Northern Wild Sheep and Goat Council

PROCEEDINGS OF THE 16TH BIENNIAL SYMPOSIUM

April 27-May 1, 2008
Homestead Resort, Midway, Utah

Sponsored by:

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Northern Wild Sheep and Goat Council

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Program Chair: Kent Hersey
Editors: Thomas S. Smith & Julie Miller

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The Northern Wild Sheep and Goat Council (www.nwsgc.org) is a non-profit professional organization developed in 1978 from the Northern Wild Sheep Council. Proceedings may also be downloaded from the NWSGC website.

Northern Wild Sheep and Goat Council Symposia

Date	Symposium	Location	Symposium Coordinator/Chair	Proceedings Editor(s)	NWSGC Executive Director
May 26-28, 1970	NWSC 1	Williams Lake, BC	Harold Mitchell		
April 14-15, 1971	NAWSC 1	Fort Collins, CO	Eugene Decker/Wayne Sandfort	Eugene Decker	
April 11-13, 1972	NWSC 2	Hinton, AB	E.G. Scheffler		
April 23-25, 1974	NWSC 3	Great Falls, MT	Kerry Constan/James Mitchell		
Feb. 10-12, 1976	NWSC 4	Jackson, WY	E. Tom Thorne		
April 2-4, 1978	NWSGC 1	Penticton, BC	Daryll Hebert/M. Nation	Daryll Hebert/M. Nation	
April 23-25, 1980	NWSGC 2	Salmon, ID	Bill Hickey		
March 17-19, 1982	NWSGC 3	Fort Collins, CO	Gene Schoonveld	James Bailey/Gene Schooneveld	
Apr. 30-May 3, 1984	NWSGC 4	Whitehorse, YK	Manfred Hoefs	Manfred Hoefs	Wayne Heimer
April 14-17, 1986	NWSGC 5	Missoula, MT	Jerry Brown	Gayle Joslin	Wayne Heimer
April 11-15, 1988	NWSGC 6	Banff, AB	Bill Wishart	Bill Samuel	Wayne Heimer
May 14-18, 1990	NWSGC 7	Clarkston, WA	Lloyd Oldenburg	James Bailey	Wayne Heimer
Apr. 27-May 1, 1992	NWSGC 8	Cody, WY	Kevin Hurley	John Emmerich/Bill Hepworth	Wayne Heimer
May 2-6, 1994	NWSGC 9	Cranbrook, BC	Anna Fontana	Margo Pybus/Bill Wishart	Kevin Hurley
Apr. 30-May 3, 1996	NWSGC 10	Silverthorne, CO	Dale Reed	Kevin Hurley/Dale Reed/Nancy Wild (compilers)	Kevin Hurley
April 16-20, 1998	NWSGC 11	Whitefish, MT	John McCarthy	John McCarthy/Richard Harris/Fay Moore (compilers)	Kevin Hurley
May 31-June 4, 2000	NWSGC 12	Whitehorse, YK	Jean Carey	Jean Carey	Kevin Hurley
April 23-27, 2002	NWSGC 13	Rapid City, SD	Ted Benzon	Gary Brundige	Kevin Hurley
May 15-22, 2004	NWSGC 14	Coastal Alaska	Wayne Heimer	Wayne Heimer/Dale Toweill/Kevin Hurley	Kevin Hurley
April 2-6, 2006	NWSGC 15	Kananaskis, AB	Jon Jorgenson	Margo Pybus/Bill Wishart	Kevin Hurley
April 27-May 1, 2008	NWSGC 16	Midway, UT	Anis Aoude	Tom Smith/Julie Miller	Kevin Hurley

GUIDELINES OF THE NORTHERN WILD SHEEP AND GOAT COUNCIL

The purpose of the Northern Wild Sheep and Goat Council is to foster wise management and conservation of northern wild sheep and goat populations and their habitats.

This purpose will be achieved by:

1) Providing for timely exchange of research and management information;
2) Promoting high standards in research and management; and
3) Providing professional advice on issues involving wild sheep and goat conservation and management.

I The membership shall include professional research and management biologists and others active in the conservation of wild sheep and goats. Membership in the Council will be achieved either by registering at, or purchasing proceedings of, the biennial conference. Only members may vote at the biennial meeting.

II The affairs of the Council will be conducted by an Executive Committee consisting of: three elected members from Canada; three elected members from the United States; one ad hoc member from the state, province, or territory hosting the biennial meeting; and the past chairperson of the Executive Committee. The Executive Committee elects it's chairperson.

III Members of the Council will be nominated and elected to the executive committee at the biennial meeting. Executive Committee members, excluding the ad hoc member, will serve for four years, with alternating election of two persons and one person of each country, respectively. The ad hoc member will only serve for two years.

The biennial meeting of members of the Council shall include a symposium and business meeting. The location of the biennial meeting shall rotate among the members' provinces, territories and states. Members in the host state, province or territory will plan, publicize and conduct the symposium and meeting; will handle its financial matters; and will prepare and distribute the proceedings of the symposium.

The symposium may include presentations, panel discussions, poster sessions, and field trips related to research and management of wild sheep, mountain goats, and related species. Should any member's proposal for presenting a paper at the symposium be rejected by members of the host province, territory or state, the rejected member may appeal to the Council's executive committee. Subsequently, the committee will make its recommendations to the members of the host state, territory or province for a final decision.

The symposium proceedings shall be numbered with 1978 being No. 1, 1980 being No. 2, etc. The members in the province, territory or state hosting the biennial meeting shall select the editor(s) of the proceedings. Responsibility for quality of the proceedings shall rest with the editor(s). The editors shall strive for uniformity of manuscript style and printing, both within and among proceedings.

The proceedings shall include edited papers from presentations, panel discussions or posters given at the symposium. Full papers will be emphasized in the proceedings. The editor will set a deadline for submission of manuscripts.

Members of the host province, territory, or state shall distribute copies of the proceedings to members and other purchasers. In addition, funds will be solicited for distributing a copy to each major wildlife library within the Council's states, provinces, and territories.

IV Resolutions on issues involving conservation and management of wild sheep and goats will be received by the chairperson of the Executive Committee before the biennial meeting. The Executive Committee will review all resolutions, and present them with recommendations at the business meeting. Resolutions will be adopted by a plurality vote. The Executive Committee may also adopt resolutions on behalf of the Council between biennial meetings.

V Changes in these guidelines may be accomplished by plurality vote at the biennial meeting

FOREWORD

The majority of papers/abstracts included in these proceedings were presented during the 16th Biennial Symposium of the Northern Wild Sheep and Goat Council, held April 27-May 1, 2008 at the Homestead Resort in Midway, Utah. Additional papers/abstracts were included herein to provide NWSGC members and other readers with pertinent information on the management of wild sheep and mountain goats.

All manuscripts received independent review by appropriate NWSGC members prior to publication. Reviewer comments were provided to each senior author, along with editorial comments to improve clarity and readability. Formatted page proofs were forwarded to respective senior authors prior to incorporation into the final product. Final content, particularly verification of literature citations, is the responsibility of the authors. Critical evaluation of information presented in these proceedings is the responsibility of the readers.

