, New Mexico, Utah, Washington and Wyoming have followed and currently allow the harvest of any ram. “Any ram” regulations have proven successful in eliminating citations and court cases for “short” rams and reduced abandonment of sub legal rams. Moreover, after replacing 3/4 curl minimums with “any ram” regulations, mean horn size and age of harvested rams did not decrease in Arizona (Lee 1993) or in Oregon (Coggins 2004) and a high percentage of rams harvested in the absence of curl restrictions continued to be 3/4 curls or larger.

The combination of state supported sheep hunter training programs emphasizing identification of mature rams combined with the desire of hunters to harvest trophy animals have rendered minimum curl restrictions unnecessary in most cases. In areas, where unspecified or over-the-counter ram hunting opportunity occurs, such as in Alberta, minimum curlsrestriction of 3/4, 4/5 and full curl remain necessary to maintain adequate sex ratios.

Colorado’s 1/2 curl regulation does not differ greatly in effect from “any ram” regulations. The difference is that in states with “any ram” regulations, all rams >12 months old are legal; while under Colorado’s 1/2 curl minimum the take of yearling rams is also prohibited. In most Colorado bighorn herds, horn growth rates allow rams to achieve 1/2 curl during their third summer (e.g. 2 year olds)

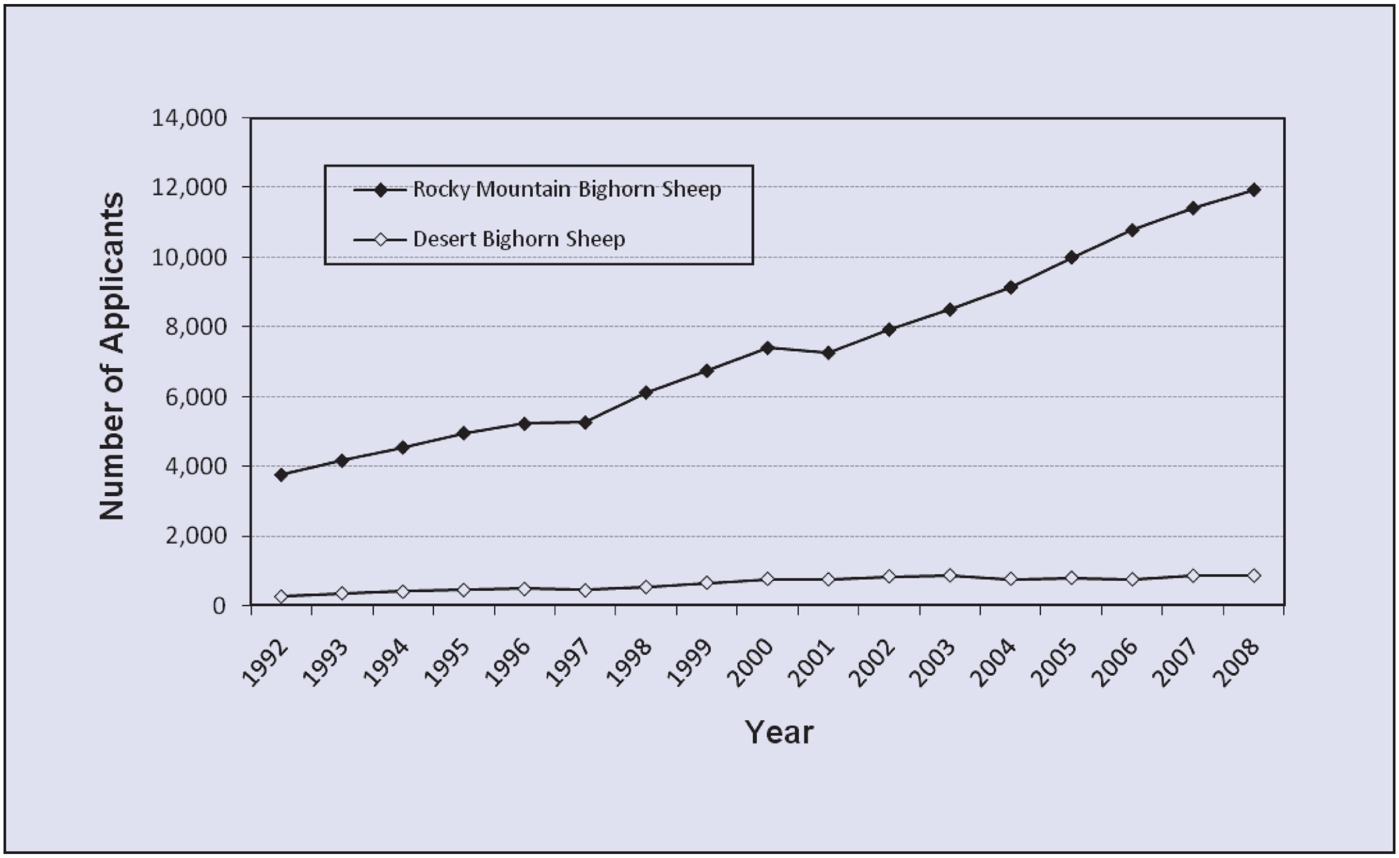

FIGURE 13. Number of applications received for Rocky Mountain and desert bighorn sheep hunting licenses in Colorado, 1992-2008.

allowing legal harvest by the fall hunting season. Rams <2 years old usually associate with ewe bands, so citations and abandonment have been rare with the 1/2 curl minimum.

Demand for Hunting Opportunity and License Allocation Methods

Hunting bighorn rams in Colorado and throughout the United States, is a rare and highly desired opportunity. Likewise, ewe hunting has a long tradition in Colorado and its popularity has grown in recent years.

Overall, demand for bighorn sheep hunting has tripled in the last 17 years with the number of applicants increasing from about 4,000 to almost 12,000 for the Rocky Mountain subspecies and from 265 to over 800 for desert sheep (Figure 13). While demand has increased 3-fold, overall the total number of hunting licenses for Rocky Mountain bighorns has declined by about 10% (Figs. 13 and 14). Desert ram licenses have been extremely limited with numbers ranging from two to nine since hunting for this subspecies began in 1988. Although application rates vary among units and seasons, overall there were 36 applicants for every Rocky Mountain bighorn sheep license and 287 applicants for every desert sheep license available in Colorado in 2006.

With bighorn sheep hunting licenses in high demand, several techniques have been used to fairly allocate hunting opportunity during the last 50 years. These include random drawings, three different preference point system drawings, “once-in-a-lifetime” ram harvest restriction, limits on nonresident participation, and 1- to 5-year mandatory waits for successful hunters before reapplication is allowed. These techniques have met with varying success and acceptance.

Currently, Rocky Mountain bighorn ram licenses are distributed via a combined preference point and weighted preference system with a 5-year wait for successful hunters before reapplication is allowed. In effect, Rocky Mountain ewe hunting licenses have been distributed through a straight preference point drawing because few preference points are needed to draw. Desert bighorn ram licenses have been for residents only and distributed through a random drawing with an once-in-a-lifetime ram harvest restriction.

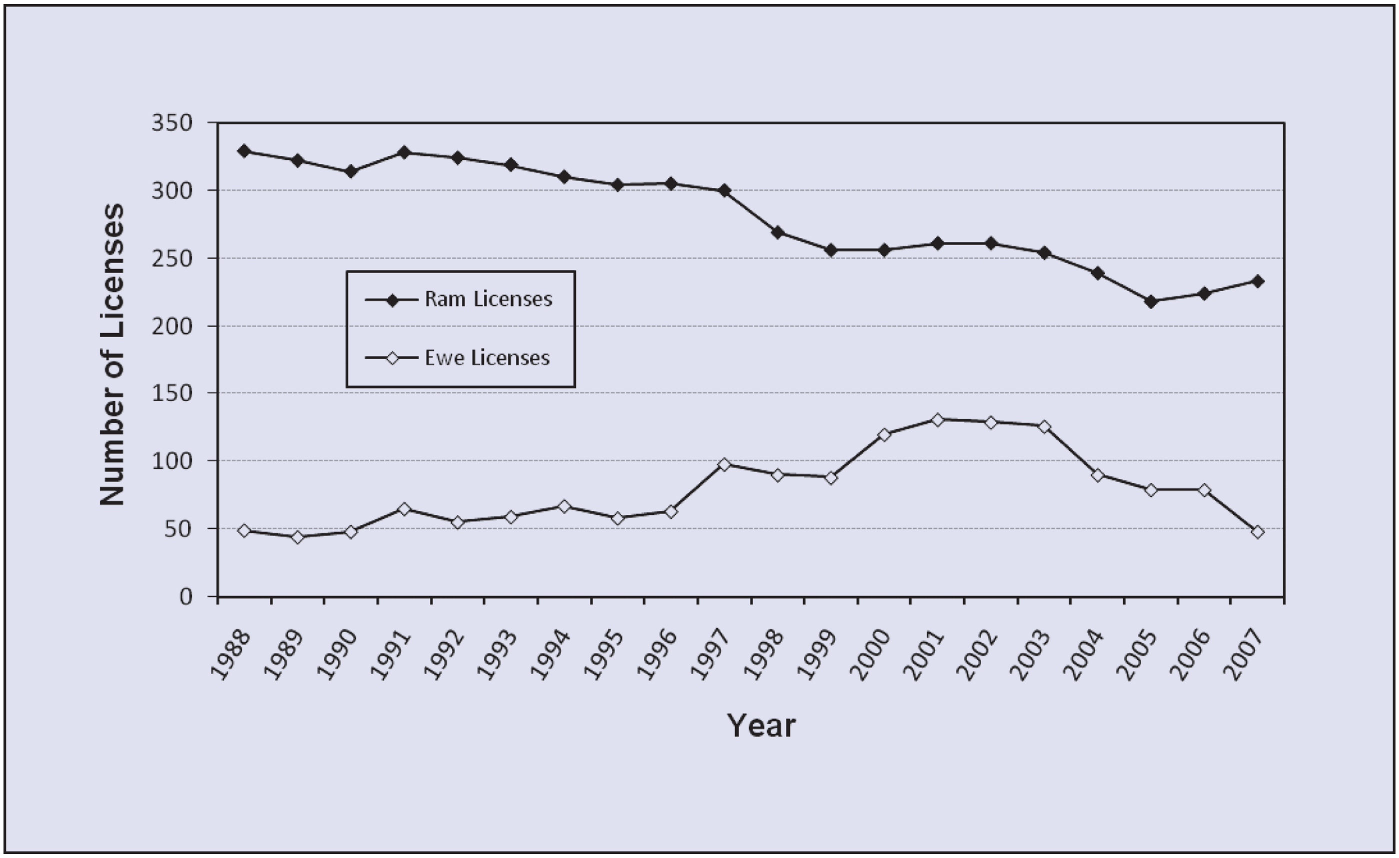

FIGURE 14. The number of hunting licenses issued for Rocky Mountain bighorn sheep in Colorado, 1988–2007.

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Ram harvested from Spanish Peaks (S51) in 2008 by John Legnard.

Ewe harvested in Rampart (S34) by Chris Roe.

Chapter 5

CAPTURE & TRANSLOCATION FOR RESTORATION & AUGMENTATION

Capturing and translocating bighorn sheep (*Ovis canadensis*) have been important elements of bighorn sheep management in Colorado since the 1940s. Scientific knowledge about population estimation, survival, herd movements and diseases affecting bighorn sheep has improved as a result of capturing and releasing bighorn sheep marked with tags or radio telemetry devices, and numerous bighorn populations have been reestablished or supplemented over the last 60 years via translocations.

In the future, capture and translocation will continue to be used as management tools for bighorn sheep in Colorado and will be used as prescribed in population management plans in order to achieve local and statewide bighorn sheep management goals related to augmenting existing populations, reestablishing populations in historical ranges, enhancing genetic diversity, establishing new populations, gathering data for research or management purposes, and exporting animals to other jurisdictions to assist in range-wide species restoration and conservation programs.

Management Goals & Strategies

To accomplish statewide bighorn management goals the following goals and strategies will apply:

Capture & Translocation

Management Goal

Capture or acquire bighorn sheep to gather biological information or to translocate individuals for reintroduction into historic or suitable habitat or augmentation of existing populations.

Strategy: Capture and handling of bighorn sheep will follow the Division's Bighorn Sheep Capture and Translocation Guidelines. (George *et al.* 2008).

Strategy: Annually determine capture needs and purposes, as well as suitable sites and source herds from within and out-of-state sources. This information will be used as part of the yearly trap and transplant plan.

Strategy: Removals of bighorn from source herds for translocation should be treated the same as removals by hunting. Therefore, translocations removals should further meeting Data Analysis Unit (DAU) plan objectives and follow removal goals and strategies. *See Population & Harvest Management, Ch. 4:*

Strategy: Develop and use approaches for capturing bighorn sheep for translocation that minimize potential adverse effects of removals on social structure and perpetuation of traditional migration and movement patterns of source herd units.

Strategy: Determine the health status of source herds prior to translocation to help ensure the greatest probability of transplant success and to minimize any risk of introducing disease to bighorn sheep in nearby herd units.

Reintroductions

Management Goal

Establish bighorn sheep herds and populations in suitable but unoccupied habitat.

Strategy: Conduct a habitat evaluation of proposed translocations sites as described in George *et al.* (2008) to determine if adequate suitable habitat is present and to project maximum geographic expansion of the transplant.

Strategy: Select reintroduction sites that have been identified as historic or suitable habitat, that if needed have been enhanced through natural events or habitat management activities.

Strategy: Avoid transplanting bighorn sheep into or adjacent to habitat occupied by domestic sheep and/or domestic goats. The anticipated maximum expansion of reintroduced bighorn herds should not overlap areas occupied by domestic sheep and/or domestic goats.

Strategy: Notify and coordinate with affected land use agency/owners prior to bighorn reintroductions.

Strategy: Identify bighorn sheep reintroduction sites as part of the DAU planning process and secure approval as part of the yearly trap and transplant plan. The trap and transplant plan will be coordinated at the biologist and staff levels to prioritize the reintroductions sites. Requests for bighorn sheep from other states will be considered and prioritized with Colorado sites.

Strategy: Source stock recommendations in George *et al.* (2008) will be followed whenever possible. Reintroductions will include at least 25 bighorns (2-3 young rams:10 ewes) from a single source herd. Source stock from indigenous, migratory herds is preferred.

Augmentations and Range Extensions

Management Goal

Augment bighorn sheep populations when necessary to increase sheep numbers, extend range, and/or increase genetic diversity without introducing disease or otherwise harming source or recipient populations.

Strategy: Conduct a habitat evaluation of proposed augmentation and range extension sites as described in George *et al.* (2008) to determine if adequate suitable habitat is present and to project maximum geographic expansion following translocation.

Strategy: Avoid range extension translocations if the extended range will bring bighorn sheep into contact with domestic sheep or goat populations.

Strategy: Populations of sheep with low numbers relative to historical numbers and history of low lamb survival (<20 lambs:100 ewes) and/or a history of disease problems will not be candidates for augmentation unless it is determined that disease, predation or habitat are not the limiting factors or translocations are part of a research or experimental management program.

Strategy: Bighorn sheep populations that might benefit from augmentation and range extensions will be identified through the DAU planning process and prospective release sites will be identified and approved as part of the yearly trap and transplant plan. The trap and transplant plan will be coordinated at the biologist and staff levels to prioritize the augmentation sites.

Strategy: The disease status (e.g., the presence and rate of carriage of or exposure to specific pathogens, history of epidemics and/or recruitment problems, etc.) of the augmentation herd and source herd must be known prior to release of sheep to minimize health risks to established and released animals.

Strategy: Notification of and coordination with affected land management agencies/land owners and other interested parties will occur prior to an augmentation or range extension.

Background & Literature Review

Colorado has a long history of translocation projects both to move bighorns within the state and to export animals to other states. The first record of an organized trap and transplant project was in September of 1944 using a corral type trap near Sugarloaf Mountain in Park County to remove surplus animals from the Tarryall Mountains herd (Hunter *et al.* 1946). Since that first effort, the trapping and transplanting projects have evolved to a process which is efficient and provides for the greatest safety for those handling the animals and the animals.

Translocation projects have historically been done to augment populations, provide genetic diversity to a population, reintroduce bighorn sheep to historic range or new suitable habitat, or to supply stock for other states that are establishing or restoring bighorn populations. Capture to mark sheep with ear tags, neck collars or radio transmitters to measure survival rates, sightability, movements, and treatment of diseases has been done. In Colorado, acceptable reasons for capture and movement of wildlife are:

- Augment existing populations
- Reestablish populations
- Enhance genetic diversity
- Establish new populations

- Scientific data collection for research or management purposes
- Export wildlife to other states to assist them in their wildlife management programs and to compensate them for providing wildlife to Colorado for purposes listed above

Translocations and Genetic Diversity

Augmentation proposals should be carefully evaluated because of the risk of transmitting novel pathogens. It is often assumed that loss of genetic variability due to inbreeding is the cause of poor population performance. Although low heterozygosity has been observed in some bighorn sheep populations, inbreeding depression has not been demonstrated as the cause of low survival and recruitment in any captive or free-ranging bighorn sheep population. Moreover, some Colorado populations with documented low heterozygosity have done well (e.g. Rampart Range S34). While low genetic diversity should be considered as a possible explanation for declining populations, inadequate habitat, high rates of predation, disease, or a combination of factors may be restricting population growth which will not be resolved by adding animals. The true cause of poor population performance should be identified and corrected before supplementing from another herd.

Minimum numbers and sources of animals for transplants.

The minimum numbers and source of animals used as founding stock has received much debate. The primary concern is loss of genetic diversity by transplanting too few individuals to adequately represent source herd genetic composition, thus resulting in reduced population viability. The effects of low founding numbers to genetic variability may be reduced by translocations into large patches of suitable habitat resulting in rapid population increases. Although investigators and managers have attempted to address genetic diversity in translocations, a relationship between herd performance and founder size has not been clearly demonstrated. While the effects of founder numbers on translocation success remain unclear, translocation costs (>$1,000/animal) and risks of disease transmission and injury associated with capturing and translocating bighorns have been demonstrated.

Two studies (Luikart and Allendorf 1996, Fitzsimmons *et al.* 1997) found greater genetic variability in indigenous herds than in previously translocated herds, and Singer *et al.* (2000) found greater translocation success rates associated with indigenous source stock. They also found that mixing genetic stocks did not improve translocation success (Singer *et al.* 2000) and this practice increases the risk of disease transmission.

Other Genetic Considerations.

Conservation genetics theory predicts that specific, isolated populations of a species may be better adapted to surviving in their local environments. These populations may have a genetic makeup differing from other populations of the same species and may be better able to survive and reproduce in their respective environments. In support of this theory, genetic studies of bighorn sheep have indicated that genotypes of populations in close proximity are more similar than populations separated by larger distances. This implies that translocation stock should be taken from habitats that are nearby and similar to the proposed release site unless specific genetic studies of the source and recipient herds indicate otherwise.

Source Population Impacts

Removals of bighorn sheep for translocations may have significant impacts on source herds (Stevens and Goodson 1993). Impacts are often magnified when removals are concentrated in a single subpopulation such as with drop-net and corral trap captures. Impacts to social structure and population dynamics should be considered prior to removals. Candidate source herds should have at least 10 years of population data including annual population estimates, an understanding of herd structure and unique movement patterns of individual bands, and observed winter lamb:ewe ratios.

Assessment of Translocation Success

Capture and translocation projects have provided managers with useful management information. The long history of trapping for relocation purposes has had successes and failures with about 52% of the transplants considered successful and resulting in a population greater than 50 sheep (Bailey 1990). It should be noted that the Division has records of 92 translocations of Rocky Mountain bighorn sheep prior to 1989 whereas Bailey (1990) reported on only 57. Some of the disparity could be related to multiple releases into the same area being considered separate versus single translocation efforts. Prior to June 2007, multiple releases into the same site or herd complex have accounted for 27 releases. Multiple releases have both advantages (increased genetic diversity, higher number of animals released) and disadvantages (potential of disease introduction, cost).

Since Bailey (1990) finished his trap and translocation evaluation, the Division has completed 50 (Appendix III) additional translocation releases (includes 4 desert bighorn releases) in Colorado (January 1, 1989 through June 30, 2007). Of these projects, 44 involved sheep translocated within Colorado and 6 involved sheep brought in from out of state.

There have been 17 translocation projects where Colorado provided Rocky Mountain bighorn sheep for other states (6 to Nevada, 4 to Utah, 3 to Arizona, 2 to Oregon, and 1 each to South Dakota and Nebraska). There have been 13 translocation projects where Colorado received desert bighorns from out-of-state (7 from Nevada, 5 from Arizona, 1 from Utah) and two instances where Rocky Mountain bighorn sheep were transported from British Columbia for release in Colorado (released in the same drainage at the same site 2 days apart).

Translocations can be for supplementation (i.e., translocated bighorns are not considered the primary origin of the herd) or to establish new herds. Overall, translocated herds in Colorado have been less successful and less likely to provide hunting opportunities than native or supplemented herds (Table 5). Since 1986, herds that could be considered unsuccessful (based on a minimum population of ≤ 25 sheep in 2007), include 12 transplanted herds, 2 supplemented herds, and 1 native herd.