A heart-felt thanks is extended to the sponsors of, and participants in, the 16th Biennial NWSGC Symposium. In addition, Anis Aoude (Symposium Chair) and Kent Hersey (Program Chair) were instrumental in leading the dedicated local organizing committee and delivering a first-class meeting. The proceedings were edited by Dr. Tom Smith and Julie Miller of Brigham Young University.

Kevin Hurley
NWSGC Executive Director
May 5, 2009

Status of Utah's Bighorn Sheep and Mountain Goats in 2008

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Populations

Utah's desert bighorn sheep (*Ovis canadensis nelsoni*) population is relatively stable. Approximately 2700 animals are estimated within Utah's borders. The overall population of the state is made up of 21 separate populations. Most of these populations are on public land and under the management authority of the State of Utah, except for 3 populations that are within National Parks boundaries and 1 population on Navajo tribal land. Seventeen of the 21 populations are stable, 3 are increasing and 1 is decreasing.

Utah's Rocky Mountain bighorn sheep *(0. c. canadensis*) population is increasing. This is a result of multiple transplants into vacant habitat and tremendous growth in 2 of the populations. Approximately 2400 animals are estimated within Utah's borders, including the California subspecies. The overall population of the state is made up of 16 separate populations. Most of these populations are on public land and under the management authority of the State of Utah, except for 1 population that is within Dinosaur National Monument boundaries, 1 population on Ute tribal land and 1 population on Antelope Island State Park. Five of the 16 populations are stable, 7 are increasing and 4 are decreasing.

Utah's Mountain Goat (*Oreamnos americanus*) population is increasing. Approximately 1,500 are estimated within Utah's borders. The overall population of the state is made up of 11 separate populations, 4 of which are increasing and 7 are stable.

Research

Much of the recent research on bighorn sheep has been a product of cooperation between the Utah Division of Wildlife (UDWR) and Brigham Young University (BYU). Multiple studies are wrapping up that include habitat use studies, disease studies, and a ram movement study. We just initiated a new study in cooperation with BYU, the National Park Service (NPS) and the Bureau of Land Management (BLM) to look at desert bighorn sheep movement as it relates to OHV and other recreational uses of public land.

Transplants

Since 1973, we have transplanted 771 desert bighorn sheep from sources within and outside the state of Utah. We have also transplanted 1019 (829 Rocky Mountain, 190 California) Rocky Mountain bighorn sheep since 1966. Recent desert bighorn sheep transplants include a 2006 transplant of 20 sheep to the Kaiparowits Unit from Fallon Nevada. In 2007, we moved a total of 30 sheep to the San Rafael, Dirty Devil unit, 15 from the San Rafael South Unit in Utah and 15 from the Escalante Unit in Utah. In 2008, we moved a total of 30 sheep from the La Sal Potah and North San Juan units to the South San Juan Unit.

For Rocky Mountain bighorn sheep, we recently conducted several transplants to establish new populations and bolster existing ones. To establish a population on the Oquirrh-Stansbury Unit, we moved 56 sheep from Antelope Island State Park in 2006 and supplemented it with an additional 36 sheep in 2008 also from Antelope Island. In 2007 we transplanted 55 sheep from Sula, Montana and 18 sheep from Forbes Colorado to the supplement the herds on the Wasatch and Central Mountains units. An additional 42 sheep from Bonner, Montana were taken to supplement the Goslin Mountain herd on the North Slope Unit. In 2009 we received 60 sheep from Augusta Montana to found a new population in the Lake Canyon area of the Wasatch Unit. Also in 2009, we moved 40 sheep from near Green River Utah 25 north to improve distribution and encourage expansion.

We transplanted 44 mountain goats in 2007 from the Tushar Mountains in our Beaver unit. Twenty four of these goats were released in Idaho's Salmon Region and 20 where released on Loafer Mountain in Central Utah. Both releases were part of an effort to establish new populations.

Colorado Status Report

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Abstract: From 1944-2007, at least 2,592 bighorn sheep have been translocated from Colorado herds and 2,492 bighorns have been released in Colorado. In 2007, approximately half of the Rocky Mountain bighorn herds were considered to be native or native with some supplementation whereas the remaining herds resulted directly from translocations. The estimated 2007 statewide, posthunt Rocky Mountain and desert bighorn sheep population estimates was 7,040 in 78 herds and 325 in 4 herds, respectively.

From 1990-2007, an average of 126 rams (range 110-145) and 31 ewes (range 18-56) have been harvested on an annual basis. 2007 statewide harvest was 117 Rocky Mountain bighorn rams, 14 Rocky Mountain bighorn ewes and 4 desert bighorn rams. Sheep licenses in Colorado are issued as either archery or rifle. To be legal for harvest rams must be at least ½ curl. In 2007, 76 ram archery licenses and 11 ewe archery licenses were issued. One hundred fifty five rifle ram licenses and 47 ewe rifle licenses were also issued. The average annual harvest rate for Rocky Mountain bighorn sheep from 1990-2007 was 2.5% (2% for rams, 0.5% for ewes) of the posthunt population available for hunting. Hunter success rates for Rocky Mountain bighorn sheep have varied since 1990 from as low as 39% to 58%. 2007 overall Rocky Mountain bighorn sheep hunter harvest per license was 46%.

Disease continues to be a major limiting factor of bighorn herds across Colorado, with predation, habitat quality/quantity, and reduced genetic diversity and other issues impacting some individual herds. Few suitable areas are left in Colorado where new bighorn sheep herds could be introduced without the likelihood of interactions with domestic sheep. To maintain Rocky Mountain bighorn sheep numbers in the future, emphasis will need to be placed on managing existing populations rather than attempting to establish new herds. The considerable amount of unused desert bighorn sheep habitat may offer the best opportunity to increase the number of bighorn herds in Colorado.

The 2007 Colorado post-hunt mountain goat population estimate was 1,800 animals. Mountain goats are distributed in 18 herd units, with 16 open to public hunting. Nineteen archery and 200 rifle licenses were issued in 2007. All mountain goat licenses are either-sex, with a legal goat being at least 1 year old. Harvest rates across management units vary widely but average between 8-10%, as a proportion of the post-hunt population. The statewide harvest in 2007 was 102 billies and 72 nannies.

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Status of Mountain Goats and Bighorn Sheep and their Management in Idaho

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Mountain goats are endemic to Idaho. Idaho's Sawtooth Range marks the southernmost distribution of the species at the time of Western exploration and settlement (Wister pp. 227-275 *in* Whitney, ed. **Musk-Ox, Bison, Sheep, and Goat**, MacMillan, 1904). Populations were estimated at 2,785 animals as a result of surveys conducted in 1949-1953 (Brandborg, **Life history and management of the mountain goat in Idaho**, Wildl. Bull. 2, Idaho Dep. Fish and Game, 1955). Since 1981, mountain goat populations have fluctuated at 2,785 $\pm$ 300 animals, and are believed to total about 2,600 presently. Most native herds are stable but are widely dispersed and exist at low density. Mountain goats have been hunted in Idaho since 1903. Harvest accelerated sharply between 1960 and 1980. More than 100 mountain goats were harvested annually between 1960 and 1980, but harvests have averaged only about 50 mountain goats annually since 1980 (less than 2 percent of the population). Hunter success is high, typically greater than 80 percent. At current rates of harvest, mean age among harvested animals has increased from 5.25 years of age at harvest in 1989 to 6.4 years of age at harvest in 2007, and continues to increase. Hunter days to harvest has averaged 3 to 5 days since 2000, and was 4.3 days in 2007. Harvest of billies is encouraged through education of hunters that receive tags each year, although harvest of both sexes is allowed (nannies with kids at heel are protected). Hunter education is somewhat successful. Harvest of nannies has declined from nearly 40 percent of the harvest in 1982 to 28 percent in 2007.

Twenty-three mountain goats were captured in Utah's Beaver Mountains and released in the northern Lemhi Range south of Salmon, Idaho in September 2007. Two deaths—one adult killed by a mountain lion and another animal dead of unknown causes—have been recorded to date. Although most of the animals (ca. 80 percent) remained in the immediate vicinity of the release site, several exhibited exploratory movements following release. In every instance, exploratory behavior (including one adult female who travel south approximately 20 miles and then returning north approximately 38 miles before settling in near the Montana state line) resulted in wandering animals encountering existing mountain goat herds.

Bighorn sheep are also endemic to Idaho, and are believed to have been the most abundant big game animal in the state in the early 19th century. An entire culture of native American Indians, the "sheep-eaters" of the Northern Shoshone, based their entire culture on the availability and utility of bighorn sheep. It is likely that Rocky Mountain bighorns (never extirpated from central Idaho Wilderness areas) and California bighorns (primarily south of the Snake River Plain) existed in Idaho. However, massive die-offs of native bighorn sheep followed closely on introduction of domestic livestock (primarily domestic sheep) as early as the 1870's, so that southern Idaho bighorns were extirpated by 1938. California bighorn sheep were reintroduced into Idaho in 1963-1967 (Toweill and Geist, **Return of Royalty**, Boone & Crockett 1999).

Since 1963, 113 California bighorns have been transplanted into Idaho, 199 moved within the state, and 195 have been sent to other states to found or supplement other herds. The current population is believed to total about 1,500 California bighorns.

Idaho hunters are allowed to harvest both one California bighorn sheep and one Rocky Mountain bighorn in their lifetime; a hunter unsuccessful in one season may begin applying again following a two-year wait period. Permits are in high demand, with about 650 applications for 21 permits in 2007. Harvest rates are high (about 85 percent success in 2007), and hunter-days to harvest are low 3.6 days in 2007 as compared with 8.3 days in 2002). Only ram harvest (currently under an "any ram" harvest rule) is allowed, and herds are hunted lightly. Average age at harvest has increased from 5 years of age in the early 1980s to 7.1 years of age in 2007.

Rocky Mountain bighorns, although decimated by documents die-off events between 1870 and 1920, were never extirpated from Idaho, although herds may have been reduced to as few as perhaps 1,000 animals (Smith, **The bighorn sheep in Idaho**, Wildl. Bull. 1, Idaho Dep. Fish and Game, 1954). Since transplants were initiated in 1969, 290 Rocky Mountain bighorns have been brought into Idaho, 176 moved about within the state, and 87 have been sent to adjoining states. Most historic transplants have been dedicated to restoration of bighorns in the Hells Canyon area, in cooperation with Oregon and Washington. Idaho herds currently number about 2,500 bighorns.

Rocky Mountain bighorns are highly sought by hunters. About 1,700 permits applications were received for 62 permits in 2007, more than 1,000 of those from non-resident hunters. Permit numbers have dropped sharply since 1992, due to several large-scale die-off events in Idaho. Currently, herds are stable to increasing, and permit numbers have been stable since 1997. Hunter success averages 50 percent annually. Average age at harvest has increased from about 6.5 years in 1980 to 7.2 years in 2007, and hunter-days to harvest has fluctuated between 5 and 9 days. No transplants have occurred since 2005, when 62 Rocky Mountain bighorns were transplanted from Montana's Sun River herd into Idaho's Lost River Range.

Idaho has been involved in a three-state bighorn sheep restoration project including long-term monitoring and disease research since 1996 (Cassirer et al, **Restoration of bighorn sheep to Hells Canyon: the Hells Canyon Initiative**, 1997). In addition to the wildlife management agencies of Idaho, Oregon, and Washington, this effort includes federal land management agencies (USDA Forest Service and USDI Bureau of Land Management), the University of Washington, and the Foundation for North American Wild Sheep (FNAWS), working through the parent organization and state chapters. Other organizations including the Nez Perce Tribe and sportsman's groups have also assisted greatly. This research effort is continuing, aided by the Idaho Department of Fish and Game's Wildlife Health Laboratory. Data collection focused on bighorn sheep elsewhere in Idaho is routinely collected by research and management staff.

Current challenges relate primarily to bighorn sheep hypersensitivity to diseases carried by domestic sheep. All-age die-offs have occurred in Hells Canyon and along the Salmon River, setting back bighorn sheep population restoration efforts. As a result, Hells Canyon became the focus for wild sheep disease research, largely conducted through Washington State University (which now has an endowed chair dedicated to research on wild sheep diseases). A recent legal challenge to the Payette National Forest Land Use Plan is currently underway. Products stemming directly from the legal action have included a risk assessment of domestic sheep allotments and management on bighorn sheep populations, a scientific review of bighorn sheep/domestic sheep diseases that resulted in the "Payette Principles" that encourages separation of the two species, a workshop on bighorn sheep/domestic sheep diseases held in Boise, Idaho, in 2008, and the creation of an Interim State Policy that emphasizes separation of the two species as the best and only practical measure available on public lands at present. Indirectly, outcomes have included a series of wild sheep/domestic sheep workshops and panels (Tucson, AZ, Irvine, CA, and Salt Lake City, UT) and creation of a Wild Sheep Working Group under the jurisdiction of the Western Association of Fish and Wildlife Agencies (WAFWA) that developed working guidelines, endorsed by Western wildlife management agency directors, that strong encourage separation of bighorn sheep and domestic sheep on public lands.

A decision on the Payette National Forest land management policy is expected in late 2008 or early 2009.

Status of Rocky Mountain Bighorn Sheep and Mountain Goats in Montana

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Abstract: Rocky Mountain Bighorn Sheep under went major declines in Montana as settlement of the west occurred by European man. Hunting of bighorn sheep was closed in 1915, and populations didn't recover sufficiently to reopen hunting until 1953. A total of 2,258 bighorns were trapped for transplants within Montana, and an additional 406 bighorns were made available to other western states. In 2008, there were 49 populations with an estimated 6,685 bighorn sheep in Montana. As hunting resumed, regulations required that rams have a minimum ¾-curl. Some areas were limited entry, while as many as 6 hunting districts were unlimited. In 1974 unlimited areas accounted for 89% of the bighorn sheep hunters and 47% of the ram harvest. The contribution of the unlimited areas to hunter effort and harvest has gradually declined. Since 1984, 14 major die-offs have occurred resulting in losses of bighorn sheep ranging from 75%-97%. Montana is currently developing a Conservation Strategy to provide management direction for bighorn sheep.