The Arkansas River population (S7, S47, S49, and S68) has received 6 transplants resulting in a combined 2007 population of approximately 520 animals in these units. DeBeque Canyon and Battlement Mesa have received 3 transplants each, but there has not been enough time since these releases to determine how successful they will be. Glenwood Canyon has received 3 transplants and has a current population estimate of 35 animals; this population has experienced losses due to pneumonia. Mount Zirkel (S73), Clinetop Mesa (S14), Dinosaur National Monument, the West Needles (S71), Apishapa River (S38), and Big Thompson River (S57) all have received 2 releases. The West Needles herd (S71) releases occurred in 2000 and 2002 with an estimated 75 animals in 2007; S71 was opened for hunting in 2007. The 2 Mount Zirkel (S73) releases occurred in 2005 and S73 will open for hunting in 2009. Dinosaur National Monument has an estimated 165 animals. The Apishapa River herd (S38) is estimated at 70 animals and is noted for large rams. This herd is the only transplant since 1989 that is located east of Interstate Highway 25. Even with 2 releases the Clinetop Mesa (S14) population is estimated at 5 animals.

The only Rocky Mountain bighorn transplants into Colorado from out-of-state, except for a private herd in GMU 105, originated in British Columbia and were released on the Forbes Trinchera Ranch (S65) in two separate groups (releases occurred at the same site only 2 days apart). This herd was estimated at 400 animals in 2007 making it the largest translocated herd in the state. The S65 herd is being used as source animals for transplant projects into other areas but not in areas in Colorado where there are extant bighorn sheep

TABLE 5. Origin of Colorado bighorn sheep herds in relation to herd size and hunted status in 2007. See Appendix I for definitions of Native, Supplemental, and Translocated herd origins.

Herd origin	Total herds	Herds with ≥ 100 sheep in 2007	% of herds with ≥ 100 sheep in 2007	Total herds outside of National Parks or Monuments	Herds open to hunting in 2007	% of herds open to hunting in 2007
Native	17	10	59	16	14	88
Supplemented	20	7	35	19	15	79
Translocated	45	10	22	43	28	67

populations. All 4 desert bighorn sheep populations in Colorado originated from translocations from out-of-state. Three of these populations have provided hunting opportunities and have been moderately successful.

The remaining 14 releases are single group releases with a wide range of apparent outcomes: the current population estimate for Trinchera Peak (S51) is 250 animals, but in the Lower Poudre Canyon and Seaman Reservoir releases there are only an estimated 20 animals remaining. Insufficient data are available to assess the status of the other releases.

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Desert bighorn sheep capture in Utah for translocation to S63.

Chapter 6

HABITAT MANAGEMENT

The quality and quantity of bighorn sheep (*Ovis canadensis*) habitat ultimately limits the number of bighorns that Colorado can support. Thirty-five of 53 bighorn sheep unit descriptions prepared by Division of Wildlife (DOW) biologists in 2006 identified deterioration of habitat quality due to fire suppression and plant succession, on US Forest Service (USFS) lands, as a limiting factor for that population of bighorns. Most bighorn habitat is managed by the USFS and the Bureau of Land Management (BLM). It is imperative that the DOW maintain a cooperative and collaborative relationship with these agencies with frequent and constructive discussion. Local, county, and state governments and private landowners also make decisions which may impact bighorn populations through loss or degradation of bighorn sheep habitat. The Division should provide these entities with current and accurate bighorn sheep distribution maps, and provide input on decisions that impact bighorn habitat.

Management Goals & Strategies

Management Goal

The DOW will work to protect all bighorn habitat that is currently in good condition, and to take advantage of opportunities to improve situations where habitats are in fair or poor condition or where other factors limit potential for bighorn populations to thrive. In some cases DOW will be directly involved in such habitat work; in many other cases, however, DOW's role more likely will be to provide technical expertise and in some cases funding to USFS, BLM, landowners, and counties to protect and improve important existing and potential bighorn habitat that has been identified through the Data Analysis Unit (DAU) planning process..

Strategy: Occupied and potential bighorn sheep habitat will be delineated in a Geographic Information System (GIS) and limiting factors will be identified for all bighorn populations as part of the bighorn DAU planning process.

Strategy: Partnerships and collaborative approaches will be established with appropriate agencies, industries, and non-governmental organizations to identify opportunities and fund activities to improve bighorn sheep habitats.

Management Goal

The distribution of bighorn sheep will be expanded as new potential ranges are identified due to changes in land use (retirement of domestic sheep grazing allotments) or natural events (large-scale fires).

Strategy: The DOW will not solicit the retirement of active domestic sheep allotments and will not solicit changes in animal type, but may take advantage of those circumstances or support the changes of a willing permitee, and may solicit the closing of vacant allotments, in order to expand bighorn distribution into unoccupied areas or to secure existing populations from perceived threats.

Strategy: In the event a natural stand replacement disturbance of a large scale occurs (e.g., Hayman and Mesa Verde fires) in suitable habitat, the DOW should evaluate the quality and quantity of habitat and work with land management agencies or land owners to determine whether a bighorn range extension should occur or whether a new population could be established.

Management Goal

The Division will work with land managers to use natural and prescribed fires to restore degraded habitats to a higher quality.[1]

Strategy: The USFS National Fire Plan has broad implications in all national forests of Colorado and many bighorn sheep habitats may be improved while

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[1] Natural fire use is the management of naturally ignited wildland fires to accomplish specific prestated resource management objectives in predefined geographic areas outlined in Fire Management Plans. Prescribed fires are any fires ignited by management actions to meet specific objectives

influencing the timing and location of fires used to accomplish multiple resource objectives. The DOW should be actively involved in habitat management/fire plans of land managers that can be used to improve many wildlife values and habitat condition while minimizing the likelihood and frequency of uncontrolled wild fires.

Management Goal

Within the scope of the Division's authority to comment on or manage roads or trails, the design and development of new roads and trails, improvement of existing roads and trails, and use of all-terrain vehicles should not expose bighorns to excessive activity of people and domestic animals (e.g. dogs and pack goats). Often, bighorn sheep will move away from otherwise suitable habitat due to increased human use.

Strategy: The Division should work closely with land managers while developing Travel Management Plans to ensure adequate human access is maintained while providing for secure undisturbed areas for all wildlife and resource protection. On some trails, domestic dogs and pack goats should be prohibited.

Strategy: The Division will monitor conflicts between bighorn sheep and ATV's and will work with land managers to address these conflicts. Roads and trails can be re-aligned, the type of use changed, or closed and rehabilitated when resource damage is adequately demonstrated.

Background & Literature Review

Habitat Description

General descriptions of bighorn sheep habitat are available in many sources (Beecham 2007, Buechner 1960, Geist 1971, Risenhoover and Bailey 1985, Van Dyke *et al.* 1983, McCarty and Bailey 1994). Bighorns are adapted to a wide variety of habitats, from sea-level to alpine, from badlands of the plains to the Rocky Mountains to the true deserts of the southwest. The consistent distinguishing feature of bighorn habitat is that it is open and has access to very steep escape terrain. Bighorns are social animals, using grouping as a predator defense mechanism (Bleich *et al.* 1997) and preferring open habitats for feeding to enhance predator detection and avoidance. Escape terrain is particularly critical to ewes and ewe-lamb groups, to the extent that those groups will sacrifice forage quality to obtain higher security from predators (Bleich *et al.* 1997, Shackleton *et al.* 1999). In Colorado, bighorns occupy a wide range in habitat from the Front Range and eastern river canyons through the mountains and into the large river canyons of the western slope. Many habitat models have been created for desert and mountain bighorns (Smith *et al.* 1991, DeYoung *et al.* 2000, McCarty and Bailey 1991, Armentrout and Brigham 1988, Zeigenfuss *et al.* 2000, Turner *et al.* 2004, Dunn 1993, McKinney *et al.* 2003, DeCesare and Pletscher 2006, Schoenecker 2004, Johnson and Swift 1995, Johnson and Swift 2000, Johnson 1995). In Colorado, bighorn sheep habitat quality is determined by its openness, diversity, forage quality, over-story composition.

Habitat Evaluation

Key elements of suitable bighorn habitat include steep, broken terrain, which serves as escape cover, and vegetation types that provide high visibility and forage such as grasslands and alpine tundra. Bighorns are primarily grazers, but also consume browse. They are not well adapted to deep snow, therefore winter snow pack can limit distribution and survival. For these reasons, many of Colorado's largest bighorn herds are associated with landscapes receiving warm, down slope, winter winds or low to mid-elevation cold desert habitats.

Spatial habitat evaluation procedures using GIS should be used to provide a quantitative evaluation to aid in the overall evaluation of proposed translocation sites. Stepwise spatial evaluations of the five physical habitat attributes should be completed as described in Table 1 of the Colorado Bighorn Sheep Capture and Translocation Guidelines (George *et al.* 2008). In addition, GIS evaluation of domestic livestock grazing presence should be included where available. In the case of supplemental transplants and range extensions, the GIS evaluation should be applied to the entire area the population is expected to occupy including areas already occupied by bighorn sheep. Additional criteria for evaluation may include distance to domestic sheep and goats, water availability, and vegetation types and density. Details of bighorn habitat evaluation are provided in the Bighorn Sheep Capture and Translocation Guidelines (George *et al.* 2008); see Appendix II for an example application.

Habitat Management

Grazing
– cattle, sheep, wild ungulates, fences

Competition with domestic and wild ungulates can potentially affect bighorn sheep. Food habits, forage preferences, and distribution patterns of wild and domestic sheep are very similar (Krausman *et al.* 1999). Several studies have examined the food habits and distribution patterns of cattle and a few wild ungulates in relation to bighorn sheep. There is more diet overlap between bighorn sheep and cattle, elk (*Cervus elaphus*), and domestic sheep, and less overlap with mule deer (*Odocoileus hemionus*) and mountain goats (*Oreamnos americanus*) (Streeter 1969). McCullough (1982) studied cattle and bighorn sheep food habits and distribution patterns on Trickle Mountain. Even though many forage species were grazed by both herbivores, the impact of cattle grazing was mitigated by habitat segregation - cattle only used 5% of the area critical to bighorn sheep, by using areas closer to water and with less slope. Bleich *et al.* (2005) discuss fence modifications that can be less detrimental to wildlife, as well as several range management practices that can accomplish both grazing and wildlife benefits.

Fires
– prescribed and natural, suppression

Many managers have used prescribed fire to manipulate vegetation to improve sheep habitat, and some wild fires have been studied in relation to sheep habitat and distribution. Because of wide-spread fire suppression for 100+ years in many sheep habitats, the loss of "openness" due to the encroachment of shrubs or trees is seen as a limiting factor and might be negatively impacting the demographics of many populations. Nelson (1976) found increased protein (4 years), calcium and phosphorus (2 years) following prescribed fires, and stated that sheep seem to survive best in ecologically stable habitats, and through social mechanisms are limited in their population dispersal capabilities (Geist 1971). Fire may be necessary to maintain some habitat conditions in a suitable condition. Peek *et al.* (1985) stated that fire can be used to reduce or retard encroachment of brush or coniferous species into sheep habitats. Some fires create habitat by removing overstory while other fires can be used to maintain areas in a grassland or shrub-steppe type. In fire dependent systems, the effects might be short-lived and therefore the response of sheep is expected to be short-lived. In addition, they caution that a fire may have deleterious effects when vegetation is in poor condition, a fire is too severe or too large, or when other ungulates are attracted to the fire. Peek *et al.* (1979) found that bighorns grazed burned sites significantly more than adjacent unburned sites for 4 years. Bighorns have been associated with stable, long-lasting climax grass communities (Geist 1971), and as a result bighorns have been considered by some (Nelson 1976) as being adversely impacted by fire. Peek *et al.* (1979) concluded that fire can be useful to retard succession and improve production and palatability of individual forages. Hobbs and Spowart (1984) evaluated a prescribed fire in grassland and mountain shrub habitats. Dietary protein and in vitro digestible organic matter increased in winter diets but not in spring diets. Protein and in vitro digestible organic matter (IVDOM) benefits were short-lived (1-2 years). They determined that dietary benefits were due to selection of specific species and plant parts rather than change in the quality of individual forages; green grass was more abundant following the fire. This also suggests that a prescribed fire may provide 2 temporal flushes of new growth forage because burned areas green-up earlier than adjacent unburned sites. Holl *et al.* (2004) found that sheep responded positively to wild fires in the San Gabriel Mountains of CA whereas fire suppression decreased habitat quality and restricted sheep distribution due to canopy closure. Woodard and Van Nest (1990) demonstrated that a prescribed crown fire during the winter could restore necessary sight distances to encourage bighorn use of previously vacant habitats. Smith *et al.* (1999) found bighorns readily moved into sagebrush-juniper stands that were burned and made more open. Seip and Bunnell (1985) compared diets on burned and unburned Stone's sheep ranges and found that forage quality, fecal protein, and forage minerals were similar, though lungworm loads were less in burned areas and lamb production was higher. Bleich (in prep) found a strong positive relationship between the springtime distribution of sheep within 15 years of a fire, and a strong negative relationship beginning 15 years following fire, in the fire dependent chaparral habitat. Prescribed and managed wildfires can be used to create or improve the condition of bighorn habitat, create movement corridors, provide access to water, and may temporarily increase herd productivity by maximizing nutrient intake (Beecham *et al.* 2007).

Mining
– gravel, mineral, petroleum

The process of mineral extraction can have impacts on sheep whether it is a liquid, solid or aggregate resource, and whether it is surface disturbance, subsurface, or point-source extraction. Bromley (1985), determined that the most likely impact will be due to behavioral changes, stress, and change in distribution, rather than direct loss of habitat due to steepness and ruggedness. Bromley (1985) also speculated that activity at the top or bottom of a slope might be disastrous to bighorn sheep with severe impacts on a population. This was due to: 1) interruption of activity with alarm and flight response, 2) avoidance and displacement from preferred habitats (Geist 1978), 3) permanent loss of habitat, 4) decreased reproductive success (DeForge 1976), 5) interference, 6) direct mortality, 7) alteration of behavior (Campbell and Remington 1981, Leslie and Douglas 1980), and 8) change in community structure. The exploration phase of mineral extraction might involve the use of off-road vehicles, thumper trucks, helicopters, and explosives. Light (1971) and Dunaway (1971) found abandonment of historical sheep ranges due to extensive activity by humans, and that ewe and lamb groups were the most sensitive. Wehausen *et al.* (1977) refuted Dunaway's theory of range abandonment, and found that sheep activity patterns were influenced, but not severely influenced, by frequent encounters with humans. MacCallum and Geist (1992) demonstrated how a coal strip mine could be reclaimed to restore bighorn habitat. They successfully built steep escape terrain, more gentle feeding areas seeded with grasses and legumes, and took advantage of mineral licks exposed during mining. Dale (1987) found that sheep readily used a reclaimed gravel pit in Waterton Canyon, presumably because of the seeded grasses and forbs. Oehler *et al.* (2005) studied mountain sheep using an area being mined for gold ore, and particularly a spring presumed to be critical to the sheep. Ewes using the mine area were dependent on the spring for water and appeared to be more vigilant and spent less time feeding during the summer, when mining activity was the highest. Diet quality was lower for these ewes, which if these conditions persisted might lead to reduced nutrient intake and possible demographic consequences. They believed that providing a water source away from the active mine might ameliorate the majority of the negative impacts. Jansen *et al.* (2006) found that bighorns in an open pit copper mine in AZ used select habitat features similarly to bighorns away from the mine. Habitat islands and high walls were used for feeding and escape terrain similar to natural features. Bleich (pers. comm., in prep.) has also studied bighorns near high-wall limestone mines in CA and found that a resource selection function was more impacted by a recent fire than by mining. Conclusions from each of these four studies in active mine areas indicate that mountain sheep can habituate to mining activity as long as suitable forage and escape terrain are present and human activity is predictable. In contrast, Risenhoover (1981) found that sheep avoided areas near roads, were more alert and had lower feeding efficiency when they were closer to a dam construction site.

Human disturbance

Wild sheep have habituated to human activity in many areas where the activity is somewhat predictable temporally and spatially (Beecham *et al.* 2007). Specific activities may be more detrimental than others. Heli-skiing, snowmobiling, walking with dogs, and activity near lambing areas may be most detrimental (Graham 1980, MacArthur *et al.* 1982, Etchberger *et al.* 1989) unless bighorns can become more habituated to such activities. Krausman *et al.* (1999) considered desert bighorns to be relatively intolerant of human activities, but stated that quantitative data are lacking. Light and Weaver (cited in Krausman *et al.* 1999) studied bighorns in relation to the development of a ski area, and found that bighorns were displaced by human activity. Holl and Bleich (1983) recognized that bighorn sheep moved in response to the presence of sheep researchers: At distances >645 m, bighorn were not concerned with their presence; however, at 440 m sheep fled the area. Stanger *et al.* (1986) found little reaction by desert sheep to riverboats in Utah; only 3% changed their behavior in response to riverboat activity. The potential implications of additional human activity associated with energy exploration and extraction in occupied bighorn ranges may be an emerging source of disturbance for some populations.

Fertilizers and herbicides

Many investigations have been made into

approaches for increasing the quantity and quality of forage by fertilization for a wide variety of ungulates. The results of those efforts are quite similar in most studies and across most habitat types. Bear (1974, 1975, 1976) applied nitrogen and phosphorus fertilizers to high and low elevation sheep ranges at conventional rates (30, 60, and 90 lbs N/acre, 0 and 30 lbs P/acre). There was significantly more herbaceous production observed with nitrogen (6%, 19%, and 24% at N rates 30-60-90 respectively) and minimal increase with phosphorus for 3-5 years. Earlier green-up of vegetation occurred on fertilized plots which may have management application for holding sheep on low elevations longer or to prolong their use of mid-elevation transitional ranges. Elk were attracted to the lower elevation Cebolla Creek site in higher numbers than without fertilization; there were not enough sheep on that site to evaluate a change in their use. At high elevation in the La Garita Mountains, no change in production or sheep use or distribution was seen in relation to fertilization.

Carpenter and Williams (1972) conducted a thorough literature review of the role of fertilizers in big game range improvements. They found that fertilizers could often increase forage yield, protein content, and palatability. The effect of fertilizers on individual or population performance (survival and production) has not been evaluated for bighorn sheep.

Bear (1974, 1975, 1976) also attempted to change herbaceous composition by applying 2,4-D at rates 0-2 lbs/acre. Total herbaceous production was lower with the herbicide application than without. Carpenter and Williams (1972) also reviewed the literature pertaining to herbicide use and found the degree of plant kill varied with application rate, season, and temperature. Forb production was usually reduced or eliminated while grass production increased

Overstory manipulation

– timber management, mechanical brush removal, herbicides

Smith *et al.* (1999) used clearcut logging to remove overstory forest cover and prescribed fire to rehabilitate sagebrush to improve bighorn range in UT. They found that sheep responded more positively to removal of forest cover but also benefited from the prescribed fires. Bleich and Holl (1982) reviewed the use of mechanical, chemical, handwork, livestock grazing, and burning to manipulate the overstory to benefit mule deer or mountain sheep. Each method produced varying effects and had different cost factors. Desired objectives can be achieved for each wildlife population and vegetation structure, but their review dealt specifically with chaparral vegetation that is extremely fire dependent. Similar results might be expected in other fire dependent habitats, but not in fire intolerant systems. Yde *et al.* (1984) used logging and fire to improve habitat for sheep in an area impacted by a new reservoir and highway that displaced sheep. Bighorn sheep used a logged area for lambing following treatment. Rominger (1983) used photographic evidence to substantiate the loss of suitable habitat due to the encroachment of oakbrush at low elevations and Douglas-fir at higher elevations in Waterton Canyon. Oaks were mechanically thinned and herbicides were used to inhibit sprouting. A short term positive response was noted but this was not seen as a long term solution on a large scale.

Water developments

Water has been identified as a limiting resource to desert sheep only during certain seasons and in some habitats (Turner and Weaver 1980). Bighorn sheep can generally obtain necessary water either from preformed water in food or metabolic processes when free water is not available (Krausman *et al.* 1999). Potential adverse effects of water developments include increased predation at water sources, drowning or starvation, disease transmission, and introduction/expansion of non-native species (Dolan 2006). Water has not been identified as a limiting resource in Colorado. Even in the several populations of desert bighorns, free water has not been identified as a limiting resource, probably because most desert sheep habitat occurs along major river systems. Even though water is not a limiting resource, water certainly effects bighorn sheep distribution (Dolan 2006, Leslie and Douglas 1980) and appears in nearly every habitat model developed for both mountain and desert bighorns (Turner *et al.* 2004). An artificial source of water was developed in Summit Canyon in San Miguel County (desert bighorns) where suitable habitat existed but bighorns were rarely seen. Within one year sheep were using the canyon and water source (Chris Kloster, CDOW pers. comm.). Various designs have been tested and are available (Dolan 2006, Bleich *et al.* 2005).

Fragmentation

Fragmentation of habitat has repeatedly been investigated in relation to population persistence and population extirpation (Berger 1990, Krausman *et al.* 1996, Wehausen 1999, Singer *et al.* 2001, McKinney *et al.* 2003). The distribution of bighorn sheep has declined and numbers have decreased, leading to populations that are isolated from occupied ranges that were once connected (Dolan 2006, Buechner 1960). Bleich *et al.* (1996) found that habitat fragmentation has had impacts to movement patterns within metapopulations that has seriously affected opportunities for movement of bighorn sheep within some populations. McKinney *et al.* (2003) found that escape terrain patch size, number of patches, and percent of landscape characterized by slopes >40% were positively correlated with estimated desert bighorn sheep population size. Highways through sheep habitat are becoming barriers to movement as vehicle traffic volume increases and highways are expanded to accommodate increased volume (Beecham *et al.* 2007). Many US and state highways in Colorado bisect sheep habitat and may be interrupting efficient use of habitat or connection of seasonal ranges. While most habitat fragmentation impacts are detrimental to bighorn sheep populations, particularly at the metapopulation level, reduction in disease transmission accomplished by limitations to bighorn sheep and domestic livestock movements may be a benefit.