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Historically, mountain goats were indigenous to Montana primarily west of the Continental Divide. Statewide trend data is lacking, but based on aerial survey data there were an estimated 2,719 goats in 2007. From 1941-2008, a total of 443 mountain goats were translocated to 27 different sites, resulting in 20 populations capable of sustaining some level of limited-entry hunting. Hunting regulations were first established for mountain goats in 1905, and the season closed briefly from 1936-1938. In 1953, quotas were established in some areas to manage the number of hunters and harvest. From 1954-1971, there were as many as 6 hunting districts that provided unlimited hunting however, this opportunity was phased out after the 1971 hunting season. From 1980-2007, there were an average of 297 hunters harvesting an average of 215 mountain goats annually. In 2007, there were a total of 53 mountain goat hunting districts or populations, with 41 open for hunting in 2008, and a total of 280 either-sex licenses issued. For the period of 1994-2008, ten hunting districts have closed due to significant declines in numbers. Seven of these districts had introduced populations. The cause of these declines is not entirely known. Recent transplants or augmentations have occurred in two areas.

Status of Bighorn Sheep

Although Rocky Mountain Bighorn Sheep (*Ovis canadensis canadensis*) were numerous in Montana, and used for food and other implements by Native Americans and the early explorers, the settlement of the west led to significant declines of bighorn sheep and other big game species (Mussehl and Howell 1971). The causes of the decline most often cited were contact with domestic sheep, range competition from livestock, contraction of diseases, and subsistence hunting (Buechner 1960). Often, poor range conditions, severe weather events, and high numbers of wild sheep were cited as concurrent factors present during reported outbreaks of scabies, anthrax, lungworm, and pneumonia-related diseases.

Hunting of bighorn sheep in Montana was closed in 1915 and remained closed until 1953. By 1930, bighorn sheep were reduced to small, remnant bands and were considered by some to be an endangered or rare species (Couey and Schallenberger 1971).

At the turn of the century, Montana sportsmen, landowners and agency personnel worked together to begin to restore Montana's wildlife populations. The first transplant of bighorn sheep into Montana occurred in 1922 on the Moiese Bison Range with 12 bighorn from Banff, Alberta. Passage of the Pittman-Robertson Act (PR) in 1937 by the United States Congress initiated the Federal Aid in Wildlife Restoration Program, which provided federal funds to states from excise taxes on firearms, archery equipment and ammunition for wildlife restoration projects. This funding allowed the Montana Fish and Game Department to begin a bighorn sheep research and management program in 1941, with the objective of increasing populations (Couey and Schallenberger 1971).

Couey (1950) estimated that about 1200 bighorn sheep occupied 16 different areas within the state in 1950. The availability of PR funding provided the impetus for transplants of all game species including bighorn. From 1941 to 1950, new populations of bighorn were established through transplants to Wildhorse Island in Flathead Lake, the Gates of the Mountains, West Fork of the Gallatin River, and Billy Creek in the Missouri Breaks. From 1939 to 2008, 2,258 bighorns have been trapped within Montana for transplants within the state (Picton and Lonner 2008). An additional 406 bighorns were trapped in Montana and were made available for transplants to other states, including, Oregon, Idaho, Washington, Nebraska, Utah, Wyoming, Colorado and North Dakota. Most bighorn sheep, about 2,456, were transplanted after 1960. The majority of transplant source animals have either come directly from Sun River populations or from transplants established from Sun River stock.

Today, there are 49 different populations in the state with an estimated 6,685 total bighorn sheep (Figure 1). The occupied habitat is diverse, from the badlands and breaks habitat of eastern Montana to the high alpine mountains of south-central Montana, and from the lower elevation mountains of southwestern Montana to the higher elevations of northwestern Montana and Glacier Park (Figure 2).

When hunting of bighorn sheep reopened in 1953, a total of 30 permits were issued in three areas for ¾-curl rams. In 1956, two areas, the Spanish Peaks and the Absaroka-Stillwater, were combined and established as unlimited hunting districts. This area has remained in an unlimited status for the most part although, some districts have closed due to declines and the area has also been portioned into smaller districts over time. Initial hunting regulations consisted of a ¾-curl regulation and a long season length (McCarthy 1986). To control harvest, a quota was implemented in the unlimited districts in 1975. Beginning in 1967, some districts went to an either-sex regulation and the hunting of ewes in certain populations was implemented in 1974 as a method of managing populations. In 1977, a simplified legal ram definition was implemented primarily in the unlimited districts to make it easier for the hunter to determine what a legal ram is in the field.

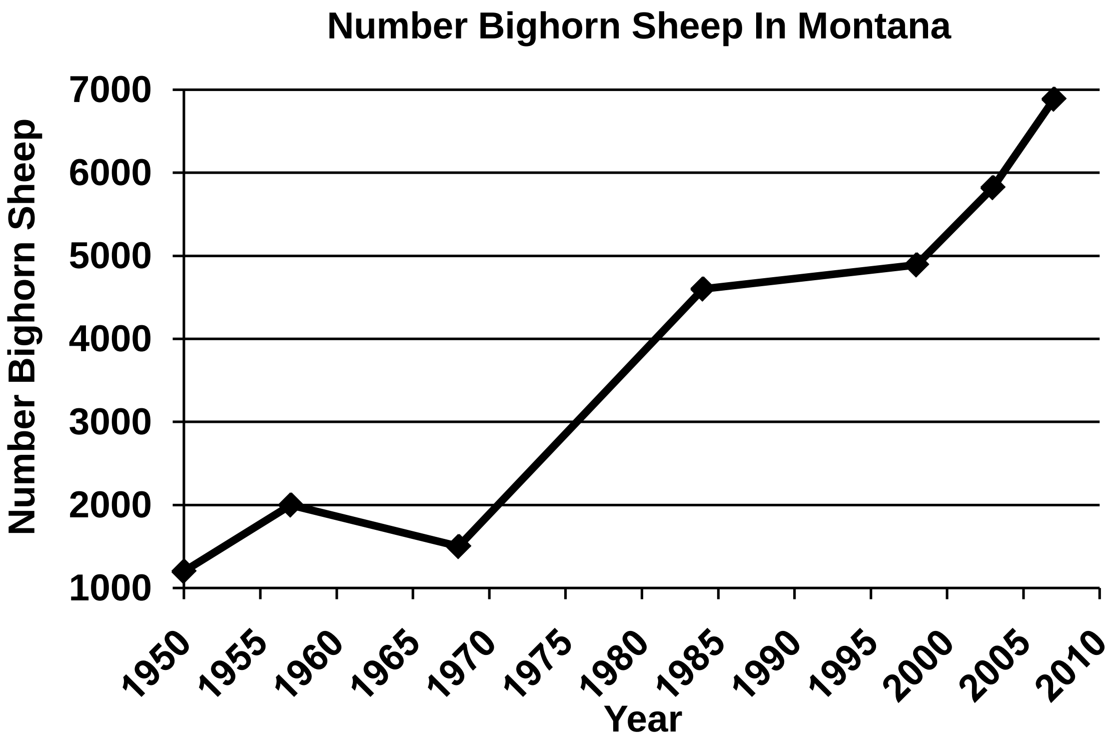

Figure 1. Trend in the number of bighorn sheep in Montana, 1950-2008.

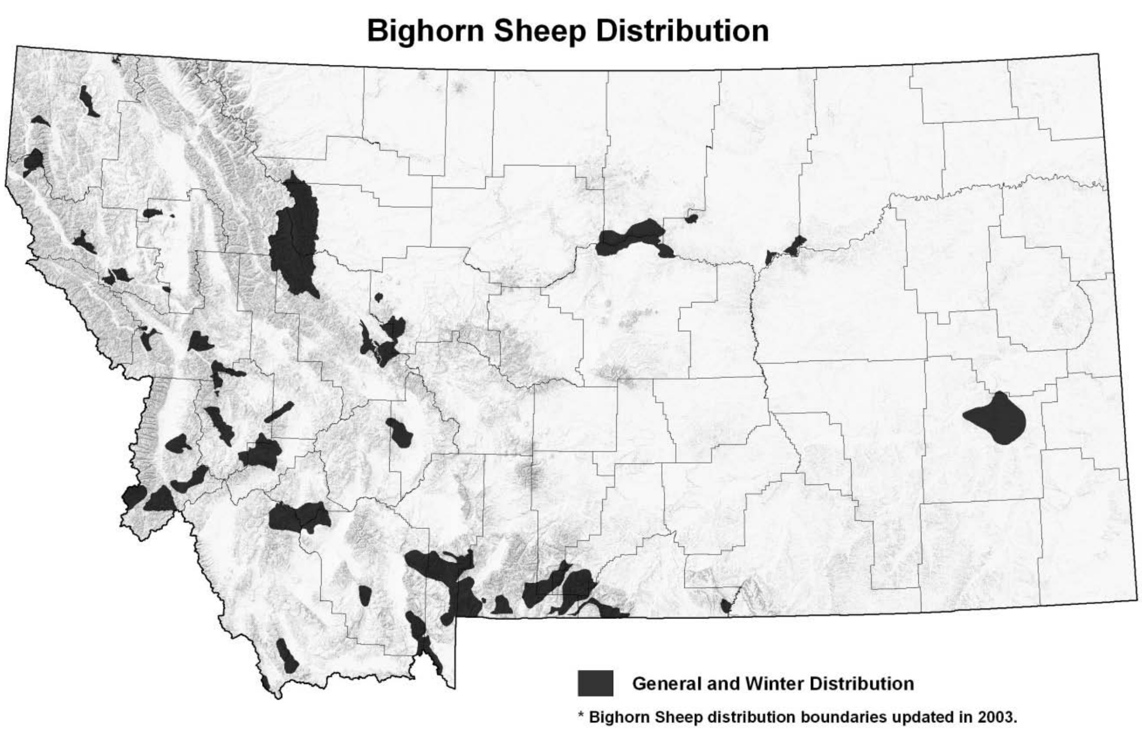

Figure 2. Distribution of bighorn sheep in Montana, 2008.

The unlimited districts, which allow anyone to purchase a license and go hunting, have over time provided significant hunting opportunity and harvest. In 1974, when hunter numbers and harvest peaked, the six unlimited districts accounted for 89% of the hunters and 47% of the ram harvest. Following that hunting season, population declines in some unlimited districts resulted in their closure and a subsequent decline in hunting opportunity and harvest (Figure 3). In 2005, the remaining four unlimited districts accounted for 43% of the state's bighorn sheep hunters but just 6% of the ram harvest.

Ewe seasons have been used since 1974 to manage bighorn populations and to provide additional bighorn sheep hunting opportunity. The number of licenses issued has varied over time depending on the objectives for certain populations and the status of those populations (Figure 4). In 2006, there were a total of 15 hunting districts providing some level of ewe harvest, and there were a total of 169 ewe licenses issued through special drawing. In some years some of the more productive bighorn populations, such as in the Sun River and Missouri River Breaks areas, require a combination of translocation of bighorn sheep in conjunction with ewe harvest to manage population numbers. Success on ewe licenses varies depending on the area, increasing with ease of access, and ranges from 75% to 90%.

In 2008, there were a total of 35 hunting districts open for the hunting of bighorn sheep. Thirty hunting districts were limited entry, and there were a total of 168 either-sex, 245 adult ewe, one legal ram and five any ram licenses issued. In the five unlimited hunting districts, there was a total quota of 11 legal rams. In the unlimited districts, licenses were purchased at license providers or through the regular drawing. Non-Residents were eligible for up to 10% of the licenses. License costs in 2008 for resident and non-resident hunters was $130 and $755, respectively, and ram and ewe license costs were the same.

Major population declines due to epizootic events are still a periodic challenge to maintaining bighorn sheep populations. Since 1984, there have been significant die-offs in 14 bighorn populations (Table 1). Most native populations tend to experience periodic gradual declines or less severe drops in population due to weather events. Although many transplanted herds seem to prosper for a decade or two, they tend to be more vulnerable to the catastrophic all age die-offs often associated with *Pasturella* outbreaks. Although several of these transplanted herds tended to recover, following augmentation, some do not. Those that did tended to be fewer in number and had reduced lamb survival for many years.

Although most of the herds experiencing die-offs recovered, some due to augmentation, the specter of another die-off still exists. Many different attempts were made over the years to prevent die-offs from occurring however; none were proven effective enough to be applied broadly. Thus, prevention included minimizing the effects of the die-offs by maintaining lower populations (herd segments generally less than 200), issuing adult ewe licenses, transplanting to control herd size, maintaining separation from domestic sheep and goats to minimize disease transmission, and inoculation of transplant stock to reduce the likelihood of disease or parasite transfer to new areas.