Migration

Seasonal migrations can increase carrying capacity for wild ungulate populations by allowing more optimal use of resources. Avoidance of predation has also been hypothesized as an advantage of migration (Wehausen 1996, Fryxell *et al.* 1988). High elevation summer ranges are commonly regarded as an extra nutritional resource that can boost carrying capacity (Hebert 1973, cited in Wehausen 1996) by allowing ungulates to stay on new growth vegetation for a longer period of time. Alternatively, in some habitats, winter range can be a source of extra nutrient input for the population, depending on the seasonality of wet seasons (Wehausen 1996). Migration also may contribute to sexual segregation distribution patterns, where females with young may sacrifice quality forage to minimize predation risk, while males maximize forage quality (Bleich *et al.* 1997). Migratory patterns appear to be traditional and learned behaviors and may be compromised or extinguished by losses from disease epidemics and perhaps translocations; historically, over-harvest also may have contributed to the loss of seasonal migration behaviors in some herds and populations. Establishing or reestablishing traditional migratory patterns in translocated bighorns appears to be problematic in most cases, and lack of migratory movement (seasonal or otherwise) may contribute to failure of some translocated herds.

Minerals

Bighorn sheep have been observed to seek out and concentrate near mineral licks, and to heavily utilize these soils (Buechner 1960, Keiss 1977). Although Geist (1971) suggested that mineral salts are nutritionally important to mountain sheep, there is no conclusive evidence that the minerals they provide are limiting bighorn populations. Various minerals have been identified in higher concentration in salt licks than in surrounding soils (e.g., calcium, iron, zinc) but there was no consistent pattern observed, suggesting that sheep used licks for some reason other than meeting a deficiency (Keiss 1977). There is still research interest in the relationship between sheep herd performance and minerals. In particular, selenium has been suggested as a possible limiting factor for bighorn sheep (Mioncyzinski 2003), but controlled studies are lacking. There is evidence of sheep making long range seasonal movements to utilize mineral licks in Whiskey Basin, Wyoming which exposed the sheep to higher predation risks (Anderson 2004).

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Desert bighorn sheep in the Dominguez Creek Herd (S62).
Photo by Ryan Lockwood.

Chapter 7

HEALTH MONITORING & MANAGEMENT

Bighorn sheep (*Ovis canadensis*) are unique among Colorado's big game species with respect to the influence that infectious diseases have on population performance and species abundance. The susceptibility of bighorn sheep to pathogens originally introduced by domestic livestock is regarded as the primary factor limiting Rocky Mountain bighorn sheep populations in Colorado. Moreover, the continued presence of introduced pathogens appears to have played an important role in preventing statewide bighorn numbers from rebounding to some approximation of historical levels, as deer and elk have done.

Respiratory disease is by far the most important health problem in contemporary bighorn populations. In addition to initial all-age die offs, pneumonia epidemics in bighorn sheep can lead to long-term reductions in lamb survival and recruitment resulting in stagnant or declining populations over many years. A number of other pathogens and parasites also affect bighorn sheep in Colorado and can cause some mortality, but are generally not considered limiting except possibly for small, struggling populations. It follows that maintaining and improving the health of bighorn populations, particularly with respect to preventing or mitigating the effects of respiratory disease epidemics, is a critical element of success in achieving other management goals for bighorn resources statewide.

Management Goals & Strategies

Management Goal

Prevent epidemics of introduced and endemic diseases that adversely impact bighorn population performance and viability.

Strategy: Conduct research and surveillance to identify key pathogens and pathogen sources that can be managed to prevent epidemics.

Strategy: Develop, evaluate, and use appropriate tools, management practices, and policies (e.g., species and herd segregation, vaccines, therapeutics, habitat management, harvest and dispersal) to control pathogen exposure and/or protect bighorn populations from select pathogens.

Management Goal

Recover bighorn populations from the effects of epidemic and endemic diseases that have sustained effects on bighorn survival and recruitment.

Strategy: Conduct research and surveillance to identify key pathogens and pathogen sources that can be managed to improve recruitment and recover populations after epidemics.

Strategy: Develop, evaluate, and use appropriate tools, management practices, and policies (e.g., species and herd segregation, vaccines, therapeutics, habitat management, harvest and dispersal) to control pathogen exposure and/or protect bighorns from select pathogens to improve recruitment and recover populations after epidemics.

Background & Literature Review

Infectious and parasitic diseases cause significant periodic mortality in bighorn populations. Because certain diseases can dramatically impair bighorn population performance, they are collectively perhaps the single greatest obstacle to long-term success in bighorn management. For reasons that aren't completely understood, bighorn sheep appear particularly susceptible to a wide variety of diseases. This inherent susceptibility, combined with numerous opportunities for exposure to both endemic and introduced pathogens, has probably allowed disease to play major roles in both historic declines and continued depression of bighorn abundance in Colorado.

Epidemics associated with large-scale mortality events in bighorn sheep in Colorado historically have generally been described as either "mange" or "pneumonia" outbreaks, although the former have not been recorded for over 50 years in Colorado's bighorn populations.

Mange

Outbreaks of mange (also called "scab" or "scabies", and most likely caused by *Psoroptes* spp. mites) were first reported in several Colorado bighorn populations in the late 1800s and early 1900s (Warren 1910, Moser 1962, Bear and Jones 1973). These outbreaks coincided with increased livestock grazing on bighorn ranges throughout the state (Warren 1910, Goodson 1982). Historic accounts suggest losses were substantial in affected populations (Warren 1910, Bear and Jones 1973, Goodson 1982), although the impact of scabies on bighorn numbers statewide cannot be reliably estimated. Mange has not been seen among Colorado's bighorn populations for several decades. Prevalence and distribution (both historic and present) of scabies, along with the causes for its apparent decline since the turn of the century, remain undetermined but may be the result of effective control of mange in domestic livestock. Scabies presently does not appear to be endemic in any of Colorado's bighorn populations, and in the future is most likely to occur via introductions of bighorns from out-of-state or in areas where bighorns come into contact with scabies-infected domestic sheep. Because scabies essentially has been eradicated from domestic sheep in Colorado, future reintroduction from domestic livestock seems unlikely unless status changes. Although scabies can cause bighorn die-offs, it appears likely that historical scabies outbreaks were concurrent with infectious disease epidemics (Moser 1962).

Pneumonia

Since at least the 1920s, periodic respiratory disease outbreaks also have caused significant losses in Colorado's bighorn populations. A variety of bacterial, viral, and parasitic agents have been identified in pneumonia outbreaks throughout Colorado (Potts 1937, Post 1962, Miller *et al.* 1995, George *et al.* 2008). Some of this variation may be attributed to the relatively limited diagnostic capabilities and support available to investigators in earlier investigations, as well as to diagnostic biases inherent in field sampling and changes in the taxonomy of some pathogens. These sources of variation notwithstanding, however, a complex of pathogens apparently can contribute to the onset and severity of pneumonia outbreaks in bighorn sheep. Bacteria (usually in the family *Pasteurellaceae*) and parasitic lungworms (*Protostrongylus* spp.) have been identified most commonly during pneumonia outbreaks in Colorado's bighorn herds; more recently, *Mycoplasma* spp., parainfluenza 3 (PI3) and bovine respiratory syncytial viruses (BRSV) also have been isolated or otherwise detected during epidemics, although the overall importance of these other pathogens isn't clearly understood.

Pasteurellosis

"Suppurative bacterial bronchopneumonia" has remained a consistent diagnostic finding in pneumonia outbreaks among Colorado's bighorn populations for nearly a century. Bacteria, all formerly in the genus *Pasteurella* (but some species now classified in the genera *Mannheimia* or *Bibersteinia*, and collectively called *Pasteurellacea* here) invariably have been isolated from bighorns dying during pneumonia epidemics in Colorado since 1990, and in most epidemics before 1990 where appropriate samples were taken and analyzed. Moreover, *Pasteurellaceae* can be isolated from healthy bighorn herds, although variation in endemic strains has varied among herds sampled (Fig. 15). In addition to indigenous sources of infection, domestic sheep (and perhaps cattle) apparently harbor novel *Pasteurellaceae* strains that are highly pathogenic in bighorns. It follows that controlling pasteurellosis (disease caused by *Pasteurellaceae*) may be more important to comprehensive management of the bighorn pneumonia complex than any other treatment strategy (Miller 2001).

Developing effective ways of managing pneumonia in bighorn herds depends in part on improving knowledge about the epidemiology of pasteurellosis to reveal viable strategies for preventing or controlling disease outbreaks. Transmission of *Pasteurellaceae* either among bighorns or from domestic sheep (and perhaps goats and cattle) most likely occurs through close contact because the responsible bacteria do not survive for extended periods of time in the environment. Understanding sources and transmission dynamics of pathogenic *Pasteurellaceae* strains is a fundamental basis for devising and improving approaches to bighorn herd health management. Ongoing field work seeks to characterize and compare *M. haemolytica*, *B. trehalosi*, and *P. multocida* strains

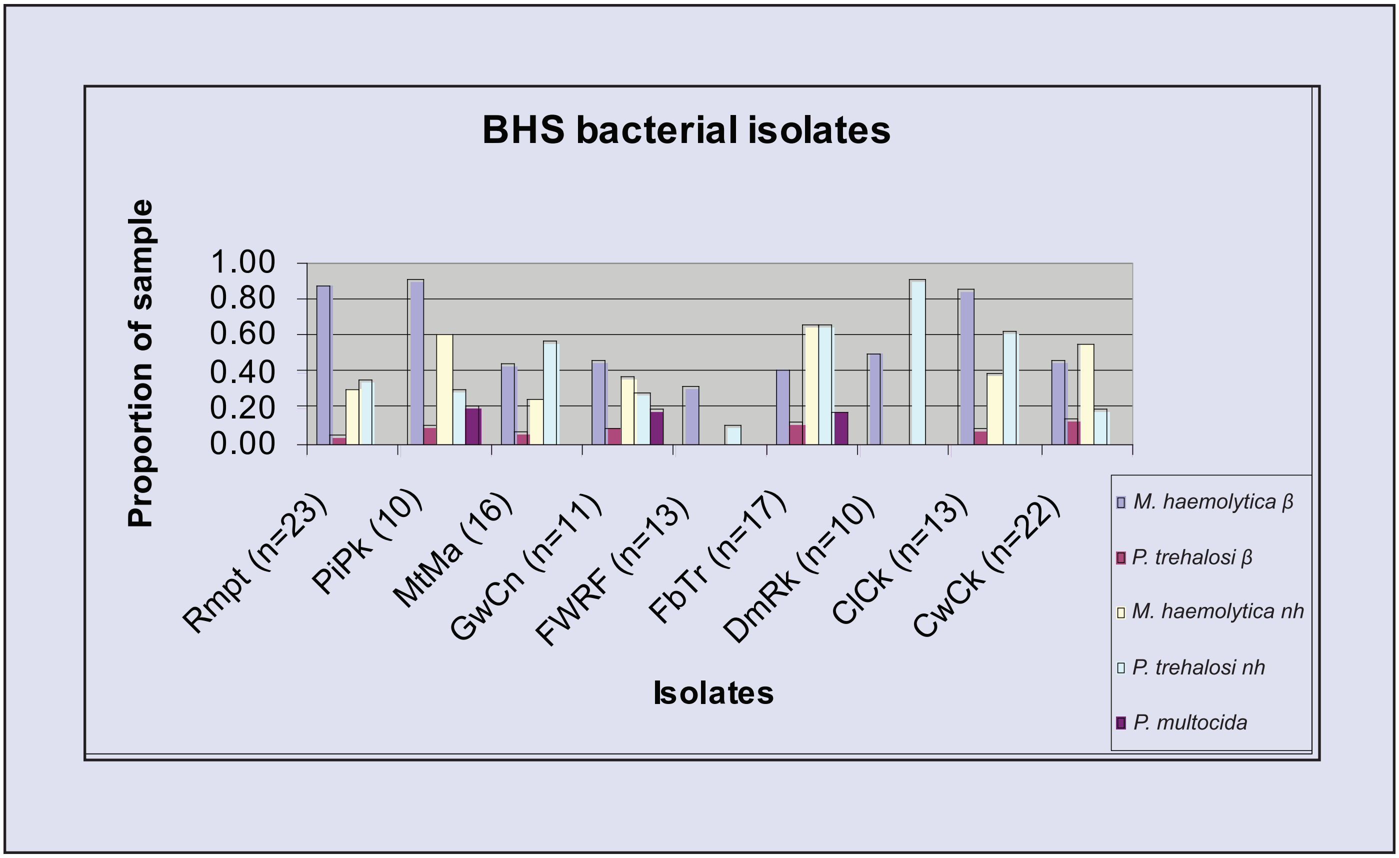

FIGURE 15. "*Pastuerellaceae*" isolates from pharyngeal swabs. β = beta hemolysis; nh = nonhomolytic; DmRk = Dome Rock; ClCk = Clear Creek; CwCk = Cottonwood Creek; FbTr = Forbes Trinchera; GwCn = Glenwood Canyon; MtMa = Mount Maestas; Rmpt = Rampart; PiPk = Pike's Peak.

and evidence of other respiratory pathogens from Colorado bighorn herds. This work is being conducted to provide better data on variation within and among populations as a means of assessing risks associated with translocations from sampled herds and potential strain-specific effects on bighorn population performance. Thus far, *Pasteurellaceae* isolates have only been grouped into one of five main species by hemolysis classes; however, these isolates have been archived for later use in more refined strain characterizations as needed for epidemiology and management.

During 2006–2007, 130 free-ranging bighorn sheep from 10 different herds (Figs. 15 & 16) were sampled. β-hemolytic (and potentially pathogenic) *M. haemolytica* was isolated at a relatively high prevalence (ranging from 31–90%) from all 9 herds where results were available (Fig. 15); β-hemolytic *B. trehalosi* was also isolated from 7 of the herds at a relatively lower prevalence (4–14%) of the isolates. The significance of these findings is unclear: some of the herds with potentially pathogenic *Pasteurellaceae* (S32 and Clear Creek Canyon, Cottonwood Creek (S11), Trinchera(S65) had recent histories of pneumonia or poor lamb recruitment, but others (e.g., Pikes Peak (S6), Dome Rock (S46), Rampart (S34) did not. Five of the 10 herds (Avalanche Creek (S25), S32 and Clear Creek Canyon, Trinchera (S65), Rampart (S34) and Poudre Canyon (S1 and S58) showed serologic evidence of exposure to BRSV (Fig. 16A); of these, only the Trinchera herd had animals with elevated titers to BRSV suggesting recent active infection. All herds tested showed some serologic evidence of exposure to PI3, and seven of these (Dome Rock (S46), S32 and Clear Creek Canyon, Glenwood Canyon, Mount Maestas (S50), Trinchera (S65), Poudre Canyon (S1 and S58) and Rampart(S34) had animals with elevated titers suggesting recent active infection (Fig. 16B). These preliminary findings, along with those from additional years, will be used to help guide use of sampled herds as potential sources of translocation stock, and also will be used in ongoing studies of bighorn population performance and in devising and improving approaches for managing respiratory disease problems in bighorn sheep.

In addition to work characterizing the occurrence and distribution of potentially important *Pasteurellaceae* strains and other respiratory pathogens in Colorado

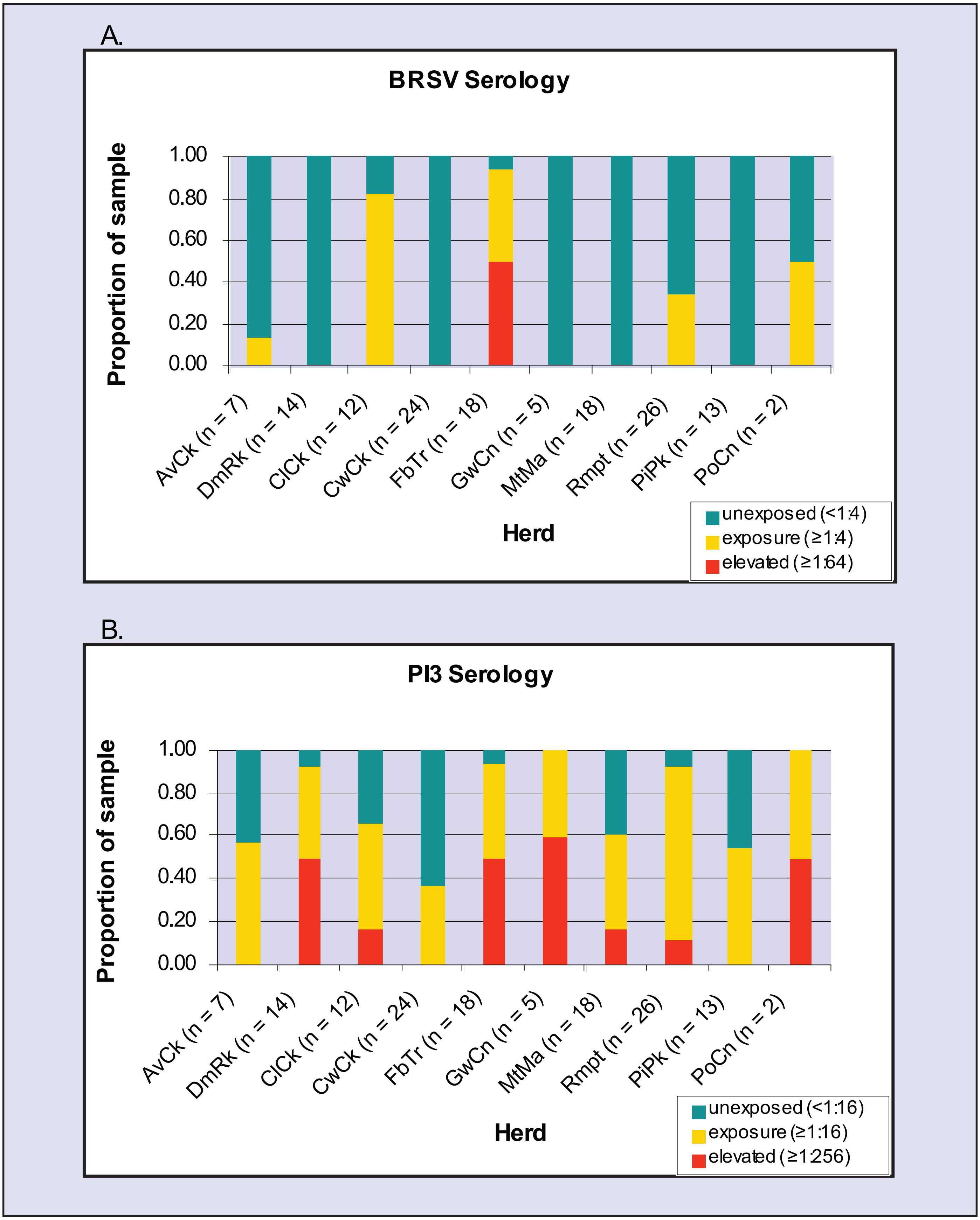

FIGURE 16. A.Bovine respiratory syncytial viru (BRSV) serdology. B Parainfluenza 3 (PI3) serology. AvCk = Avalanche Creek; DmRk = Dome Rock; ClCk = Clear Creek; CwCk = Cottonwood Creek; FbTr = Forbes Trinchera; GwCn = Glenwood Canyon; MtMa = Mount Maestas; Rmpt = Rampart; PiPk = Pike's Peak; PoCn = Poudre Canyon.

bighorn herds, other field and laboratory work is underway to develop and evaluate methods for either reducing the probability of pneumonia epidemics or more rapidly recovering populations stricken by epidemics – the latter primarily involves developing practical tools for improving lamb recruitment in affected herds. Data from previous studies on vaccines (Miller *et al.* 1997, Kraabel *et al.* 1998, Cassirer *et al.* 2001, McNeil *et al.* 2000) and anthelmintic treatments (Miller *et al.* 2000) are being used in conjunction with assessments of novel approaches (e.g., long-term antibiotic treatments, trace mineral supplementation, transmissible vaccine strains) to devise one or more management approaches that can be more formally evaluated in future field experiments.

Lungworm

Lungworm (*Protostrongylus stilesi* and *P. rushi*) and scabies are the only parasites that have been suspected to contribute to limiting Rocky Mountain bighorn sheep populations in Colorado. Verminous pneumonia caused by lungworm infestation has been considered by some as a possible limiting factor in Colorado since the 1950s (Moser 1962). However, it has become increasing evident that the effect of lungworm infection on bighorn populations probably is due to exacerbation of susceptibility to pasteurellosis rather than a true "verminous pneumonia" *per se*. Lungworms are natural parasites of bighorn sheep, and do not appear to compromise the overall health of bighorn sheep at typical levels of infection. Greater dispersal of Rocky Mountain bighorn sheep across available habitat can help reduce lungworm loads by reducing "hot-spot" areas where the intermediate snail host can become highly infected and seems a worthwhile management strategy. The value of prophylactic lungworm treatment using anthelmintics is inconclusive (Miller *et al.* 2000, Dreher 2005) and is under further investigation (Dreher 2005).

The epidemiology of protostrongylosis is well-described (see review by Hibler *et al.* 1982), although its relative importance to the bighorn pneumonia complex is debatable (Samson *et al.* 1987, Miller *et al.* 2000). Observations made throughout Colorado suggest that lungworm infections can precipitate and/or exacerbate both all-age pneumonia epidemics and summer outbreaks of pneumonia among bighorn lambs. For this reason, anthelmintic treatments have been applied to select bighorn herds throughout the state in an attempt to reduce lungworm burdens, thereby reducing lamb mortalities and the likelihood of all-age pneumonia outbreaks (Schmidt *et al.* 1979, Bailey 1990, Miller *et al.* 2000). Although bighorn numbers ostensibly increased statewide during nearly two decades of lungworm treatment, pneumonia outbreaks still occurred among both treated and untreated herds with surprising regularity (about 1-2 per year since 1980), and several treated herds still suffered from poor lamb survival despite annual treatment suggesting that anthelmintics are only useful in improving bighorn population performance when lungworm infection is the true cause of survival and recruitment problems (Miller *et al.* 2000).

Other diseases

Although most recent work on bighorn diseases in Colorado has focused on pneumonia, other health problems are known to occur and occasionally to have consequences for population health or management. Among other pathogens of potential importance, bluetongue virus (BTV) and epizootic hemorrhagic disease virus (EHDV) could be of consequence for bighorn sheep populations in Colorado. These "hemorrhagic disease" viruses can cause individual mortality and possibly epidemics in bighorns, but hemorrhagic disease generally is not considered a limiting factor except perhaps in small, struggling populations. In addition, contagious ecthyma (also called "CE", "sore mouth", or "orf", and caused by a parapox virus), infectious keratoconjunctivitis (also called "pink eye" and potentially caused by several different agents including bacteria, *Chlamydia* spp. *Mycoplasma* spp., and possibly viruses), and paratuberculosis (also called "Johne's disease" or "wasting disease" and caused by bacteria in the genus *Mycobacterium*) occasionally occur in bighorn sheep in Colorado. Although these diseases are usually infrequent, are localized, and do not appear to cause large-scale losses that limit population size or productivity in Colorado's bighorn populations, all of these have potential management implications. An outbreak of infectious keratoconjunctivitis and CE introduced by domestic goats caused extensive losses in an Arizona desert bighorn population (Jansen *et al.* 2006). Contagious ecthyma is a zoonotic disease (i.e., transmissible to humans) and outbreaks may necessitate modification of hunting seasons or notification of licensed hunters to minimize human exposure. Similarly, paratuberculosis is also a disease of concern to domestic livestock producers, and endemic paratuberculosis in the Mount Evans bighorn herd complex has prevented the Division of Wildlife from using these herds as sources for translocation stock.

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Chapter 8

BIGHORN SHEEP–DOMESTIC LIVESTOCK DISEASE INTERACTIONS

Interaction between bighorn sheep (*Ovis canadensis*) and domestic sheep is a significant management issue for bighorn populations in Colorado and elsewhere. The primary concern is transmission of novel respiratory pathogens from domestic sheep to bighorns and the concomitant deleterious acute and long-term effects on bighorn populations. In addition, the potential for pathogens to be introduced into bighorn populations from interactions with domestic goats, cattle, and other ruminants, although less well understood, also needs to be considered and perhaps addressed. Domestic sheep grazing allotments often overlap or occur in close proximity to occupied or historic bighorn range in Colorado (Fig. 17).

Management Goals & Strategies

Management Goal

Prevent introductions of infectious or parasitic diseases from domestic livestock that could adversely impact bighorn population performance and viability.

Strategy: Conduct research and surveillance to identify key pathogens of domestic sheep and other livestock species that can be managed to prevent epidemics.

Strategy: Develop, evaluate, and use appropriate tools, management practices, and policies (e.g., species and herd segregation, education, vaccines, therapeutics, habitat management, harvest and dispersal) to prevent pathogen introductions and/or protect bighorn populations from select pathogens that may be introduced via interactions with domestic ruminants.

Background & Literature Review

Bighorn sheep in Colorado likely have suffered from epidemics of infectious and parasitic diseases for over a century. Disease has contributed significantly to the decline of bighorn populations throughout Colorado and much of western North America, reducing abundance and imperiling some native populations and subspecies. The emergence of mange and pneumonia epidemics in Colorado's bighorn populations coincided with settlement and the advent of domestic livestock grazing in native bighorn ranges, suggesting that novel pathogens (including respiratory viruses and some *Pasteurella* spp. strains) were introduced into naive bighorn populations beginning in the late 1800s (Warren 1910, Shillinger 1937, Bear and Jones 1973, Goodson 1982, George *et al.* 2008). The absence of both pneumonia epidemics and livestock-associated respiratory pathogens or pathogen strains in more northern thinhorn sheep (*O. dalli*) populations where livestock interactions have not historically occurred (Jenkins *et al.* 2007) supports the notion that many of the respiratory pathogens of bighorn sheep at lower latitudes are introduced agents that have become endemic in some herds over the last century.

Native North American wild sheep species are quite susceptible to pasteurellosis, the generic term for disease (often respiratory) caused by bacteria in the family *Pasteurellaceae* (Miller 2001). Some strains of these bacteria carried by domestic sheep (and probably domestic goats, and perhaps cattle) are particularly pathogenic in bighorns (reviewed by Miller 2001, US Department of Agriculture [USDA] 2006, George *et al.* 2008). Pasteurellosis often is associated with individual deaths, large-scale mortality events, and depressed lamb recruitment in contemporary bighorn populations. Among the pasteurellosis epidemics described in bighorns, some appear to have resulted from flare-ups of now-endemic bacteria strains, perhaps catalyzed by other respiratory pathogens, parasites, or environmental or social stressors. In other cases, however, pneumonia and other epidemics in bighorns appear to have arisen from the introduction of either novel bacteria strains or other novel pathogens; potential sources of these introduced pathogens include other bighorn

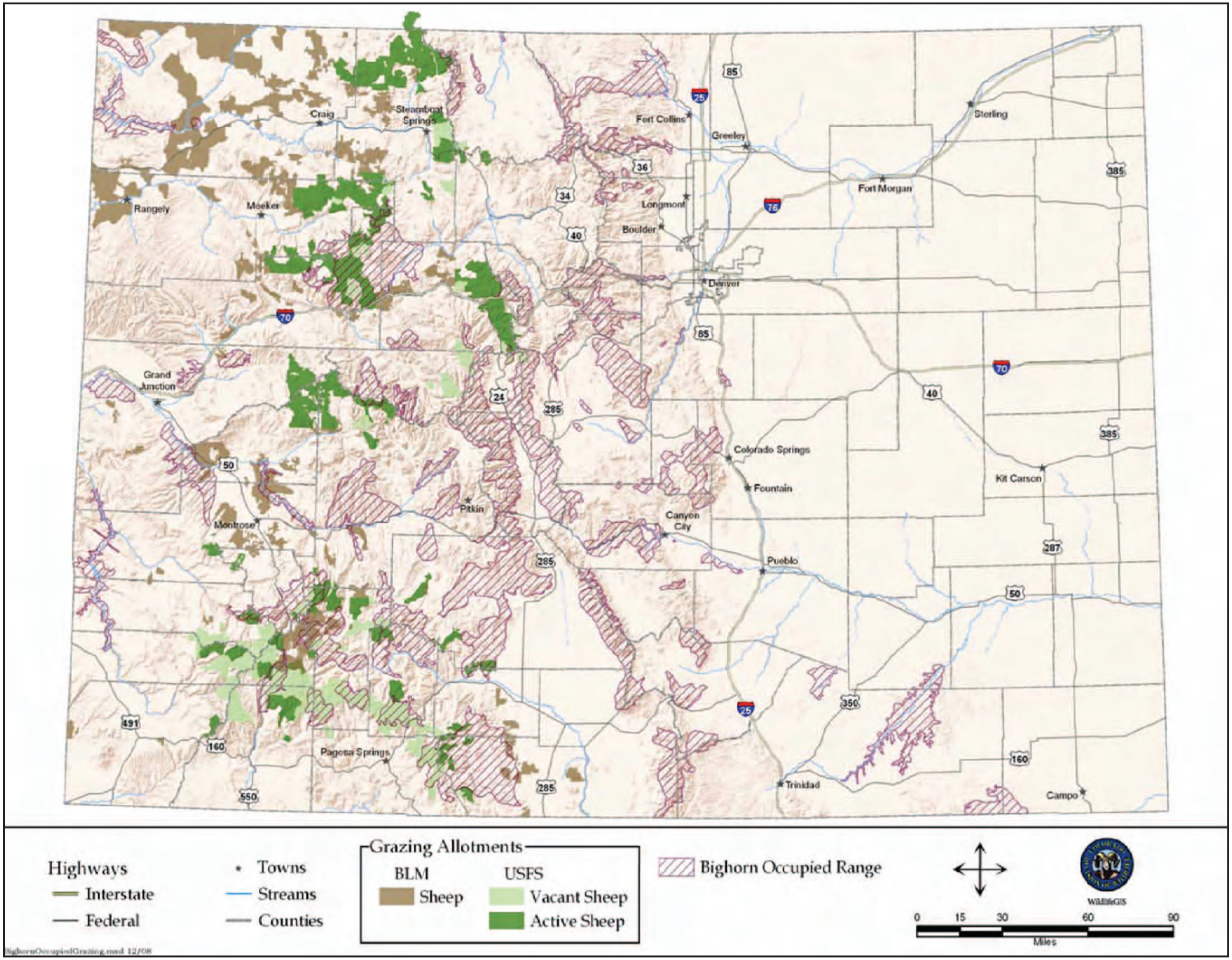

FIGURE 17. Occupied bighorn sheep range in relation to United States Forest Service (USFS) and Bureau of Land Management (BLM) domestic sheep allotments in Colorado, 2008.

populations, as well as domestic sheep and goats. It follows that maintaining and improving the health of bighorn populations depends on preventing or mitigating the effects of respiratory disease epidemics and that preventing the introduction of pathogens from domestic sheep and goats into bighorn populations is a particularly critical to success in achieving management goals for bighorn resources statewide.

The disease complex is covered in other parts of this document, but suffice it to quote Beecham *et al.*, (2007), as a succinct synopsis of this dilemma as it pertains to the United States Forest Service Region 2 (Wyoming, Colorado, South Dakota, Kansas Nebraska) conservation assessment, "Threats to the long-term viability of bighorn sheep in Region 2 include diseases transmitted by domestic livestock, the lack of connectivity and/or loss of genetic variability (fitness) due to habitat fragmentation, habitat loss, increased human disturbance, competition with domestic livestock, and predation on small, isolated herds. The relative importance of these threats to the persistence of bighorn sheep in Region 2 varies from area to area. However, the risk of disease outbreaks resulting from contact with domestic sheep and goats is widely believed to be the most significant threat facing bighorns in Region 2 and elsewhere across their range."

Several recent publications provide more information on the risks of disease introduction from domestic sheep and goats. In particular, the Council for Agricultural Science and Technology (CAST) (2008) Commentary on *Pasteurellosis Transmission Risks between Domestic and Wild Sheep* (CAST 2008) and the literature review section of the *Risk Analysis of Disease Transmission Between Domestic Sheep and Bighorn Sheep on the Payette National Forest* (USDA 2006, pages 2-5) provide background information and literature citations on bighorn sheep status, effects of disease on bighorn sheep, and management of bighorn sheep. The Western Association of Fish and Wildlife Agencies (2007) provides recommendations on management approaches to minimize potential for disease introductions into bighorn sheep populations from domestic sheep and goats. Additional work is needed to better clarify the potential for pathogen introductions from cattle, llamas, and other domestic ruminants (CAST 2008).

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Disease surveillance of bighorn sheep.

Chapter 9

BIGHORN SHEEP–MOUNTAIN GOAT INTERACTIONS

The increase in mountain goat (*Oreamnos americanus*) population numbers since their introduction into Colorado in 1948, concomitant with an expansion of their range, has led to concerns that mountain goats may compete with indigenous bighorn sheep (*Ovis canadensis*), thereby displacing sheep or reducing the vigor of their populations. These concerns stem from observed similarities in habitats and wide overlap in the forages they consume. Further, compared to northern populations, Colorado's mountain goats range farther from cliffs and occur in larger sized groups which may further increase potential for competition with bighorn sheep.

Disease, as discussed in Chapters 7 and 8, can lead to rapid and sustained reductions in bighorn sheep populations, and competition with mountain goats may exacerbate disease effects resulting in further reductions and even extirpation of bighorn sheep populations. Computer simulation models of the projected impacts of establishment of mountain goat populations within occupied bighorn ranges predict subsequent declines in bighorn numbers; however, these models also suggest that population management actions may mitigate competition-disease interactions by using an aggressive harvest strategy for mountain goats.

Despite the potential for negative impacts sympatric mountain goat populations might have on bighorn sheep, it is reasonable to maintain viable (and sometimes sympatric) populations of both species on selected ranges within Colorado, provided that mountain goat numbers and distribution are carefully managed within primary and secondary core (i.e., Tier 1 and Tier 2) (see Ch. 1, pp. 13 for definitions) bighorn sheep Data Analysis Units (DAUs).

Management Goals & Strategies

Management Goal

The Division of Wildlife will manage mountain goat populations and distribution via the DAU planning process to limit expansion and possible negative population level impacts on Tier 1 and Tier 2 bighorn sheep DAUs.

Strategy: Through the DAU planning process establish population and distribution objectives that will minimize dispersal of mountain goats outside of DAU boundaries.

Strategy: Mountain goats dispersing outside of mountain goat DAUs will be removed primarily through hunting under special regulations or, secondarily, through capture for translocation.

Strategy: Temporary mountain goat Game Management Units (GMUs) may be established in areas where negative impacts to bighorn sheep populations are a concern, but where mountain goat numbers are greater than can be removed using special management licenses.

Strategy: Mountain goat GMUs established prior to 1980 (e.g., G4, G6) that have been sympatric with bighorn sheep GMUs will be managed for sustainable populations for both species. Sustainability may require conservative population objectives for mountain goats within these DAUs

Management Goal

Establish mountain goat DAUs for all existing or anticipated mountain goat populations in the state that do not present concerns to the viability of Tier 1 and Tier 2 bighorn sheep populations.

Strategy: Combine mountain goat GMUs into DAUs as appropriate to represent interacting herds that should be managed collectively. DAUs should include anticipated and appropriate range expansion of current mountain goat populations and future translocations. Mountain goat DAUs should include only units where sustained mountain goat populations do not have the potential to negatively impact Tier 1 and Tier 2 bighorn sheep DAUs.

Strategy: Develop DAU plans with population and distribution objectives, that identify issues and concerns (e.g. competition, habitat condition, recreation, mountain goat-human conflicts), and specify management actions required to meet objectives.

Strategy: Hunter harvest will be used to meet mountain goat DAU plan population and distribution objectives. Harvest/removal rates of <=5% should result in increasing populations; rates of approximately 10% should result in stable populations, and >15% in population reductions. Recently established populations (<15 years) may require higher harvest rates than longer established populations (>25 years).

Strategy: Annual harvest objectives and license number recommendations should consider previous winter and spring snow depths, 3-year average hunter success rates, percentage of females in harvest, observed minimum population numbers and current kid production, and estimated population size in relation to DAU population objective.

Management Goal

Develop and implement standard inventory and monitoring protocols for mountain goats that are sustainable on a consistent and long term basis.

Strategy: Conduct either helicopter or coordinated ground surveys during July or August in as many herds as possible to obtain minimum numbers, population trend and age ratio information. Kids: 100 older adults will be the primary recruitment metric in these surveys.

Strategy: Utilize maximum May snow depth as a negative correlation to kids: 100 older adults. (Hopkins 1992)

Management Goal

Conduct research to determine survival rates, recruitment rates, and population density for selected mountain goat herds in Colorado.

Strategy: Identify a number of herds to collect population demographic data from.

Strategy: Using controlled experiments test the efficacy of census and removal methods for achieving population objectives and monitor herd response to management.

Strategy: Use controlled experiments to determine whether hunting is additive mortality in mountain goat populations and whether compensatory reproduction is occurring.

Strategy: Determine effects of weather on mountain goat survival and production.

Background & Literature Review

The history of the mountain goat in Colorado is as colorful as it is contentious. Mountain goats were first successfully introduced into central Colorado in 1948 by the (then) Colorado Game, Fish and Parks Department with the intent of developing a population that would support controlled hunting (Hibbs 1966). In his status report, Hibbs (1977) details the following initial transplant info: an initial release of nine animals onto Mt Shavano (G1) in the Sawatch Range in 1948, followed by a release 15 animals on Mt Evans (G4) in 1961. The Needle Mountains (G5) received 10 mountain goats in1964 and 4 in 1971. The Gore range herd (G6) was established by transplanting 16 mountain goats into the area from 1969 to 1972. Six mountain goats were released in three phases on Marceline Mountain in 1975.

The historical status of mountain goats in Colorado is controversial. Prior to 1993 mountain goats were considered a non-native species (Rutherford 1972). In 1993 the Colorado Wildlife Commission passed a resolution granting native status to the species. The compelling information presented to the Commission was primarily the work of Irby and Chappell (1994). Wunder (2000) refutes the conclusions of these authors and states, "Irby and Chappell reviewed and cited several intriguing reports supporting their conclusion that goats were native to the state. We were unable to verify these reports. In some instances, records were clearly references to pronghorn antelope (referred to as "white goats" in many reports from the 1800s)." Their single new report of a mountain goat specimen in a lay collection was determined, by us, to have been collected in Idaho. Wunder concludes, "That there is no evidence that mountain goats inhabited Colorado during historical times, and that they should be considered non-native to the state." Likewise, most authorities consider mountain goats to be an introduced species in Colorado (Armstrong, 1973, Fitzgerald *et al.* 1994,Wunder, 2000, Festa-Bianchet and Cote 2008). In the future, the Wildlife Commission may choose to revisit the native designation

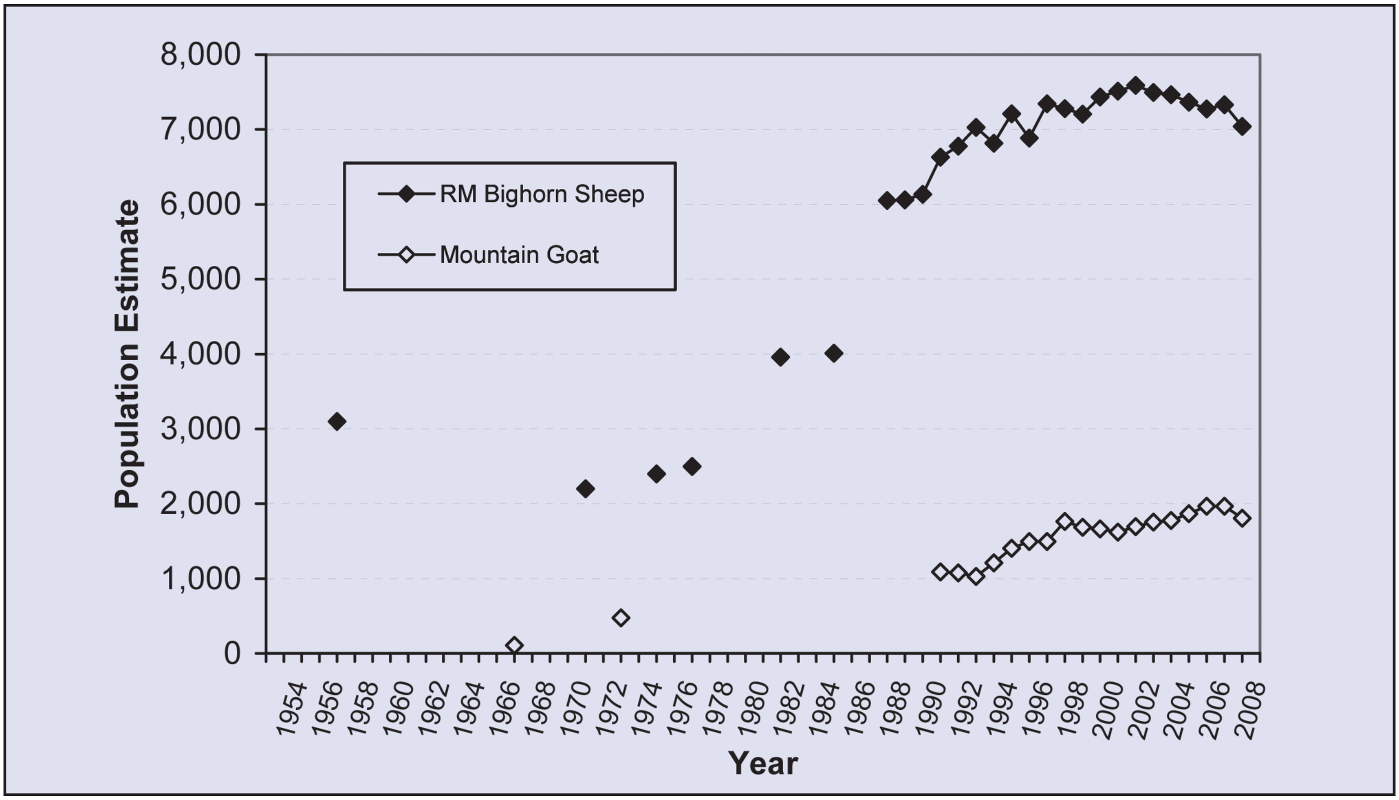

FIGURE 18. Population estimates of mountain goats and Rocky Mountain bighorn sheep in Colorado, 1966 – 2007.

for mountain goats. Regardless of their status as native or non-native wildlife, mountain goats have continued to thrive and expand their range in Colorado.

Mountain Goat Population Characteristics

Population and Distribution Trends

In 1977 the total mountain goat population of Colorado was estimated to be approximately 600 animals (Hibbs 1977) which has tripled during the subsequent three decades to an approximately 1800 animals in 2007 (Fig. 18).