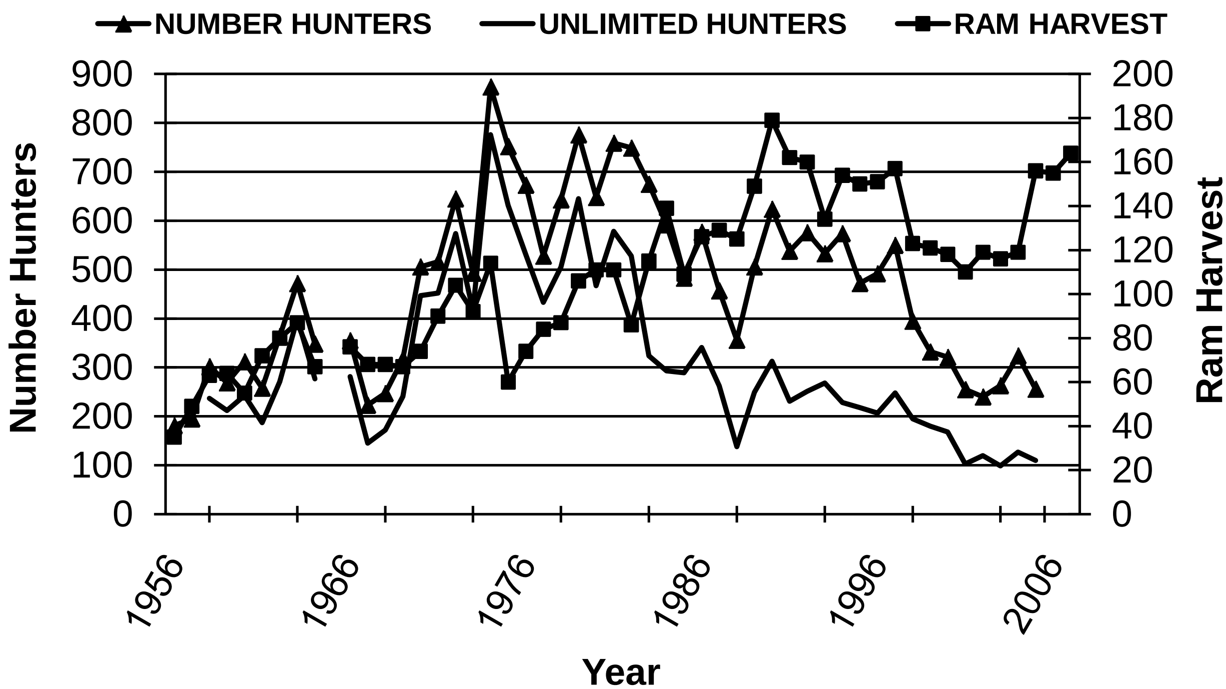

Figure 3. Total number of hunters, number of hunters in unlimited districts, and ram harvest in Montana, 1956-2007.

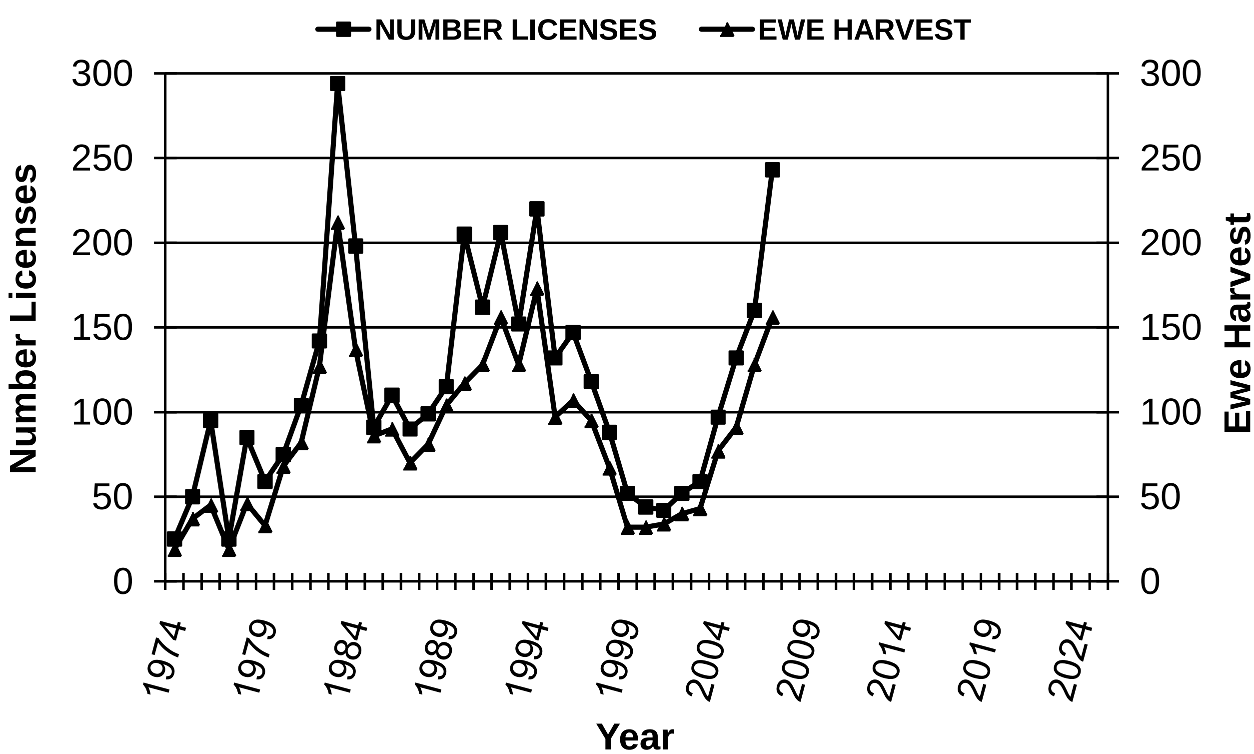

Figure 4. Number of ewe licenses and ewe harvest in Montana, 1974-2007.

Table 1. History of recent die-offs in Montana bighorn sheep populations, 1984-2008.

Population	Hunting District	Pre die-off number	Post die-off number	Native or Transplanted	Year(s) Transplanted	Year(s) of Die-off
Sun River	441, 421,423, 424	900	500	Native		1984
Ural Tweed	101	200	<100	Native	Augmented 1963	1999
Mickey Brandon Buttes	622	150	50	Transplanted	Transplanted 1980	1997,01
Kootenai Falls	100	100	30	Transplanted	1954, 55	1995
Spanish Peaks	301	200	<100	Native	Augmented 1944,47	1999
Pryor Mtns	503	250	145	Transplanted	1971,74	1995
Highlands	340	400	12	Transplanted	1967-69	1994
Tendoys	315	150	20	Transplanted	1984-86,96	1994
Lost Creek	213	400	100	Transplanted	1967	1991
Beartooth WMA	455	300	50	Transplanted	1971,73,75	1984
Taylor/Hilgards	302	>100	20-30	Native	Augmented 1988,89,93	1997
Lower Boulder River	504	100	2	Transplanted	1987, 89	1999, 2000
Sleeping Giant	381	115	39	Transplanted	1992, 93	2001,06
Elkhorn Mtns	380	230	20	Transplanted	1996,97,00	2008

Montana does not have a statewide management plan for bighorn sheep. Montana Fish, Wildlife and Parks is currently in the process of developing a comprehensive “Conservation Strategy” for bighorn sheep. The primary objectives of that strategy include:

1. Document the history of Rocky Mountain Bighorn Sheep in Montana from decline to recovery.
2. Include a history of all existing herds in the state with a discussion of past and current management and the challenges facing each of these populations.
3. Develop protocols for how we survey bighorn sheep, monitor the health of our herds, track the status and condition of important habitats, and update our guidelines for trapping and transplanting bighorns.
4. Identify areas that might be suitable for transplanting that currently don’t have bighorn sheep.
5. Make the Conservation Strategy available to the public and use as a tool for informing them about Montana’s management of bighorn sheep.

Status of Rocky Mountain Goats

Rocky Mountain goats are indigenous to Montana, and historically occurred mostly west of the Continental

Divide (Figure 5). While periodic surveys are conducted on most mountain goat populations in Montana, long-term statewide data hasn't been compiled on a consistent basis. In 1947, it was estimated there were a total of 4,451 goats in Montana (Vogel et al. 1995). Based on most recent survey information, there were approximately 2,719 goats in Montana in 2007. The source of the 1947 number could not be determined, so direct comparison of number estimates is questionable.