Within the first 3 decades following introduction, mountain goat distribution expanded resulting in additional herds within the original transplant mountain ranges (Rutherford 1972) and goats continue to expand their range. Mountain goats have expanded to include most of the Sawatch Range (G1, G2, G3, G8, G9, G13, G14, and G17; Fig. 19). The Gore range transplant has resulting in a viable herd in unit G-6. The Mount Evans transplant has expanded to include the Mount Evans massive (G4) and adjacent areas along the Continental Divide (G7, G15, and G16) including verified locations of mountain goats outside established goat GMUs to the north into Rocky Mountain National Park (Gross *et al.* 2000) and to the south and west into the Mosquito Range. Mountain goats also have been reported on Pikes Peak and in the northern Sangre de Cristo range (A.Vitt and B. Dreher, pers. comm.). The Ragged Mountain population of goats (G11) is believed to be expanding into the Elk Mountains (G12). There have also been reports of mountain goats in the Holy Cross Wilderness.

Population Growth Rate

Hobbs *et al.* (1990) reported a simulated growth rate of 0.13 for mountain goats which resembles rates calculated for other introduced populations of mountain goats (Vaughn 1975, Stevens and Driver 1978).

Harvest Rates

Mountain goat populations introduced outside of native ranges have sustained harvest rates of 7% to as much as 15% while maintaining stable or increasing populations (Adams and Bailey 1982, Houston and Stevens 1988, and Williams 1999). In Colorado, from 1999-2006 the estimated statewide harvest rate relative to estimated post-hunt populations was 8-12%. These harvest rates would cause rapid reductions in native populations where harvest rates of less than 5% are typical (Festa-Bianchet and Cote 2008). Maintenance

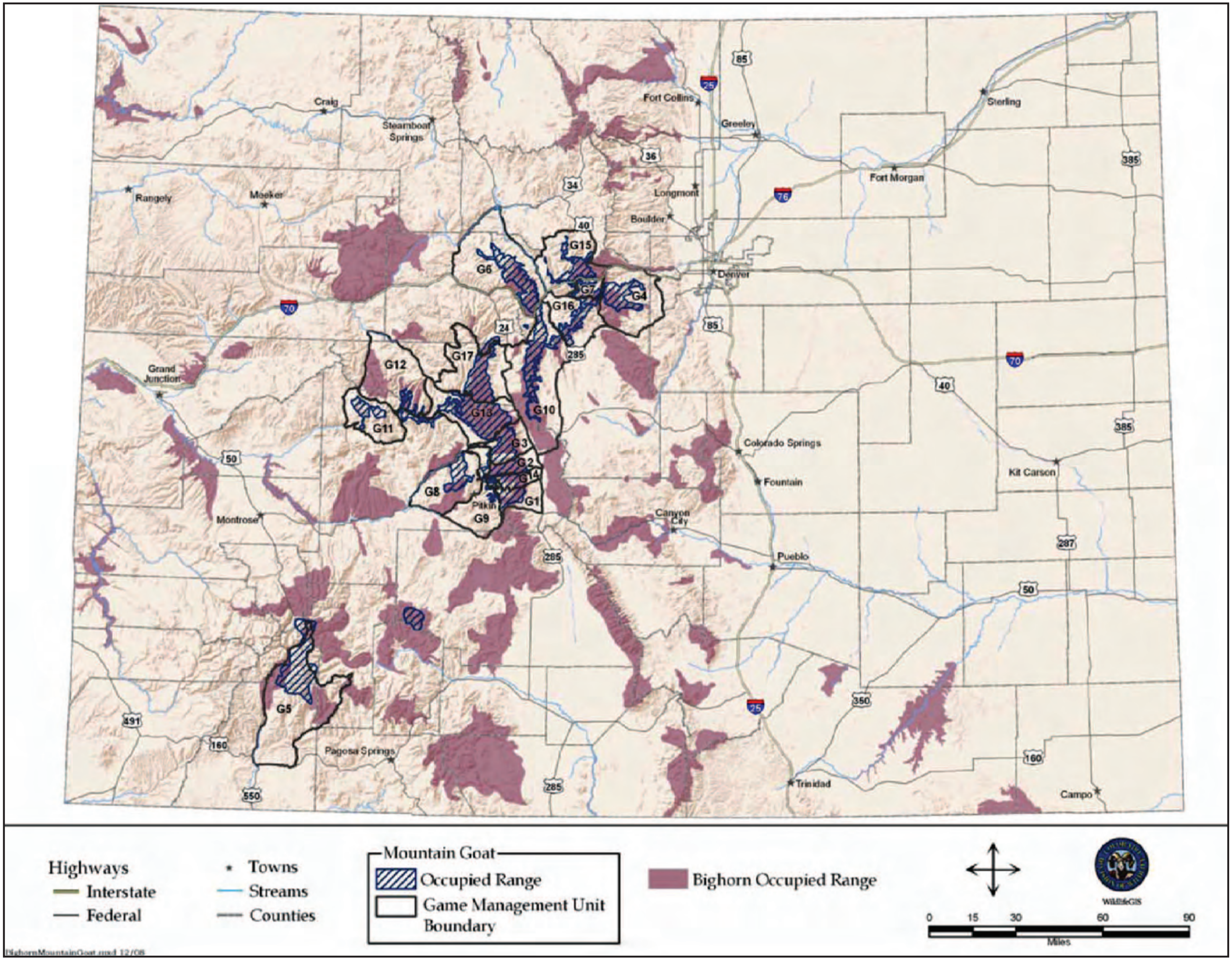

FIGURE 19. Mountain goat game management units and occupied range in relation to occupied bighorn sheep range in Colorado, 2008.

of relatively high harvest rates are likely explained by the initial irruptive behavior and high rates of increase typical of introduced ungulate populations (Caughley 1970). Moreover, Colorado's mountain goats occupy ranges further south of native ranges which may contribute milder winter conditions. For these reasons, harvest rates of 5-10% are likely sustainable in Colorado mountain goat populations and harvest rates >15% may be required to reduce populations.

Age ratios

Average age ratios reported for native herds or herds that have been established at least 16 years is 28 kids:100 adults, but herds that had been established for 15 years or less averaged twice as many kids: 100 older animals (Bailey and Johnson 1977). Adams and Bailey (1982) first observed evidence of a density dependant decrease in reproduction 25 years after release in the Sheep Mountain-Gladstone Ridge population in Colorado.

Survival

As reported in Gross (2001), "Survival rates of adult mountain goats and bighorn sheep are relatively high and consistent across most habitats and population densities (Hayden, 1984; Gaillard *et al.* 1998)." Likewise, Festa-Bianchet and Cote (2008) observed high adult survival rates in an Alberta population. In contrast, recruitment rates of juvenile goats can vary widely with density (Adams and Bailey 1982, Houston and Stevens 1988) and weather (Houston and Stevens 1988, Smith 1988).

Hunting

Hunting mortality has been observed to be additive in some native mountain goat populations (Chadwick 1983, Herbert and Turnbull 1977, Kuck 1977, Smith 1988) while Adams and Bailey (1982), Houston and Stevens (1988) , Swenson (1985) and Williams (1999) noted that hunting mortality was compensatory in the introduced populations they studied. Thompson (1981) stated that the yearly hunting harvest was perhaps the most significant source of adult mortality in the Gore Range (G6) mountain goats.

Weather

Increased snowfall and snow depth during the winter and early spring has a negative effect on kids:100 older animals ratios (Hopkins 1992). Adams and Bailey (1982) and Thompson (1981) found that spring snow depth negatively affected reproductive success. Other studies have found lower kid production after severe winters (Brandborg 1955, Chadwick 1973, Hjeljord 1971, Rideout 1974, Smith 1984). Thompson (1981) documented 56% and 40% kid mortality over winters of 77-78 and 78-79.

Mountain goat competition with Rocky Mountain bighorn sheep

In native populations of mountain goats, Varley and Varley (1996) suggest that temporal and spatial habitat selection differences between bighorn sheep and mountain goats minimizes conflict and that the contrasting resource use patterns found in sympatric populations are indicative of niche divergence that would be expected given the two species extensively overlapping distribution and evolutionary history (Adams *et al.* 1982, Varley and Varley 1996).

Adams *et al.* (1982) expressed concern about potential competition between bighorn sheep and mountain goats due to the fact that introduced mountain goat populations exhibit unusual patterns of habitat selection that infringe on bighorn sheep habitat and that access to existing habitat for bighorn sheep had been reduced by man's activities. Hopkins (1992) documented mountain goats far from escape terrain on Elliot ridge. Hobbs *et al.* (1990), citing Chadwick's (1983) conclusion that in the absence of pressure from predators, distribution of mountain goats is not limited to steep terrain, assumed then (for simulation modeling of inter-specific competition) that the spatial mechanisms of ecological separation seen in northern ranges were not strongly operative in Colorado.

A simulation model was used to evaluate population-level effects that mountain goats might have on bighorn sheep in Rocky Mountain National Park should they become established (Gross 2001). Gross (2001) found that competition did not influence dynamics of either species until the combined density (sum of both species, adjusted for the degree of competition) exceeded the density threshold. The results indicated that the combined effects of competition and disease led to populations that were both small and variable, and thus subject to a much higher risk than populations exposed to either factor alone (Gross 2001). Competition further exacerbates risks to small populations because it delays recovery, causing populations to remain at small sizes for an extended period (Gross 2001). Gross concluded that mountain goats, once established, would reduce bighorn sheep populations by 10 to 50%.

Hobbs *et al.* (1990) used simulation models to display the potential for competitive interactions between bighorn sheep and mountain goats when goats are introduced into occupied bighorn sheep habitat. The simulations showed that sheep populations would fluctuate primarily due to periodic die-offs caused by parasites and disease. In the absence of mountain goats, sheep would eventually recover to densities similar to previous levels. In the presence of mountains goats, sheep populations wouldn't recover to densities similar to what occurred before the die-off. This was attributed to the fact that the goat population would expand to fill the vacant niche left during the sheep die-off and would prevent the sheep population from returning to their previous level due to competition for limited resources (food and space). The investigator's model predicted local extinction of mountain sheep occurred after 27 years of purported sympatry. Hobbs *et al.* (1990) simulation results indicate that disease regulates mountain sheep numbers at levels well below the food based carrying capacity of the environment. The investigators found it was possible to achieve long term equilibrium between sheep and goats using an aggressive harvest strategy propelled by liberal investments in census, because mountain sheep populations were stabilized by maintaining their densities below a threshold critical for disease outbreak.

To date, little research in the way of closely monitored control-treatment experiments has been conducted to document the existence of competition between bighorn sheep and mountain goats. However, as reported by Gross (2001), " the fact that there is large overlap in habitat use by mountain goats and bighorn sheep in Colorado (Adams *et al.* 1982), combined with knowledge that mountain goats are behaviorally dominant to bighorn sheep and displace them from preferred sites (Reed 1984, 2001), and that, diet overlap between the species is extensive (Laundre, 1994; Swift and Popolizio, 2000), stresses the need to simultaneously account for multiple biological processes when assessing conservation risk of mountain goat expansion."

Adams *et al.* (1982) offer a realistic assessment and conclusion stating, "New and increased contact between bighorn sheep and mountain goats in Colorado is occurring with numerical and geographic expansion of goat herds. It is imprudent, and risky for bighorns, to allow further expansion of goats onto bighorn sheep ranges without analyzing each bighorn sheep herd and its habitat. Unthrifty bighorn herds having lost seasonal ranges, migrating corridors, and movement traditions already have bleak futures. The added impact of competition from goats could only exacerbate these problems, but eliminating goat expansion will not solve these problems either. With or without mountain goats, information on seasonal habitats, migration corridors, habitat conditions, and opportunities for habitat improvement is needed to secure the future of Colorado's bighorn sheep. Once this information is obtained, threats to sheep from expanding herds can be realistically evaluated as can opportunities to support sympatric populations of both species."

Hobbs *et al.* (1990), concluded that, "Success in managing mountain sheep populations appears to hinge on preventing recurrent disease epidemics, regardless of whether sympatric mountain goat populations are present."

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Aggressive behavior by a mountain goat towards bighorn sheep at a salt lick in S17.

Photos by Lance Carpenter.

Chapter 10

PREDATION

The cumulative impacts of predation to populations of wild sheep in Colorado are largely unknown. However, burgeoning interest in bighorn (*Ovis canadensis*) management in the state will likely result in recurrent examination of predator management strategies, particularly in situations where local sheep populations are suppressed or declining and there is information available that implicates predation as a limiting factor. Alternatively, selective predation may be beneficial in removing unhealthy individuals from bighorn populations that have suffered epidemics, and thus could be a tool for helping recover populations after epidemics have occurred.

Management Goals & Strategies

Management Goal

Prevent predation from severely impacting or extirpating bighorn sheep populations.

Strategy: Given management considerations within this plan, identify cases where predation (particularly mountain lion (*Puma concolor*) predation) threatens to extirpate introduced or established bighorn herds or populations that already have suffered declines from other causes (e.g., epidemics).

Strategy: Develop, evaluate, and use appropriate tools, management practices, and policies (e.g., habitat management, harvest and selective removal) where cost-effective and practical to temporarily or focally control predators in cases where introduced or established bighorn herds or populations are threatened with extirpation because of excessive predation.

Management Goal

Allow selective predation to aid bighorn populations in recovering from epidemics

Strategy: Improve understanding about circumstances where predation (from mountain lions or other carnivores) may aid in recovering bighorn herds or populations that have suffered from epidemics by selectively removing unhealthy individuals.

Background & Literature Review

Modern bighorn sheep management in Colorado presents unique challenges for the Division of Wildlife. Although there are many management concerns for wild sheep in the state, disease and habitat loss often rise to the top in terms of regional priorities. Biologists may reasonably assume that if sufficient amounts of quality bighorn habitat exist within a given area and disease risks are minimized, sheep should flourish. Healthy bighorn populations in quality habitat are also less likely to incur additive mortality from other potential limiting factors such as severe winters, drought, poaching, or predation. However, the reality is that many wild sheep populations in Colorado no longer have optimal conditions available to them throughout the year which in some cases has resulted in diminished herd performance. Smaller, isolated populations of bighorn sheep, especially those beset by disease and reduced habitat capability are more likely to experience pronounced population fluctuations in response to epizootics, severe winters, or in certain instances, predation (Wehausen 1996, Ross *et al.* 1997, Cougar Management Guidelines Working Group 2005, Festa-Bianchet *et al.* 2006, McKinney *et al.* 2006b).

Most western states and Canadian provinces continue to experience controversy regarding the impacts of predation on big game populations. Societal beliefs regarding predatory animals are often the result of long-established cultural traditions, life experiences, or in some cases, a basic misunderstanding or lack of knowledge concerning predator/prey interactions. Predators have often become a focal point for discussions pertaining to changes in ungulate populations and wildlife managers are continuously engaged in dialogues concerning predation. Often, there is clear division between constituents with regard to predator management; those lobbying for rigorous predator control, and those that promote predator preservation. When engaged in decision making processes, wildlife managers must make management recommendations that achieve what is scientifically defensible and biologically sustainable, while also considering diverse social and political variables.

Most of the predatory species common to the Rocky Mountain region are sympatric with mountain sheep in Colorado. Those species include the coyote (*Canis latrans*), mountain lion, black bear (*Ursus americanus*), golden eagle (*Aquila chrysaetos*), red fox (*Vulpes vulpes*), bobcat (*Lynx rufus*), and lynx (*Lynx canadensis*). Predation is one of many factors possibly influencing sheep population dynamics throughout the state, however very little research specific to predator/prey interactions of bighorn sheep in Colorado has been conducted. The majority of information wildlife managers have obtained concerning predation on wild sheep has come as the result of radio collar projects in which mortality causes have been evaluated during routine monitoring. Anecdotal information collected by resource professionals and the public throughout Colorado has also provided additional insight into localized predation issues. Mountain lions, coyotes, bobcats, and golden eagles are perhaps the species' most often associated with predation of bighorn sheep in Colorado.

Golden Eagle

There are several references to interactions between golden eagles and bighorn sheep throughout scientific literature (Sawyer and Lindzey 2002), and it is not unusual in Colorado to receive reports of golden eagles actively hunting in proximity to bighorn sheep herds. Hunting activity may peak during the lambing season when small lambs are most vulnerable, but golden eagles have been reported to hunt bighorn sheep throughout the year. Golden eagles likely hunt sheep opportunistically but there is currently no information available demonstrating that golden eagle predation is a significant limiting factor for wild sheep populations.

Bobcat

Bobcats are common throughout Colorado and are capable of killing bighorn sheep when circumstances allow. Anecdotal information suggests that bobcat predation is focused primarily on young of the year animals; however bighorns are not generally considered a primary food source for bobcats (Fitzgerald *et al.* 1994). Biologists speculated that predation by bobcats on lambs was impacting the transplanted Black Ridge desert bighorn (*O. c. nelsoni* or *O. c. mexicana*) population in northwestern Colorado. Duckett (2006) and Watkins (2005) describe an incident involving a bobcat and lambing ewe in the Uncompahgre desert bighorn herd in which the ewe apparently kicked a bobcat off of a ledge in defense of her lamb. Despite anecdotal accounts, the cumulative effects of bobcat predation on bighorn sheep populations remain uncertain.

Coyote

Coyotes are ubiquitous throughout bighorn sheep habitat in Colorado and undoubtedly hunt and kill wild sheep. References to coyotes interacting with bighorn sheep are frequent throughout the literature (Buechner 1960, Giest 1971, Festa-Bianchet 1988, Berger 1991, Sawyer and Lindzey 2002). Prey selection by a particular predator is dependent on many factors. Most predators rely on specific hunting techniques and attempt to take advantage of favorable habitats and prey vulnerability. Potential prey species may be selected based on morphology, behavior, habitat selection, capture probability, and risk of injury during attack (Husseman *et al.* 2003). Generally considered coursing predators, coyotes may be at a distinct disadvantage while hunting in steep escape terrain favored by wild sheep, and rarely are sheep vulnerable to extended chases through open terrains. Suitable escape terrain is a key component of quality bighorn sheep habitat which is likely to minimize coyote predation throughout much of the year (Bleich 1999). Coyotes may be considered a primary predator of bighorn sheep in most regions of Colorado; however there is generally no inference in the literature that coyote predation limits bighorn populations. Following several transplants, Creeden and Graham (1997) suspected that coyote predation and disease were limiting lamb survival in the Black Ridge desert sheep herd during the 1990s, although specific mortality causes were never determined.

Mountain Lion

In Colorado, mountain lions are perhaps the most significant predator of bighorn sheep, although very little research has been conducted examining specific relationships between the two species. Mountain lions are powerful carnivores capable of killing all sex and age classes of wild sheep, and bighorn ranges in the state generally provide suitable lion habitat. The broken, rugged terrain that sheep inhabit is well suited for stalking predators like lions that rely on stealth while hunting prey. Bighorn habitat in Colorado also typically overlaps with mule deer (*O. hemionus*) and elk (*Cervus elaphus nelsoni*) ranges, providing lions with ample forage resources.

Mountain lion control is often suggested by constituents as a management tool for increasing bighorn sheep populations. Those recommendations may stem from increased lion sightings, tracks, kills, or changes in bighorn distribution throughout a particular area that may or may not be concurrent with a population decline. Future research specific to mountain lion and bighorn sheep interactions would be of great interest to Colorado wildlife managers. Limited data suggest that lion predation may be suppressing some desert bighorn populations in the state, although caution is recommended when interpreting those data due to the complexity of predator/prey interactions; even fewer data are available to suggest that mountain lion predation adversely affects Rocky Mountain bighorn population performance in Colorado. Banulis (2005) states that 11 of 12 radio collared desert bighorn sheep in the Middle Dolores herd died within 2 years after transplant, with 9 identified as probable lion kills. Creeden and Graham (1997) state that "mountain lion predation was the single most important mortality factor for radio-collared sheep" in the Black Ridge desert sheep population. They suspected that predator mortality was additive in that population which had declined and was experiencing poor lamb survival and recruitment. Anecdotal reports suggest that a segment of the Saint Vrain bighorn sheep herd has declined possibly as a result of lion predation (S. Huwer, personal communication 2007). Instances of mountain lions actively hunting sheep have been reported for that herd, and several carcasses of lion-killed sheep have been found over the last ten years. Mountain lion predation has been suspected as a limiting factor for the Dome Rock bighorn herd in southeast Colorado (B. Dreher personal communication 2007). During a two year period, biologists discovered seven sheep carcasses, three of which were confirmed as lion kills. Preliminary analysis of radio collar data from the Poudre Canyon herd suggests that lion predation may be a significant limiting factor (Vieira, personal communication 2007). During the initial year of that project, lions killed more than 30% of collared ewes over a short period of time, and all mortality was confirmed or probable mountain lion predation; however, losses at this rate apparently were confined to that single year.

Although research is lacking in Colorado, several long-term research projects throughout the west and Canada have concluded that in certain instances, predation by mountain lions may result in population declines or inhibit population recovery following declines (Wehausen 1996, Hayes *et al.* 2000, Logan and Sweanor 2001, Real and Festa-Bianchet 2003, Festa-Bianchet *et al.* 2006, McKinney *et al.* 2006a). From 1989 through 1992, Wehausen (1996) documented a decline in bighorn numbers in California's Granite Mountains, with lion predation accounting for most mortality. During the spring of 1992 lion predation stopped, which resulted in increased survival rates for radio-collared ewes and an increase in the population of 15% per year from 9 ewes in 1992 to 14 ewes in 1995. During the same period, biologists documented the abandonment of traditional low elevation winter ranges by sheep in the Mount Baxter population, which was attributed to increased lion abundance and predation. Monitoring of Sierra Nevada Bighorn sheep for more than 20 years led Wehausen (1996) to conclude that "native mountain lions have not only reversed a successful restoration program for Sierra Nevada bighorn, but have caused the virtual extirpation of 1 of the last 2 native populations." Hayes *et al.* (2000) conducted research focused on bighorn sheep in the Penninsular Ranges of southern California, which indicated that adult bighorn survival rates were driven by mountain lion predation. During that study, lion predation accounted for 69% of all known mortalities, which was four times higher than the rate of non-predator mortality. That research demonstrated that adult survival was significantly lower for bighorns in their study area than rates observed in several other bighorn populations, largely due to lion predation. Long-term mountain lion research conducted by Logan and Sweanor (2001) in the San Andres Mountains of New Mexico not only indicated that lions were a limiting factor for desert bighorn, but that lion predation may have ultimately led to the extinction of that sheep population. Analysis of long-term data from three individual bighorn populations in Alberta and Montana demonstrated that each herd experienced "stochastic predation episodes" that generally reduced survival for all sex and age classes, and were associated with population declines (Festa-Bianchet *et al.* 2006). Mountain lion predation on studied bighorn sheep populations appears to be intermittent over long periods of time, or may vary seasonally, mainly intensifying in winter (Ross *et al.* 1997, Hayes *et al.* 2000, Schaefer *et al.* 2000, Festa-Bianchet *et al.* 2006).

Translocation efforts in many locations have been attempted in order to restore bighorn sheep to their former range. Although some translocations have been successful, others have failed because of various factors including predation, disease, and dispersal (Rominger *et al.* 2004). More recently, mountain lion predation has been implicated as the proximate cause limiting some translocation successes, particularly for desert bighorns (Krausman *et al.* 1999, Kamler *et al.* 2002, Rominger *et al.* 2004, McKinney *et al.* 2006a). Predation ultimately has been linked to other factors such as marginal escape cover, habitat quality and quantity at release sites, and presence of other prey species sustaining mountain lion densities, but inherent in translocation efforts is the small size (and often the limited geographic distribution) of translocated populations which may predispose translocated bighorn sheep to potential mountain lion predation impacts in some cases (e.g., McKinney *et al.* 2006a, Festa-Bianchet *et al.* 2006). Proposed actions for enhancing success of bighorn sheep translocations include short-term predator control (Rominger *et al.* 2004, McKinney *et al.* 2006a), release of larger groups to increase bighorn sheep vigilance at translocation sites (10 or more ewes and rams; Mooring *et al.* 2004), and improved evaluation of forage quantity and quality (Bender and Weisenberger 2005) and escape terrain (McKinney *et al.* 2006a) prior to translocation site selection.

Management Considerations

Ungulate numbers and distribution may vary over time often as the result of heavy winters, drought, disease, hunter harvest, or any number of other factors, including predation. During instances where populations fall below long-term objectives or distribution of game animal's shifts noticeably over time, concerns frequently arise, particularly from those interested in predictable levels of hunting opportunity or linked economically to big game related tourism. Predator control is often suggested as the solution for reviving declining ungulate populations, although rarely is there enough information available to support such management prescriptions. Some perceive predator control as a "quick-fix" which will elicit an immediate population response while demonstrating that work is getting done on the ground. Before considering a control program, managers should carefully evaluate the current status of the bighorn sheep herd in question, with attention given to habitat condition, herd health problems, and both predator and prey issues and how those issues may be relative to one another. Following are several issues that should be considered.

Habitat

Managers should evaluate the current condition of seasonal bighorn sheep habitats to verify that suitable habitat is available throughout the year that contains adequate forage, water and escape terrain. Increased tree and/or shrub cover may potentially be limiting visibility and predisposing sheep to predation within a given area. Changes in land use may be inhibiting or eliminating key sheep habitats within an area or blocking preferred migration corridors. In areas where water is a limiting factor, sheep that are forced into water sources surrounded by heavy cover or in narrow canyons are subject to greater predation risk. Predation may be the proximate cause of bighorn sheep mortality, but at the population scale short or long-term changes in habitat conditions could be the overriding population regulator. Logan and Sweanor (2001) and Bender and Weisenberger (2005) interpreted prolonged severe drought as the primary mechanism leading to increased predation. Similarly, habitat succession was implicated as the ultimate cause of decline of a California bighorn sheep herd (Holl *et al.* 2004). Consideration also should be given to population size in relation to carrying capacity. Bighorn populations at or above carrying capacity may be experiencing reductions in body condition, lamb recruitment, or annual adult survival. As described for other ungulates, habitat capacity and compensatory mechanisms play an important role in the effect of predation (Bartmann *et al.* 1992, Ballard *et al.* 2001). Thus, predation losses in bighorn sheep herds at or above carrying capacity may be compensatory and of less consequence or interest from a long-term management standpoint.

Specialized Hunting by Individual Lions

Various studies and anecdotal reports have highlighted the significance of individual lions that learn to specialize in hunting bighorn sheep. Festa-Bianchet *et al.* (2006) observed that individual mountain lions did not necessarily hunt bighorn sheep, despite having overlapping home ranges. However, one radio collared female lion in the Sheep River study area preyed heavily on bighorns during several years, including one year in which she killed 9% of the Sheep River population over the course of one winter. In New Mexico, one male lion in the San Andres study area accounted for nearly 30% of bighorn sheep kills documented (Logan and Sweanor

2001). The importance of individual lion hunting behavior and prey selection is a key consideration when evaluating predator control measures; however there are rarely enough data available to quantify predation by individual mountain lions. Also, the sporadic nature of predation on bighorn sheep by mountain lions appears largely due to changes in predation behavior by relatively few individuals (Wehausen 1996, Ross *et al.* 1997, Hayes *et al.* 2000, Logan and Sweanor 2001). Therefore, mountain lion predation on bighorn sheep does not appear related to mountain lion (Hoban 1990, Ross *et al.* 1997, Logan and Sweanor 2001, McKinney *et al.* 2006a) or bighorn sheep density (Ross *et al.* 1997). Specialization of some mountain lions in preying on bighorn sheep also results in variable selection of bighorn sheep sex/age classes, where ram (Bleich *et al.* 1997, Schaefer *et al.* 2000), ewe (Krausman *et al.* 1999), lamb (Ross *et al.* 1997) and no apparent selection by mountain lions (Hoban 1990, McKinney *et al.* 2006a) has been reported, perhaps due in part to the sex and age class of bighorn sheep that occur within an individual mountain lion's home range in combination with the individual's behavior and hunting preferences (Ross *et al.* 1997, Mooring *et al.* 2004).

Because of the density independent relationship of mountain lion predation on bighorn sheep populations, population-level mountain lion management may be a relatively inefficient management approach for alleviating predation impacts to bighorn sheep populations. Thus, some bighorn sheep investigators (e.g., Ross *et al.* 1997, Mooring *et al.* 2004) suggest targeting specific mountain lions to address predation impacts in some cases.

If one or more individual lions are contributing to undesirable levels of bighorn sheep mortality, managers should focus on those animals if control measures are employed. Random removal of mountain lions within bighorn sheep range is not likely to achieve desired results, particularly if the sheep hunting specialist(s) are not removed. Attempts to reduce mountain lion population size in relatively small areas (<1,000 km2) by generalized increased hunting mortality may be compensated for by increased immigration and a change in gender and age structure of the population favoring younger males (Robinson *et al.* 2008). Random removal of lions from an area actually may have the potential to exacerbate bighorn predation problems. Managers may facilitate immigration of a sheep hunting lion from adjacent areas as home ranges are vacated during random control efforts (Cougar Management Guidelines Working Group 2005). However, modeling efforts by Ernest *et al.* (2002) suggested that population level mountain lion management may be equally or more effective in a situation where numerous mountain lions preyed on a small bighorn sheep population, but suggested removal of 1-2 mountain lions per year was sufficient to sustain populations >15-30 ewes. Such small levels of mountain lion removal might be viewed more as selective removal if conducted in the vicinity of bighorn sheep predation sites. From a practical standpoint, removal of mountain lions in such a situation might target individuals with home ranges that overlap the distribution of the small sheep population. The importance of individual lion hunting behavior and prey selection is a key consideration when evaluating predator control measures; however there are rarely enough data available to quantify predation by individual mountain lions. As circumstances allow, managers may consider using lion hunters during established seasons to target individual lions, especially in areas that typically do not receive much hunting pressure.

Alternate Prey

The composition and availability of alternate prey species to area predators should be evaluated by managers. Another explanation for individual mountain lions that exhibit relatively high predation on bighorn sheep is that they are acting opportunistically. Particularly in habitats with small bighorn sheep populations, mountain lions probably rely on other prey species (e.g., mule deer) as their major prey sources (e.g., Logan and Sweanor 2001). However, because of the location of mountain lion home ranges in relation to bighorn sheep distribution, certain mountain lion have greater opportunities to prey on bighorn sheep. Thus, some individual mountain lions would be expected to have greater predation rates on bighorn sheep. Yet, those mountain lions are expressing opportunism, not specialization. This is consistent with the notion that availability of mule deer is a factor influencing mountain lion predation on bighorn sheep (Schaefer *et al.* 2000, McKinney *et al.* 2006a). Despite the specialized or opportunistic sheep hunting behavior demonstrated by some individual mountain lions, it is reasonable to assume that in most cases, increased availability of alternate prey may help lessen annual predation rates on wild sheep. Increased occurrence of lion predation on bighorn sheep that is concurrent with mule deer or elk population declines may warrant further investigation. Prior to sheep reintroductions or supplements, managers should inspect the abundance and distribution of potential prey species within the project area. Transplants or supplements occurring within occupied mountain lion habitat may be destined to stagnate or fail if prey availability is poor and a novel prey resource is suddenly available to resident lions.

The availability of alternate prey has the potential to influence a bighorn population in several ways. In a theoretical "predator pit", an established mountain lion population could hinder the performance of a healthy sheep herd below carrying capacity when alternate prey is readily available and selective hunting of sheep by one or more individual lions is occurring. Rominger *et al.* (2004) hypothesized that the availability of domestic livestock to mountain lions in the Sierra Ladron of New Mexico was allowing lions to persist in areas surrounding bighorn habitat that did not support high densities of native ungulates. These so called "subsidized predators" were able to maintain higher population densities than could be sustained by native ungulate resources, and were documented to prey heavily on transplanted wild sheep.

Disease/Fitness

Disease issues should be carefully evaluated when investigating the causes of bighorn sheep declines. Predation is often suspected when a population is declining or during periods of poor lamb recruitment, however the significance of disease in wild sheep population dynamics cannot be understated. Wild sheep occupying marginal habitats or subjected to heavy parasite loads or other pathogens may be experiencing poor health, predisposing them to predation. In the Sheep River study area in Alberta, Ross *et al.* (1997) found that more than 30% of lion killed bighorn sheep appeared to have disabilities prior to death. In some instances, increased levels of predation may be the byproduct of a more important disease related issue.

Monitoring

Regular monitoring is critical for detecting changes in bighorn sheep populations over time. Ground or aerial surveys are perhaps the most common methods for surveying bighorn populations, which in most cases provide useful data sets for evaluating population trends. If and when a bighorn population begins to decline, it is important for managers to attempt to determine cause-specific mortality factors so that appropriate management responses may be considered. Where radio collared animals are available, timely investigations of mortalities will yield excellent data on causes of death. For bighorn populations that do not contain marked individuals, managers should encourage members of the public and local resource professionals to report bighorn sheep observations, particularly those related to mortalities or episodes of predation.

Population Viability

Various authors have examined the concepts of population persistence and minimum viable population size for bighorn sheep. The majority of bighorn sheep populations in Colorado contain ≤100 animals, which some biologists would argue is not ideal for long term persistence (Berger 1990, Douglas and Leslie Jr. 1999). Most managers would agree that small, isolated populations of sheep are less likely to endure or recover from stochastic events such as extended drought, disease epizootics, or episodes of intense predation. Mountain lion predation may threaten the long-term persistence of isolated bighorn sheep populations having fewer than about 125 individuals (<95% probability of persistence; Festa-Bianchet *et al.* 2006). Under these circumstances short-term predator management may be warranted if mountain lion predation is a major mortality factor (McKinney *et al.* 2006a). Mountain lion management for sustaining larger bighorn sheep populations (>125) or management of other predator species does not appear to be an effective management strategy, and efforts addressing habitat quality and quantity may be more effective in preventing sheep densities from reaching low levels where mountain lion predation may become a factor. Managing for specific population objectives for bighorn sheep herds in Colorado is extremely challenging, especially in herds infected with pathogenic strains of *Pasteurellaceae*. Managers should recognize that predation is simply one of several potential limiting factors intrinsic to small, isolated sheep herds in Colorado.

Research and Management Needs

As part of any predator control actions, managers need to structure monitoring programs that are sufficient to estimate parameters that could be related to predation impacts and effect size of management actions. At a minimum, parameter estimates might include bighorn sheep population numbers, survival, and agent-specific mortality rates. Standardized population monitoring and radiotelemetry techniques could be used to acquire the baseline data needed to assess the importance of predation as a mortality factor affecting bighorn sheep population growth. Ideally, before-after-control-impact studies would be implemented over sufficiently long time periods to address mechanisms related to bighorn sheep population decline and subsequent management actions monitored to evaluate success. In addition, bighorn sheep populations in Colorado could be inventoried and characterized (e.g., subspecies, population size, habitat quality and quantity, predators, disease, weather) to evaluate the potential to structure an experimental framework that might include treatment and control areas.

Much of the current literature addressing potential impacts and management recommendations of mountain lion predation relative to bighorn sheep populations are based on modeling efforts (e.g., Ernest *et al.* 2002, Fiesta-Bianchet *et al.* 2006). Recommendations based on model outputs should be treated as management hypotheses and tested in an adaptive management framework, where predictions are made relative to management treatments and are evaluated and modified over time based on the outcome (Cougar Management Guidelines Working Group 2005, McKinney *et al.* 2006a)

Summary of Recommended Considerations

The following conditions should be considered prior to and during predator (primarily mountain lion) control efforts to benefit bighorn sheep. Any predator control effort to benefit bighorn sheep will require approval by the Director.

- Approved Bighorn Sheep DAU and Herd Unit Plans are in place.
- The bighorn population has declined to <65% of management objective.
- Available data support the management objective as an attainable number greater than 125 bighorn sheep (i.e., data suggest that the area can support the plan's population objective and that objective is ≥125 bighorn sheep.)
- Data on cause-specific mortality of bighorn sheep show that predation is a factor in bighorn sheep population performance (e.g., low adult survival and high proportion of losses to predation).
- Herd health screening and mortality investigations suggest that infectious disease does not appear to be contributing significantly to population performance problems.
- Predator control efforts are practical, cost-effective, and will be short term and focused on the individual mountain lion(s) that have been documented as having killed bighorn sheep, or will emphasize mountain lion removal at identified bighorn sheep predation sites.
- Predator control efforts may use hunters and mountain lion harvest limit quotas in certain areas or may use US Department of Agriculture, Animal and Plant Health Inspection Service, Wildlife Services or other professional services.
- Terrain, vegetation, land ownership status, access, and hunting (snow) conditions are suitable for hunters and/or professional personnel and control technologies.
- Success of bighorn sheep translocation efforts may be enhanced by short-term predator control, increased vigilance of releasing larger groups at release sites, and improved evaluation of habitat conditions in the course of release site selection to consider forage and escape terrain requirements for bighorn sheep and potential stalking cover for mountain lions.
- Habitat enhancement projects improving forage quality, quantity, and reducing mountain lion stalking cover will likely provide the best long term benefit for bighorn sheep and must have either been attempted and evaluated prior to implementing predator control activities, or have been determined to be infeasible or ineffective.
- Effectiveness of control efforts to increase bighorn sheep populations should be monitored and compared to non-control areas. Non-control areas should be of the same habitat type, preferably within the same bighorn sheep unit and of similar size.
- If coyotes are determined to be the proximate cause of bighorn sheep declines and the foregoing management conclusions have also been considered, then relevant portions of statewide or local management plans shall govern coyote control actions.
- Non-lethal techniques have been considered.
- DOW commits resources to adequately monitor the effects of the predator control efforts.
- A public information program is instituted to fully explain predator control activities.
- Control efforts will be designed to maximize the opportunity to learn about the impacts of control efforts and the role of predation in bighorn population dynamics.

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Rocky Mountain bighorn sheep in Clear Creek Canyon (S32).
Photo by Nick Clement, Colorado Division of Wildlife.

APPENDIX I

Colorado bighorn sheep posthunt population estimates by unit or herd, 1986-2007.