Mountain goat populations were evidently more stable than bighorn sheep populations as European man moved into the west, presumably because their habitat is more isolated, high elevation, and unsuitable for human settlement. However, Montana did begin transplanting mountain goats into unoccupied habitat in 1941. From 1941-2008, a total of 443 mountain goats were translocated to 27 different sites, resulting in 20 populations capable of sustaining some level of limited-entry hunting. A total of 56 mountain goats were provided for transplant to other states, including, Colorado, Wyoming and Washington.

Hunting regulations were established for mountain goats in 1905, when the hunter was restricted to one goat per hunting season (Foss and Rognrud 1971). The one-goat regulation was in effect for several years and was followed by a closure of the entire state to the hunting of goats. From 1929 through 1935, a season was authorized for goats on the west side of the Bitteroot River in Ravalli County. A closure was in effect for the entire state from 1936 through 1938. In 1939 and 1940, seasons were again opened in parts of the Flathead, Lewis and Clark, Missoula, Powell and Ravalli Counties. During the preceding interval, the season length was approximately one month with a variety of opening dates (mid-September to early November). During the next decade, areas that were open for hunting varied, but generally, the northwest part of the state, currently Region 1 had the majority of the areas open. A special goat license was created in 1953 in an attempt to limit both the number of hunters and harvest in certain areas. In 1954, there were 14 hunting districts open for hunting with several districts in Region 1 open for unlimited hunting (no quota). The unlimited areas occurred mostly in the northwest part of the state with as many as six hunting districts providing unlimited hunting opportunity. These areas included the Swan Range, Lower South and Middle Fork of the Flathead River, Upper South and Middle Fork of the Flathead River, Cabinet Mountains and the Mission Mountains. In the mid 1960's, two areas in Region 2, the West and East Fork of the Bitteroot River, also provided unlimited hunting opportunity. Seasons generally extended from mid-September through late November.

Similar to the earlier discussion of unlimited areas for bighorn sheep, unlimited hunting areas for mountain goats provided a tremendous amount of hunter recreation and mountain goat harvest (Figure 6) (Table 2). In 1963, when the number of mountain goat hunters and harvest peaked, the number of hunters in unlimited areas represented 68% of the total and accounted for 58% of the total harvest. Unfortunately, this level of harvest could not be sustained, and the unlimited areas were phased out after 1971 when only one district in Region 1 still provided unlimited hunting.

Figure 5. Distribution of Rocky Mountain Goats in Montana, 2008.

From approximately 1980-2007, the number of hunters has been relatively stable with an average of 297 hunters harvesting an average of 215 mountain goats annually (Figure 6). In 2007, there were a total of 53 mountain goat hunting districts or populations, with 41 of those open for hunting in 2008 and a total of 280 either-sex licenses issued.

Population declines have plagued many mountain goat populations in recent years. For the period 1994-2008, 10 Hunting Districts have closed due to significant declines. Seven of these districts included introduced populations. The cause of these declines is not entirely known. In some cases, circumstantial evidence implicates predation, primarily by mountain lions as playing a role. Hunting is not thought to be a factor, as many of the introduced populations, while relatively small in numbers, were being hunted very conservatively. Interestingly, other introduced populations, specifically in the Crazy Mountains and the Absaroka Mountains, have some of the more robust populations and are providing significant hunter opportunity and harvest. During this same period of decline, five new populations were established (Figure 7).

Recent transplants or augmentations have occurred in two areas. Ten mountain goats from the Crazy Mountains were released during the winter of 2002 on Red Mountain in the Scapegoat Wilderness Area north of Helena, Montana. In 2008, 10 mountain goats from Round Butte near Great Falls, Montana were released on the Ear Mountain Wildlife Management Area on the Rocky Mountain Front west of Great Falls and augmented an existing population.

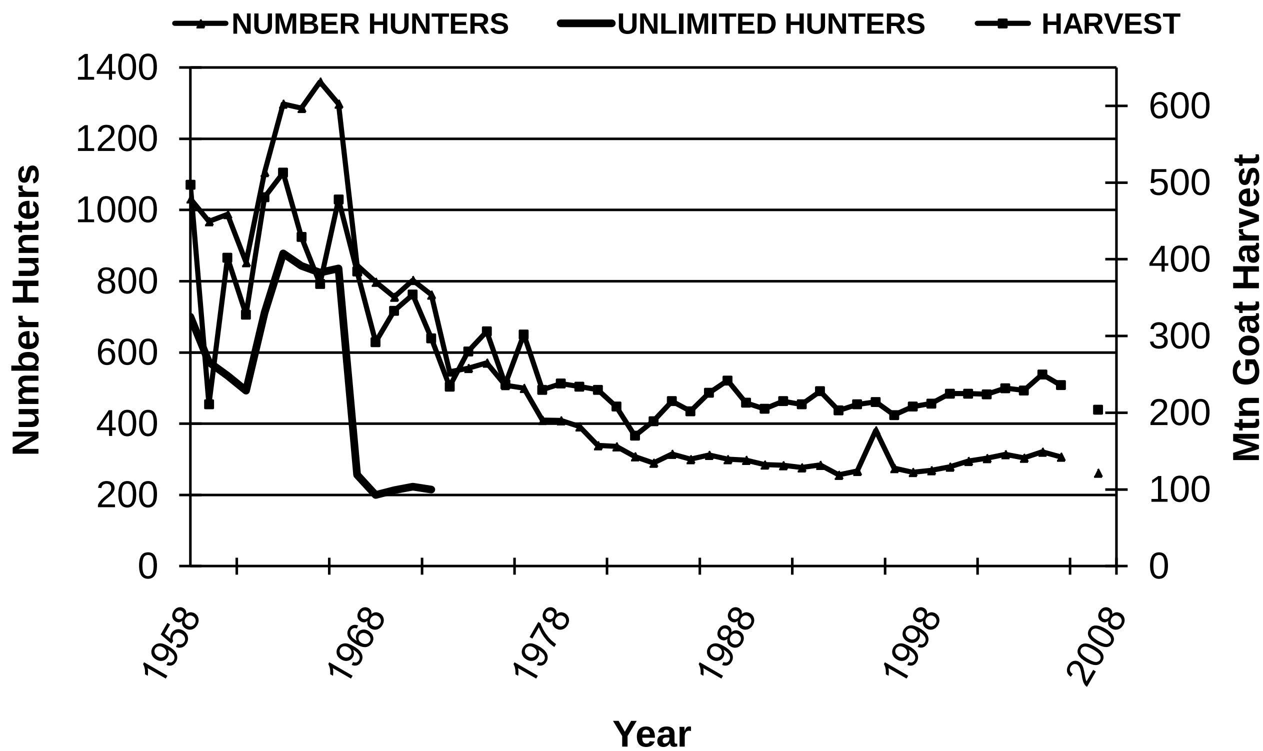

Figure 6. Total number of mountain goat hunters, number of hunters in unlimited areas and total harvest in Montana, 1958-2007.