UNITS						POPULATION ESTIMATES																					
UNIT	Pre-1998	UNIT NAME	Region	Origin	Notes	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007
ROCKY MOUNTAIN BIGHORN SHEEP																											
S1	S1	Poudre River	NE	Trans		100	100	100	100	100	100	145	145	145	145	150	150	120	120	120	115	105	95	95	65	55	55
S2	S2	Gore-Eagle's Nest	NW	Suppl		30	25	25	25	60	100	100	100	100	100	100	80	80	80	100	100	100	100	100	100	100	100
S3	S3	Mount Evans	NE	Trans		75	75	75	75	75	150	100	135	130	215	240	240	200	200	200	200	160	125	125	175	100	90
S4	S3A	Grant	NE	Trans		100	100	100	100	100	125	75	60	130	110	110	110	100	100	150	150	110	110	110	100	100	90
S6	S6	Pikes Peak	SE	Native	1	250	250	200	200	225	225	250	220	250	250	300	300	300	350	350	350	350	350	350	300	300	140
S7	S7	Arkansas River	SE	Suppl		120	120	160	160	160	60	60	60	75	100	125	190	215	215	85	85	85	85	85	85	85	85
S8	S9S	Huerfano	SE, SW	Trans	2	—	25	25	25	30	50	50	50	50	50	50	55	55	55	55	50	70	70	70	65	65	65
S9	S9N	Sangre de Cristo	SE, SW	Suppl	2	600	600	600	600	600	650	600	630	700	685	685	685	685	685	685	685	630	630	400	400	325	325
S10	S10	Trickle Mtn.	SW	Trans		250	250	250	250	250	250	400	200	300	150	85	85	85	60	60	60	55	55	50	50	50	45
S11	S11N	Collegiate, North	SE	Native		160	160	160	160	160	200	200	210	210	200	180	180	170	170	160	160	160	160	160	160	160	160
S12	S12	Buffalo Peaks	SE, NE	Suppl		150	150	150	150	150	150	150	150	150	150	200	200	200	200	200	200	200	200	200	200	200	200
S13	S13E	Snowmass, East	NW	Native		250	150	150	150	150	150	150	150	150	150	150	100	100	100	100	75	75	115	115	110	110	110
S15	S15	Sheep Mtn.	SW	Native		50	50	50	50	50	50	50	50	75	100	100	100	100	100	100	100	100	100	100	100	100	100
S16	S16	Cimarrona Peak	SW	Native		70	70	70	70	70	70	70	70	100	100	100	100	100	100	100	100	100	100	100	90	90	90
S17	S11S	Collegiate, South	SE	Native		70	70	70	70	100	80	100	100	100	80	100	100	100	100	100	100	100	100	100	100	100	100
S18	S18	Rawah	NE,NW	Native		—	20	20	20	20	20	20	20	20	20	20	20	40	40	40	30	30	45	45	20	15	15
S19	S19	Never Summer Range	NW, NE	Native		250	250	250	250	250	200	200	190	175	175	175	175	100	100	50	50	50	50	25	25	25	25
S20	S20	Marshall Pass	SE	Native		100	100	100	100	100	100	150	150	150	100	100	100	100	75	75	75	75	75	75	75	75	75
S21	S21	Cow Creek	SW	Suppl		—	40	40	40	40	40	40	40	70	80	80	80	80	80	80	80	80	80	90	100	110	125
S22	S22	San Luis Peak	SW	Suppl		200	200	200	200	150	150	150	150	75	100	100	100	50	50	50	50	80	80	80	80	85	85
S23	S23N	Kenosha	NE	Native		75	75	75	75	100	100	75	87	100	100	150	150	150	80	80	80	80	75	75	60	60	60
S25	S13W	Snowmass, West	NW	Suppl		200	200	200	200	200	200	200	150	150	145	145	125	125	125	125	125	125	125	125	125	125	75
S26	S26	Taylor River	SW	Suppl	5	150	150	150	150	150	90	90	90	120	140	140	140	140	150	150	150	135	135	150	75	75	70
S27	S23S	Tarryall	NE	Native		200	200	200	200	250	250	250	250	250	165	225	225	225	125	125	100	100	100	100	100	100	100
S28	S28	Vallecito	SW	Suppl		40	40	40	40	40	40	40	50	60	80	80	80	80	80	100	100	100	125	125	125	125	125
S29	S29N	Alamosa Canyon	SW	Trans		100	100	100	100	50	50	80	80	50	50	65	50	50	50	80	60	50	50	35	35	35	35
S30	S29S	Conejos River	SW	Suppl		—	—	—	—	150	150	150	150	150	50	110	100	100	100	80	80	80	80	75	75	75	75
S31	S29W	Blanco River	SW	Native		40	40	40	40	40	40	40	40	60	80	80	80	80	80	100	100	100	100	100	100	100	100
S32	S32	Georgetown	NE	Suppl	3	150	125	150	150	150	175	260	228	260	250	300	350	350	450	450	450	400	250	300	300	400	400
S33	S33	Lake Fork/Pole Mtn	SW	Suppl		33	60	60	60	20	20	20	20	20	20	20	20	20	25	25	25	25	25	60	60	90	90
S34	S34	Rampart Range	SE	Trans		100	100	145	145	150	150	225	150	175	145	130	45	60	65	65	65	65	65	65	75	75	75
S35	S35	Greenhorn	SE	Trans		75	75	75	75	75	75	85	90	75	75	85	85	85	85	85	85	85	50	50	70	70	70
S37	S57S	St. Vrain	NE, NW	Trans	4	—	—	—	—	55	55	—	—	—	—	—	—	80	80	80	80	100	100	100	100	100	50
S38	S38	Apishipa	SE	Trans		130	130	75	75	75	75	45	50	50	50	52	55	55	55	55	55	55	55	55	70	70	70
S44	S44	Basalt	NW	Trans		60	60	60	60	60	60	60	60	60	75	75	75	85	85	100	100	100	100	100	100	100	100
S46	S46	Dome Rock	SE	Native		55	55	55	55	125	125	65	65	65	70	90	90	90	75	75	75	75	75	85	85	85	35
S47	S47	Brown's Canyon	SE	Trans		125	125	125	125	125	125	125	140	140	140	140	100	80	80	150	150	150	150	150	150	150	150
S48	S48	Carrizo Canyon	SE	Trans		45	45	45	45	45	45	45	50	50	50	55	55	55	55	55	55	45	45	45	45	45	55
S49	S49	Grape Creek	SE	Trans		115	115	100	100	100	100	100	220	195	190	200	200	290	290	290	290	290	290	290	225	225	225
S50	S50	Mt. Maestas	SE	Trans		100	85	100	100	100	150	160	170	205	140	150	140	140	120	120	120	120	120	120	125	125	125
S51	S51	Spanish Peaks, Culebra	SE	Trans		—	10	25	25	105	100	100	110	145	145	150	150	150	170	225	225	225	225	225	250	250	250
S53	S53	Bristol Head	SW	Trans	6	—	50	50	50	25	25	25	25	25	25	25	30	30	30	30	30	50	50	50	50	85	110
S54	S54	West Elk-Dillon Mesa	SW	Suppl		50	50	50	50	50	50	90	90	90	90	90	90	90	150	150	150	130	130	110	110	105	100
S57	S57	Big Thompson Canyon	NE	Suppl	4, 7	100	100	150	150	125	125	300	325	160	75	140	140	60	50	50	60	80	80	80	80	80	85
S59	S59	Derby Creek	NW	Suppl		—	40	40	40	60	110	110	90	60	65	65	65	65	80	115	115	115	115	115	90	90	90
S60	S60	Shelf Road	SE	Trans		—	75	75	75	100	100	100	100	110	150	150	150	150	150	150	150	150	150	150	150	150	150
S61	S61	Purgatorie Canyon	SE	Trans		—	100	100	100	125	125	125	130	160	200	240	240	240	240	240	240	240	240	240	240	240	240
S65	S65	Costilla	SW	Trans		—	—	—	—	—	—	—	—	100	100	100	100	160	150	200	300	300	300	400	400	400	400
S66	S66	Mt. Ebert	SE	Native		—	—	—	—	—	—	—	—	—	60	60	60	75	75	75	75	75	75	75	75	125	125
S67	S67	White R., South Fork	NW	Trans		—	30	30	30	50	60	60	60	60	60	60	75	75	75	60	60	60	60	60	40	40	40
S68	S68	Cotopaxi	SE	Trans		—	—	—	—	—	—	—	—	—	—		25	65	65	60	60	60	60	60	60	60	60
S69	S69	Lower Cochetopa Canyon	SW	Trans		—	—	—	—	—	—	—	—	—					65	65	65	65	65	55	55	55	50
S70	S70	Fossil Ridge	SW	Trans	5	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	60	55	50
S71	S71	West Needles	SW	Trans		—	—	—	—	—	—	—	—	—	—	—	—	—	—		30	45	45	50	70	75	75
S5	S6A	Beaver Cr.	SE	Native		70	70	80	80	80	80	70	80	80	80	80	80	30	30	30	30	30	30	30	30	30	30
S14	S14	Cimetop Mesa	NW	Suppl		—	—	—	—	23	40	40	20	20	20	20	20	20	10	10	10	10	10	10	5	5	5
S24	S24	Battlement Mesa	NW	Suppl		—	30	30	30	30	30	30	25	25	25	25	25	25	25	25	20	20	20	20	20	25	30
S36	S55W	Bellows Cr.	SW	Suppl		—	30	30	30	30	30	90	30	30	40	40	40	40	40	40	20	35	35	35	35	35	45
S40	S1A	Lone Pine	NE	Trans		—	20	20	20	23	23	23	0	0	0	0	0	0	0	0	0	0	5	5	15	15	25
S45	S45	Cross Mountain	NW	Trans		—	20	20	20	20	20	20	0	0	0	0	0	0	0	0	10	10	10	10	0	0	0
S52	S52	Rock Creek	SW	Trans		—	100	—	100	20	20	20	0	0	0	0	0	0	0	0	0	20	20	20	25	25	25
S55	S55E	Natural Arch, Cameo Crk	SW	Trans		75	75	75	75	100	100	100	75	100	70	50	50	50	50	40	40	40	40	25	20	20	20
S58	S58	Lower Poudre River	NE	Trans		60	60	60	60	90	100	125	140	140	100	100	60	40	40	40	30	30	30	30	25	25	20
NA		Black Canyon	SW	Trans		—	50	50	50	90	90	90	90	90	75	75	75	40	25	25	25	25	25	25	30	30	30
NA		DeBeque Canyon	NW	Trans		—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—		20	20	40	45	40
NA		DNM - Harper's Corner	NW	Trans		—	40	40	40	40	40	40	40	40	40	40	40	40	40	40	40	40	40	40	40	40	40
NA		DNM - Ladore Can.	NW	Trans		—	70	70	70	70	70	60	60	60	60	60	60	60	60	60	90	90	90	90	90	90	90
NA		DNM - Yampa River	NW	Trans		—	—	—	—	—	—	—	—	—	—	—	30	30	30	30	35	35	35	35	35	35	35
S74		Glenwood Canyon	NW	Trans	11	—	—	—	—	27	35	35	35	35	35	35	15	15	15	15	15	15	15	15	35	35	35
S72		Greenland	NE	Expan	10	—	—	—	—	—	—	—	—	—	—	—	—	20	20	20	20	20	20	20	35	50	40
NA		Lower Lake Fork	SW	Suppl		—	15	15	15	15	15	20	20	20	20	20	20	20	10	10	10	10	10	10	10	10	10
NA		Mesa Verde	SW	Trans		—	25	25	25	25	25	0	0	0	0	0	10	10	10	10	25	25	25	25	20	20	20
NA		Mount Silverheels	NE	Trans		—				15	0	12	12	12	12	12	25	25	25	25	25	25	25	25	25	25	25
S73	S8	Mount Zirkel	NW	Trans	11	—	—	—	—	0	0	0	0	0	0	0	0	0	0	0	5	5	5	5	45	50	50
NA		Rifle Hogback	NW	Trans		—	30	30	30	30	5	5	5	5	5	5	0	0	0	0	0	0	0	0	0	0	0
NA		Pueblo Reservoir	SE	Trans																					20	20	15
NA		Rio Grande R., Box Can.	SW	Trans		—	—	30	—	30	30	30	30	30	30	30	35	35	35	35	35	35	35	35	35	NA	NA
NA		RMNP - East Side	NE	Suppl		—	200	200	200	130	130	130	130	130	130	130	130	130	75	75	75	75	75	75	75	75	75
NA		RMNP - Continental Div.	NE,NW	Native		—	—	—	—	—	—	—	—	—	—	—	—	60	125	125	125	125	125	125	100	100	100
NA		RMNP - Never Summer	NE,NW	Native	8	—	—	—	—	—	—	—	—	—	—	—	—		200	150	150	150	250	250	200	200	200
NA		Sawpit	SW	Trans		—	10	10	10	10	10	10	10	3	10	10	10	10	10	10	10	10	10	10	10	10	20
NA		Waterton Canyon	NE	Native		—	14	16	16	22	22	22	22	22	22	22	25	25	25	25	25	25	25	25	25	25	25
NA		Deep Creek	NW	Trans		—	—	—	—	—	—	—	—	25	25	25	35	35	35	—	—	—	—	—	—	—	—
NA		Cold Springs	NW	Trans		—	50	50	50	80	80	40	40	40	40	40	5	5	5	—	—	—	—	—	—	—	—
		TOTAL				**4973**	**5949**	**5961**	**6031**	**6540**	**6685**	**7097**	**6814**	**7207**	**6884**	**7341**	**7230**	**7245**	**7475**	**7510**	**7590**	**7495**	**7465**	**7365**	**7275**	**7330**	**7040**
		Hunted Subtotal				4,773	4,840	4,905	5,005	5,275	5,685	6,235	6,010	6,270	6,120	6,577	6,535	6,455	6,325	6,510	6,580	6,495	6,340	6,265	6,120	6,215	5,990
		Nonhunted Subtotal				200	1109	1056	1026	1265	1000	862	804	937	764	764	695	790	1150	1000	1010	1000	1125	1100	1155	1115	1050
DESERT BIGHORN SHEEP																											
S56		Black Ridge	NW	Trans		100	100	100	100	110	110	110	150	90	90	70	70	70	70	70	70	70	70	70	70	70	75
S62		Uncompahgre	SW	Trans			60	60	60	80	80	80	100	120	150	150	175	150	175	175	175	100	100	125	150	150	150
S63		Middle Dobres	SW	Trans		—	—	—	—	19	19	19	19	25	35	35	35	35	35	35	55	55	30	30	30	30	30
S64		Upper Dobres	SW	Trans			65	65	65	65	65	125	125	130	180	180	180	180	180	180	180	125	50	50	60	70	70
		TOTAL				**100**	**225**	**225**	**225**	**274**	**274**	**334**	**394**	**365**	**455**	**435**	**460**	**435**	**460**	**460**	**480**	**350**	**250**	**275**	**310**	**320**	**325**
		Hunted Subtotal				0	0	100	100	110	110	315	375	340	420	400	355	330	355	355	355	225	150	175	210	220	295
		Nonhunted Subtotal				100	225	125	125	164	164	19	19	25	35	35	105	105	105	105	125	125	100	100	100	100	30

ABBREVIATIONS

- NA = No unit number available or not applicable.
- DNM = Dinosaur National Monument.
- RMNP = Rocky Mountain National Park.
- NE = Northeast, NW = Northwest, SE = Southeast, SW = Southwest.

ORIGIN

- Native = Indigenous herd that has not been supplemented with translocated bighorns.
- Suppl = Indigenous herd that has been supplemented with translocated bighorns (translocated bighorns are not considered the primary origin of the herd).
- Trans = Herd that has resulted entirely or primarily from translocated bighorns.
- Expan = Herd resulting from natural expansion of an existing herd.

HIGHLIGHT COLOR CODES (based on calendar year)

- Bighorns translocated from unit or area.
- Bighorns released into unit or area.
- Bighorns translocated from and released into unit or area.
- Onset of confirmed or suspected disease outbreak with subsequent all-age die-off.
  Change in inventory method resulting in change in population estimate.
- Unit combined or split.

FONT COLOR CODES

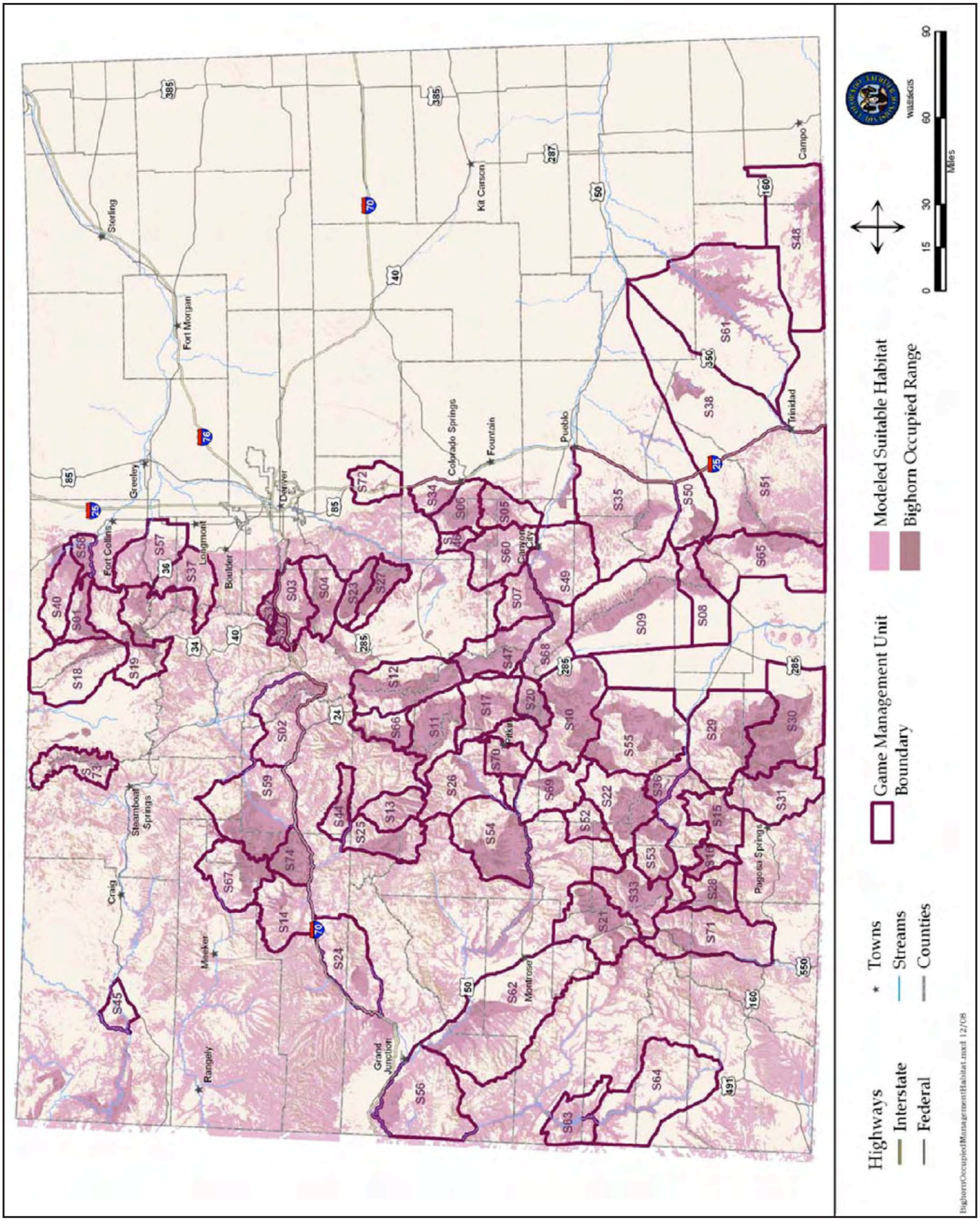
- Black = Population estimate for population open to hunting.
- **Red (bold) = Population estimate for population closed to hunting.**
- **Blue (bold) = Missing population estimate filled in to calculate statewide totals**.

NOTES

1. Population estimate adjusted after mark/resight population estimation began in 2007
2. S9 was divided into S9 and S8 in 1997
3. Population estimate adjusted after mark/resight population estimation began in 2006
4. S57 was divided into S57 and S37 in 1998.
5. S26 was divided into S26 and S70 in 2005.
6. Rio Grande River Box Canyon added to S53 in 2006
7. Population estimate adjusted after mark/resight population estimation in 1992.
8. Population estimate adjusted after mark/resight population estimation in 2003.
9. Unit created in 2007.
10. Unit created in 2008.
11. Unit created in 2009.

APPENDIX II

Occupied and potential bighorn sheep habitat in Colorado, 2008.



APPENDIX II. Bighorn sheep game management units, occupied bighorn sheep range, and modeled potentially suitable bighorn sheep habitat (based primarily on slope) in colorado, 2008.

APPENDIX III

Bighorn sheep trap and release sites in Colorado, 1945-2007.

Year	Bio Year	Date	Subsp	Trap Site	Trap Region	Trap GMU*	Trap Sheep Unit	Release Site	Release Region	Release GMU*	Release Sheep Unit	Rams	Ewes	Yrlgs	Lambs	Total
1945	1944	3/15/45	RM	TARRYALL RANGE	SE	501	S27	SANGRE DE CRISTO RANGE	SW		S9	1	7		6	14
1945	1944	3/1/45	RM	TARRYALL RANGE	SE	501	S27	GRANT	CE	46	S4	3	8		5	16
1946	1946	12/6/46	RM	TARRYALL RANGE	SE	501	S27	UPPER POUDRE	NE	8	S1	3	6	3	4	16
1946	1946	10/29/46	RM	TARRYALL RANGE	SE	501	S27	GEORGETOWN	NE	39	S32	3	20	3	7	33
1946	1945	1/?/46	RM	TARRYALL RANGE	SE	501	S27	MESA VERDE	SW	73	None	3	7		4	14
1946	1945	2/?/46	RM	TARRYALL RANGE	SE	501	S27	RAMPART RANGE	SE	511	S34	2	10		2	14
1947	1947	12/5/47	RM	TARRYALL RANGE	SE	501	S27	GLENWOOD CANYON	NW	34	S74	4	9		4	17
1948	1947	1/16/48	RM	TARRYALL RANGE	SE	501	S27	GORE RANGE	NW	36	S2	1	6			7
1948	1947	1/16/48	RM	TARRYALL RANGE	SE	501	S27	GRANT	CE	46	S4		7			7
1948	1947	1/16/48	RM	TARRYALL RANGE	SE	501	S27	RIFLE HOGBACK	NW	33	None	4	8		5	17
1949	1948	3/3/49	RM	TARRYALL RANGE	SE	501	S27	GEORGETOWN	NE	39	S32	2	8	2	2	14
1950	1949	3/9/50	RM	TARRYALL RANGE	SE	501	S27	BRUSH CREEK	NW			2	3		3	8
1951	1950	2/15/51	RM	TARRYALL RANGE	SE	501	S27	TRICKLE MT.	SW	681	S10	3	8		4	15
1952	1951	2/19/52	RM	RIFLE HOGBACK	NW	33	None	DINOSAUR NORTH (LADORE)	NW	2	None	5	12			17
1952	1951	1/29/52	RM	TARRYALL RANGE	SE	501	S27	DINOSAUR NORTH (LADORE)	NW	2	None	3	12			15
1970	1970	12/?/70	RM	GLENWOOD CANYON	NW	34	S74	LITTLE HILLS	NW	22	NA					5
1970	1970	9/23/70	RM	PIKES PEAK	SE	59	S6	TAYLOR RIVER	SW	55	S26		1			1
1970	1970	1&8/70	RM	PIKES PEAK	SE	59	S6	LOWER LAKE FORK (SAPINERO)	SW	66	None	1	3	1	1	6
1970	1970	9/23/70	RM	PIKES PEAK	SE	59	S6	LAKE FORK	SW	66	None	1	1			2
1972	1971	1/?/72	RM	TRICKLE MT. (SAGUACHE)	SW	681	S10	LITTLE HILLS	NW	22	NA					2
1972	1971	1/8/72	RM	TRICKLE MT. (SAGUACHE)	SW	681	S10	BASALT (FRYING PAN)	NW	444	S44	6	12			18
1974	1974		RM	PIKES PEAK	SE	59	S6	CSU	NE	19	NA					7
1974	1973	1/15/74	RM	TRICKLE MT. (SAGUACHE)	SW	681	S10	DILLON MESA (ELK CR.)	SW	54	S54	3	22			25
1975	1975		RM	TRICKLE MT. (SAGUACHE)	SW	681	S10	DILLON MESA	SW	54	S54					20
1975	1974	1/14/75	RM	TRICKLE MT. (SAGUACHE)	SW	681	S10	LOWER LAKE FORK (SAPINERO)	SW	66	None	5	11			16
1975	1974	1/21/75	RM	UPPER POUDRE	NE	191	S1	LOWER POUDRE	NE	191	S58	7	18			25
1976	1975	1/?/76	RM	TRICKLE MT. (SAGUACHE)	SW	681	S10	GREENHORNS	SE	84	S35	6	14			20
1976	1975	1/?/76	RM	TRICKLE MT. (SAGUACHE)	SW	681	S10	SAN LUIS PEAK (CEBOLLA)	SW	67	S22		3			3
1976	1975	1/?/76	RM	TRICKLE MT. (SAGUACHE)	SW	681	S10	SAN LUIS PEAK (CEBOLLA)	SW	67	S22	3	6			9
1977	1976	1/26/77	RM	MOUNT EVANS	NE	46	S3	CROSS MT.	NW	11	S45	3	12		5	20
1977	1976	3/8/77	RM	PIKES PEAK	SE	59	S6	DILLON MESA (SOAP CR.)	SW	54	S54	1	12		6	19
1977	1976	3/17/77	RM	TARRYALL RANGE (COTTON GORDONS)	SE	501	S27	RMNP EAST (COW CREEK)	NE	20	None	2	14		4	20
1977	1976	3/31/77	RM	TRICKLE MT. (SAGUACHE)	SW	681	S10	CEBOLLA CREEK	SW	67	S52		7		7	9
1977	1977		RM	TRICKLE MT. (SAGUACHE)	SW	681	S10	LONE PINE (LAMB PROPERTY)	NE	191	S40	2	13		4	19
1977	1976	2/9/77	RM	UPPER POUDRE	NE	191	S1	APISHAPA SWA	SE	133	S38	3	15		7	25
1978	1977	2/22/78	RM	ALMONT TRIANGLE	SW	55	S26	ALAMOSA RIVER	SW	80	S29	3	12		7	22
1978	1978	12/21/78	RM	BASALT (FRYING PAN, SEVEN CASTLES)	NW	444	S44	MARBLE	NW	43	S13	4				4
1978	1978	12/20/78	RM	BASALT (FRYING PAN, SEVEN CASTLES)	NW	444	S44	AVALANCHE CR.	NW	43	S25	5				5
1978	1977	3/23/78	RM	PIKES PEAK	SE	59	S6	BUFFALO PEAKS (RIVERDALE)	SE	49	S12	2	5		1	8
1978	1977	3/28/78	RM	PIKES PEAK	SE	59	S6	BUFFALO PEAKS (RIVERDALE)	SE	49	S12	1	3			4
1978	1977	1/26/78	RM	TARRYALL RANGE (Sugarloaf)	SE	501	S27	BUFFALO PEAKS (LANGHOFF)	SE	49	S12	5	7		5	17
1978	1977	3/8/78	RM	TRICKLE MT. (SAGUACHE)	SW	681	S10	RAMPART RANGE (MONUMENT)	SE	511	None	3	7		10	20
1978	1977	2/9/78	RM	UPPER POUDRE	NE	191	S1	ALAMOSA CANYON (CONEJOS	SW	80	S29		11		9	20
1979	1979	11/8/79	D	ARIZONA - KOFA GAME RANGE	—	—	OS	DEVILS CANYON	NW	40	S62	3	8		0	11
1979	1979		RM	GRANT (GENEVA CREEK)	NE	46	S4	CSU	NE	19	NA	1	10		10	21
1979	1979		RM	ROCKY MT. NATL. PARK (NEVER SUMMERS)	NW	18	None	ARIZONA AND NEVADA	—	—	OS					16
1980	1979	4/8/80	RM	COLLEGIATES NORTH (COTTONWOOD CR.)	SE	481	S11	SAWPIT	SW	70	None	1	11		8	20
1980	1979	2/12/80	RM	COLLEGIATES SOUTH (CHALK	SE	481	S17	CARRIZO CANYON	SE	143	S48	4	9		7	21
1980	1980		RM	GRANT (GENEVA CREEK)	NE	46	S4	CSU	NE	19	NA					12
1980	1980	6/17/80	D	NEVADA - LAKE MEAD	—	—	OS	MONUMENT CANYON	NW	40	S56	4	7		5	16
1980	1980		RM	TARRYALL RANGE	SE	501	S27	ARIZONA & NEVADA	—	—	OS					24
1980	1979	2/19/80	RM	TARRYALL RANGE	SE	501	S27	BROWNS CANYON	SE	57	S47	5	9		6	20
1980	1980		RM	TRICKLE MT. (SAGUACHE)	SW	681	S10	ALAMOSA CANYON (PASO CR.)	SW	80	S29					24
1980	1979	2/7/80	RM	TRICKLE MT. (SAGUACHE)	SW	681	S10	ALAMOSA CANYON (HOT CR.)	SW	80	S29	2	7		15	24
1980	1980	3/7/80	RM	UPPER POUDRE	NE	191	S1	BUTTON ROCK	NE	20	S37	3	7		9	20
1981	1981	11/19/81	D	ARIZONA - BLACK MTS	—	—	OS	DEVILS CANYON	NW	40	S56	0	9		0	9
1981	1980	2/20/81	RM	BASALT (FRYING PAN, SEVEN CASTLES)	NW	444	S44	DERBY CREEK	NW	25	S59		11		8	19
1981	1980	3/4/81	RM	TRICKLE MT. (SAGUACHE)	SW	681	S10	NOLAND GULCH				9	9		1	19
1981	1980	3/12/81	RM	TRICKLE MT. (SAGUACHE)	SW	681	S10	SPANISH PEAKS EAST	SE	85	S51		14		6	20
1981	1980	4/21/81	RM	TRICKLE MT. (SAGUACHE)	SW	681	S10	BROWNS CANYON (WELLS GULCH))	SE	57	S47	5	14			19
1982	1981	4/2/82	RM	COLLEGIATES NORTH (COTTONWOOD CR.)	SE	481	S11	SHELF ROAD	SE	581	S60	2	11		6	19
1982	1981	4/22/82	RM	ROCKY MT. NATL. PARK (NEVER SUMMERS)	NW	18	None	PURGATOIRE	SE	147	S61	2	10		5	17
1982	1981	3/26/82	RM	UPPER POUDRE	NE	191	S1	NATURAL ARCH (EAGLE ROCK)	SW	68	S55	2	11		7	20
1983	1983	8/2/83	D	ARIZONA - LAKE MEAD	—	—	OS	DOMINGUEZ CREEK	SW	62	S62	2	6		2	10
1983	1982	2/8/83	RM	BASALT (FRYING PAN, SEVEN CASTLES)	NW	444	S44	BEAVER CR. (BROWNS PARK)	NW	201	None	4	10		8	22
1983	1982	3/9/83	RM	COW CREEK (ESTES PARK)	NE	20	None	BRISTOL HEAD	SW	76	S53	3	11		5	19
1983	1982	2/21/83	RM	KENOSHA PASS	NE	501	S23	MT. MAESTAS	SE	85	S50	1	14		6	21
1983	1982	4/19/83	RM	MUMMY RANGE (RMNP EAST)	NE	171	None	BIG THOMPSON	NE	20	S57	2	9		8	19
1983	1982	2/21/83	RM	TARRYALL RANGE	SE	501	S27	ALAMOSA CANYON (ELK CR.)	SW	80	S29	2	10		9	21
1983	1980	3/22/83	RM	TRICKLE MT. (SAGUACHE)	SW	681	S10	COPPER GUCLH (GRAPE CR.)	SE	69	S49	2	11		9	22
1984	1983	2/10/84	RM	ALMONT TRIANGLE	SW	55	S26	BRISTOL HEAD	SW	76	S53	5	11		4	20
1984	1984	7/16/84	D	ARIZONA - LAKE MEAD	—	—	OS	DOMINGUEZ CREEK	SW	62	S62	2	5		3	10
1984	1983	3/13/84	RM	COLLEGIATES NORTH (COTTONWOOD CR.)	SE	481	S11	TRICKLE MT. (FINDLEY GULCH)	SW	681	S10	1	11		8	20
1984	1983	1/3/84	RM	RAMPART RANGE	SE	511	S34	SPANISH PEAKS WEST	SE	85	S51	3	10		7	20
1984	1983	4/12/84	RM	ROCKY MT. NATL. PARK (NEVER SUMMERS)	NW	18	None	DINOSAUR SOUTH	NW	10	None	1	13		5	19
1984	1983	3/2/84	RM	TRICKLE MT. (SAGUACHE)	SW	681	S10	COPPER GUCLH (TEXAS CR. SOUTH)	SE	691	S49	2	10		8	20
1985	1984	3/31/85	RM	COLLEGIATES NORTH (COTTONWOOD CR.)	SE	481	S11	SAGUACHE (FINDLEY GULCH)	SW	681	S10	1	11		8	20
1985	1984	3/6/85	RM	COLLEGIATES NORTH (COTTONWOOD CR.)	SE	481	S11	BLUE CREEK	SW	79	S36	2	10		8	20
1985	1985		RM	GRANT (GENEVA CREEK)	NE	46	S4	CSU	NE	19	NA					12
1985	1985	7/24/85	D	NEVADA - LAKE MEAD	—	—	OS	BIG DOMINGUEZ CREEK	SW	62	S62	1	8		4	13
1985	1985	8/3/85	D	NEVADA - LAKE MEAD	—	—	OS	BIG DOMINGUEZ CREEK	SW	62	S62	0	8		0	8
1985	1984	1/11/85	RM	OURAY-JACKASS FLATS	SW	65	S21	BROWNS CANYON	SE	57	S47	2	15		3	20
1985	1984	3/21/85	RM	TARRYALL RANGE	SE	501	S27	COPPER GULCH (GRAPE CR.)	SE	69	S49	2	10		8	20

APPENDIX III - *Continued*

Year	Bio Year	Date	Subsp	Trap Site	Trap Region	Trap GMU*	Trap Sheep Unit	Release Site	Release Region	Release GMU*	Release Sheep Unit	Rams	Ewes	Yrlgs	Lambs	Total
1986	1985	2/24/86	RM	ALMONT TRIANGLE	SW	55	S26	NEVADA	—	—	OS	1	16		3	20
1986			D	ARIZONA - LAKE MEAD	—	—	OS	UPPER DOLORES	SW	711	S64	5	25		5	35
1986	1985	3/14/86	RM	COLLEGIATES NORTH (COTTONWOOD CR.)	SE	481	S11	PURGATOIRE (CHACUACO)	SE	147	S61	2	10		8	20
1986	1986		RM	GEORGETOWN	NE	39	S32	CLEAR CREEK (20 MILES)	SE	38	None					20
1986	1985	3/6/86	RM	ROCK CREEK (CEBOLLA SWA)	SW	67	S52	TAYLOR CANYON	SW	55	S26	1				1
1986	1985	3/6/86	RM	ROCK CREEK (CEBOLLA SWA)	SW	67	S52	GUNNISON GORGE	SW	64	None	3	12		5	20
1987			D	ARIZONA - LAKE MEAD	—	—	OS	UPPER DOLORES	SW	711	S64	5	11		5	21
1987	1986	2/4/87	RM	BASALT (FRYING PAN, SEVEN CASTLES)	NW	444	S44	NEVADA	—	—	OS					22
1987	1986	2/4/87	RM	BASALT (FRYING PAN, SEVEN CASTLES)	NW	444	S44	UTAH & NEVADA	—	—	OS	6	16			22
1987	1986	2/19/87	RM	COLLEGIATES NORTH (COTTONWOOD CR.)	SE	481	S11	HUERFANO (MT. BLANCA)	SW	861	S8	4	7		9	20
1987	1886	3/3/87	RM	GEORGETOWN	NE	39	S32	SOUTH FORK, WHITE RIVER	NW	24	S67	2	14		8	24
1987	1986	1/16/87	RM	MUMMY RANGE (RMNP EAST)	NE	171	None	BIG THOMPSON	NE	20	S57	5	14		7	26
1987	1986	3/13/87	RM	ROCK CREEK (CEBOLLA SWA)	SW	67	S52	GUNNISON GORGE	SW	64	None	2	12		9	23
1987	1986	3/13/87	RM	ROCK CREEK (CEBOLLA SWA)	SW	67	S52	POLE MT. (UPPER LAKE FORK)	SW	66	S33	1	1			2
1987	1986	2/10/87	RM	TRICKLE MT. (SAGUACHE)	SW	681	S10	RIFLE HOGBACK	NW	33	None	3	9		6	21
1987	1986	2/10/87	RM	TRICKLE MT. (SAGUACHE)	SW	681	S10	POLE MT. (UPPER LAKE FORK)	SW	66	S33	1	2			3
1988	1987	1/6/88	RM	ALMONT TRIANGLE	SW	55	S26	SAN LUIS PEAK (CEBOLLA)	SW	67	S22	1				1
1988	1987	1/21/88	RM	ALMONT TRIANGLE	SW	55	S26	BLUE CREEK	SW	79	S36	2	9		9	20
1988	1987	1/6/88	RM	ALMONT TRIANGLE	SW	55	S26	GUNNISON GORGE	SW	64	None	3	14		2	19
1988	1987	2/12/88	RM	AVALANCHE CREEK	NW	43	S26	PINE RIVER	SW	751	S28	4	12		5	21
1988	1987	2/18/88	RM	GEORGETOWN	NE	39	S32	SPANISH PEAKS WEST	SE	85	S51	2	10		8	20
1988	1987	1/23/88	RM	PIKES PEAK	SE	59	S6	CEDAR SPRINGS GULCH (TEXAS CR.)	SW	86	S68	3	9		8	20
1988	1987	1/23/88	RM	TARRYALL RANGE	SE	501	S27	HARDSCRABBLE CREEK	SE	68	S55	2	8		10	20
1988	1987	1/7/88	RM	TRICKLE MT. (SAGUACHE)	SW	681	S10	MT. SILVERHEELS	NE	49	None	2	11		7	20
1989	1988	1/27/89	RM	ALMONT TRIANGLE	SW	55	S26	TRINCHERA PEAK	SE	85	S51	2	10		13	25
1989	1988	1/27/89	RM	ALMONT TRIANGLE	SW	55	S26	BUFFALO PEAKS	SE	49	S-12					5
1989	1988	1/4/89	RM	COW CREEK (ESTES PARK)	NE	20	None	W. OF CARTER LAKE	NE	20	S57		9	8	9	26
1989	1988	1/19/89	RM	GEORGETOWN	NE	39	S32	NEVADA	—	—	OS					26
1989	1988	2/10/89	RM	MT MAESTAS - MAURICIO CANYON	SE	85	S50	APISHAPA SWA	SE	133	S38	4	1		1	6
1989	1988	1/17/89	RM	WATERTON CANYON	NE	461	None	NEVADA	—	—	OS					26
1990	1989	3/20/90	RM	BRITISH COLUMBIA	—	—	OS	FORBES TRINCHERA	SW	83	S65	4	8		8	20
1990	1989	3/18/90	RM	BRITISH COLUMBIA	—	—	OS	FORBES TRINCHERA	SW	83	S65	1	11		2	14
1990	1989	2/2/90	RM	COLLEGIATES NORTH (COTTONWOOD CR.)	SE	481	S11	DERBY CREEK	NW	35	S59	3				3
1990	1989	2/20/90	RM	COLLEGIATES NORTH (COTTONWOOD CR.)	SE	481	S11	OREGON	—	—	OS		6		3	9
1990	1989	2/20/90	RM	COLLEGIATES NORTH (COTTONWOOD CR.)	SE	481	S11	CLINETOP MESA	NW	33	S14	1	7	3	10	21
1990	1989	2/20/90	RM	COLLEGIATES NORTH (COTTONWOOD CR.)	SE	481	S11	APISHAPA SWA	SE	133	S38	4				4
1990	1989	1/23/90	RM	COW CREEK (ESTES PARK)	NE	20	None	NO NAME CREEK (GLENWOOD CANYON)	NW	34	S74					27
1990	1989	1/22/90	RM	RAMPART RANGE	SE	511	S34	BADGER CREEK	SE	58	S47	1	7	2	9	19
1990	1989	1/22/90	RM	BROWNS CANYON (SUGARLOAF)	SE	57	S47	OREGON	—	—	OS					21
1991	1990	1/17/91	RM	ALMONT TRIANGLE	SW	55	S26	BOX CANYON (RIO GRANDE)	SW	76	S53	2	9	1	7	19
1991	1990	1/17/91	RM	ALMONT TRIANGLE	SW	55	S26	GLENWOOD, GRIZZLY CREEK	NW	34	S74	2	14		4	20
1991	1990	1/18/91	RM	AVALANCHE CREEK	NW	43	S26	CLINETOP MESA	NW	33	S14					20
1991	1990	2/3/91	RM	COW CREEK (ESTES PARK)	NE	20	None	LOWER POUDRE R.	NE	191	S58					18
1991	1990	2/3/91	RM	FALL RIVER	NE	20	None	RES.)	NE	191	S58	2	9	2	5	18
1991	1990	1/30/91	RM	GEORGETOWN	NE	39	S32	SOUTH DAKOTA	—	—	OS	8	19			27
1992	1991	2/5/92	RM	GEORGETOWN	NE	39	S32	COW CREEK, OURAY - CUTLER CREEK	SW	65	S21	4	5	3	9	21
1992	1991	1/21/92	RM	RAMPART RANGE	SE	511	S34	PARKDALE (TAYLOR GULCH)	SE	581	S7	3				3
1992	1991	1/21/92	RM	RAMPART RANGE	SE	511	S34	N. FORK S. ARKANSAS RIVER	SE	481	S17	3	7		11	21
1993	1993	7/26/93	D	ARIZONA - BLACK MTS	—	—	OS	ROUBIDEAU CANYON	SW	62	S62	3	12		3	18
1993	1993	7/26/93	D	ARIZONA - LAKE MEAD	—	—	OS	ROUBIDEAU CANYON	SW	62	S62	3	15		2	20
1993	1992	1/29/93	RM	GEORGETOWN	NE	39	S32	NEVADA	—	—	OS	1	5	9	7	22
1994	1993	2/9/94	RM	RAMPART RANGE	SE	511	S34	ARIZONA	—	—	OS	3	10		8	21
1995	1994	2/15/95	RM	ALMONT TRIANGLE	SW	55	S26	COCHETOPA (POISON GULCH)	SW	551	S69					24
1995	1994	1/24/95	RM	ALMONT TRIANGLE	SW	55	S26	ARIZONA	—	—	OS					28
1995	1994	3/10/95	RM	DOME ROCK SWA	SE	581	S46	DEEP CREEK (NORTH OF DOTSERO)	NW	34	None		14	1	5	20
1995	1994	1/25/95	RM	GEORGETOWN	NE	39	S32	UTAH	—	—	OS	10	17		1	28
1995	1995	10/28/95	D	NEVADA - MUDDY MTNS	—	—	OS	KNOWLES CANYON	NW	40	S62	4	18			22
1996	1995	2/9/96	RM	ALMONT TRIANGLE	SW	55	S26	COTOPAXI (WEST McCOY	SE	86	S68		12	1	7	20
1996	1995	1/23/96	RM	RAMPART RANGE	SE	511	S34	WEST ELK, SOAP CREEK	SW	54	S54	3	10		9	22
1997	1996	1/8/97	RM	AVALANCHE CREEK	NW	43	S25	COTOPAXI (HENTHORN GULCH)	SE	58	S7	2	12		6	20
1997	1996	3/18/97	RM	DOME ROCK SWA	SE	581	S46	DINOSAUR NATIONAL MONUMENT	NW	10	None	3	10		8	21
1997	1996	2/7/97	RM	MT MAESTAS - SILVER	SE	85	S50	GLENWOOD, GRIZZLY CREEK	NW	34	S74	8	9		12	29
1998	1997	1/14/98	RM	GEORGETOWN	NE	39	S32	BROWNS CANYON	SE	57	S47	3				3
1998	1997	1/14/98	RM	GEORGETOWN	NE	39	S32	COTOPAXI	SE	86	S68		11	2	8	21
1999	1998	4/8/99	RM	DOME ROCK SWA	SE	581	S46	HOLY CROSS WILDERNESS	NW	45	None	3	12			15
2000	1999	2/27/00	RM	ALMONT TRIANGLE	SW	55	S26	WEST ELKS (DILLON GULCH)	SW	54	S54		6			6
2000	1999	1/26/00	RM	GEORGETOWN	NE	39	S32	DINOSAUR	NW	10	None	6	7	8	6	27
2000	1999	2/1/00	RM	GEORGETOWN	NE	39	S32	BIG THOMPSON	NE	20	S57	5	13		4	22
2000	1999	2/21/00	RM	MT MAESTAS - SILVER MOUNTAIN	SE	85	S50	TROUTCREEK PASS - BUENA VISTA	SE	58	S12		10	1	1	12
2000	1999	2/27/00	RM	ALMONT TRIANGLE	SW	55	S26	DILLON GULCH	SW	54	S54		6			6
2001	2000	1/26/01	RM	GEORGETOWN	NE	39	S32	WEST NEEDLES	SW	75	S71	2	15		11	28
2001	2000	3/1/01	RM	RAMPART RANGE	SE	511	S34	NEBRASKA	—	—	OS		12	4	6	22
2001	2000	2/7/01	D	UTAH - SAN RAFEAL REEF	—	—	OS	BULL CANYON	SW	70	S63	3	14	8		25
2001	2000	1/8/01	RM	BASALT (TONER CREEK)	NW	444	S44	UTAH	—	—	OS	0	14	4	4	22
2002	2001	2/7/02	RM	GEORGETOWN	NE	39	S32	POWDERHORN	SW	67	None	3	17		7	27
2002	2001	2/21/02	RM	ALMONT TRIANGLE	SW	55	S26	ROCK CREEK	SW	67	S52	1	4		1	6
2003	2003	12/31/03	RM	BASALT	NW	444	S44	DeBEQUE CANYON	NW	31	None	3	9		3	15
2003	2003		RM	GEORGETOWN	NE	39	S32	WEST NEEDLES	SW	75	S71	5	2			7
2003	2002	2/14/03	RM	RAMPART RANGE	SE	511	S34	DeBEQUE CANYON	NW	31	None		7	3	8	18
2004	2003	2/27/04	RM	ALMONT TRIANGLE	SW	55	S26	DeBEQUE CANYON	NW	31	None	7	8			15
2005	2004	2/4/05	RM	BASALT (TONER CREEK)	NW	444	S44	BATTLEMENT MESA	NW	421	S24		3	1		4
2005	2005	12/30/05	RM	BASALT (TONER CREEK)	NW	444	S44	BATTLEMENT MESA	NW	421	S24	1	3			4
2005	2004	1/27/05	RM	FORBES TRINCHERA	SW	83	S65	MT ZIRKEL (RED CANYON, NORTH PARK)	NW	161	S73	8	11		7	26
2005	2004	1/28/05	RM	FORBES TRINCHERA	SW	83	S65	MT ZIRKEL (RED CANYON, NORTH PARK)	NW	161	S73		6		8	14
2006	2006	12/29/06	RM	BASALT (TONER CREEK)	NW	444	S44	BATTLEMENT MESA	NW	421	S24	2	2			4
2007	2006	3/7/07	RM	FORBES TRINCHERA	SW	83	S65	UTAH	—	—	OS	1	16		1	18