Table 2. The number of mountain goat hunters and harvest in Montana, 1958-2007.

Year	Total Hunters	Hunters-Unlimited Areas	Total Harvest	Harvest-Unlimited Areas
1958	1032	700	497	296
1959	968	573	211	62
1960	988	535	402	205
1961	853	493	328	136
1962	1106	712	481	236
1963	1298	878	513	296
1964	1286	843	429	184
1965	1360	824	368	112
1966	1298	836	478	250
1967	845	256	384	90
1968	798	200	292	
1969	756	213	333	66
1970	803	223	354	51
1971	762	215	297	59
1972	546		234	
1973	556		280	
1974	571		306	
1975	508		237	
1976	500		302	
1977	410		230	
1978	409		238	
1979	392		234	
1980	339		230	
1981	336		208	
1982	308		170	
1983	290		189	
1984	315		215	
1985	300		202	
1986	312		226	
1987	300		242	
1988	298		213	
1989	285		205	
1990	283		215	
1991	277		211	
1992	284		228	
1993	256		203	
1994	267		211	
1995	381		214	
1996	275		197	
1997	264		208	
1998	269		212	
1999	279		225	
2000	295		225	
2001	303		224	
2002	314		232	
2003	304		229	
2004	321		250	
2005	307		236	
2006				
2007	262		204	

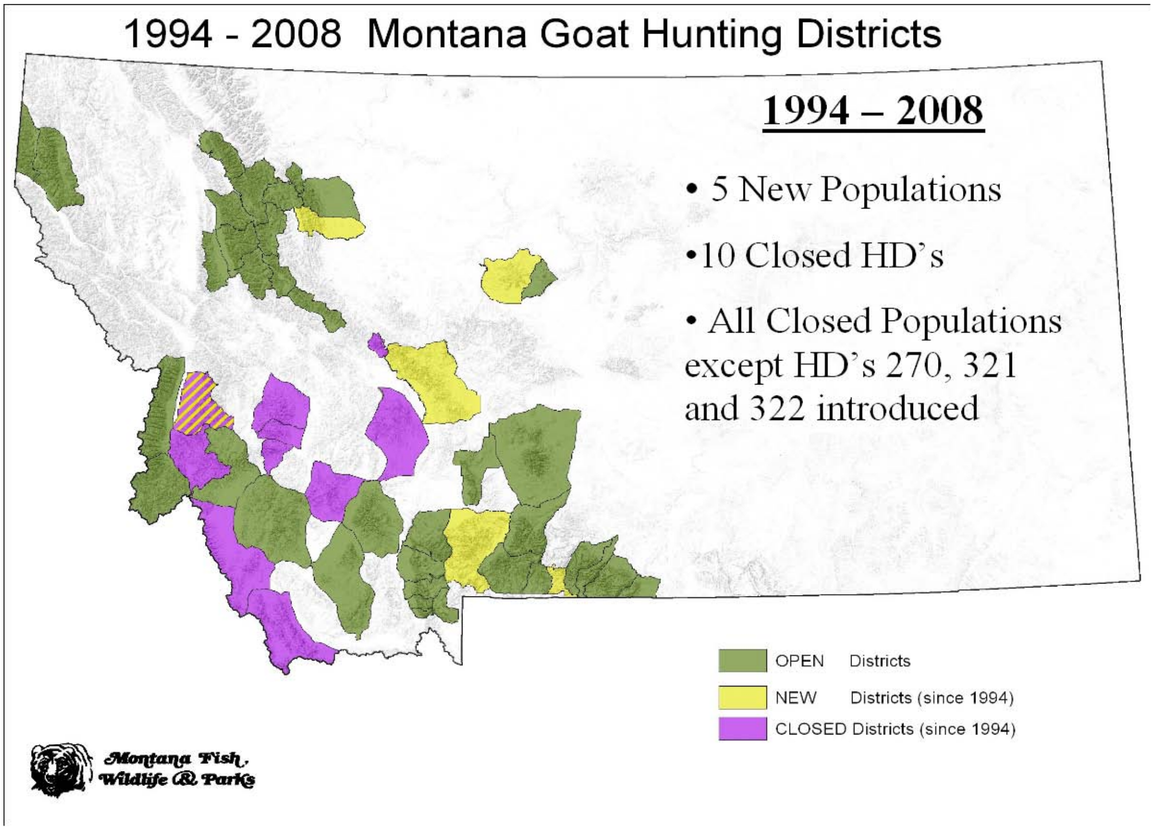

Figure 3. Status of mountain goat hunting districts in Montana, 1994-2008.

Conclusion

The development of the Conservation Strategy for bighorn sheep will provide needed management direction. Protocols and policies on how Montana Fish, Wildlife and Parks will deal with certain issues will be defined. Challenges remain regarding herd health, specifically maintaining separation between domestic sheep/goats and wild sheep to prevent disease transmission. Identifying potential new transplant sites has become difficult due, in part, to the proximity of domestic animals.

The decline in mountain goat populations is alarming and deserves investigation by Montana Fish, Wildlife and Parks. When mountain goat populations decline, it appears they don't recover. A management plan, similar to what's being developed for bighorn sheep, needs to be developed for mountain goats.

Acknowledgements

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Status of Bighorn Sheep in North Dakota

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Abstract: Bighorn sheep (*Ovis canadensis*) were extirpated from North Dakota by 1905 and reintroduced in 1956. A total of 45 transplant projects, involving 357 animals, have occurred. In 2008, a minimum of 335 bighorn sheep, distributed among 15 sub-populations, inhabited the Little Missouri National Grassland of southwestern North Dakota. A catastrophic die-off occurred in 1997 within the southern metapopulation due to contact with domestic goats. Consequently, in 1999, a management partnership commenced with the Minnesota-Wisconsin Chapter of the Foundation for North American Wild Sheep in an effort to expedite the population's recovery. The first modern day hunting season occurred in 1975. A total of 203 licenses have been issued with 198 rams harvested through 2008. The ¾-curl restriction was abandoned in favor of an Any-Ram designation in 1990. One license is auctioned annually with the remainder issued via a lottery system, no more than one of which may be issued to a non-resident. Supplemental data has been gathered from radio-marked bighorn since 2000, including cause-specific mortality, home range size, and population demographics. Implications of introducing Rocky Mountain bighorn sheep (*Ovis canadensis canadensis*) to North Dakota are discussed.

BIENN. SYMP. NORTH. WILD SHEEP AND GOAT COUNC. 16: 19-27

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The first recorded observation of bighorn sheep (*Ovis canadensis)* in North Dakota was made by a member of the Lewis and Clark Expedition in 1805. However, bighorn were extirpated from the state by 1905 when the last known ram was killed in Magpie Creek. Disease from domestic sheep and unregulated hunting were the likely causes of the population's demise (Knue 1991). Although Cowan (1940) originally classified the state's native bighorn population as a distinct subspecies, *Ovis canadensis auduboni,* Wehausen and Ramey (2000) concluded that Audubon's bighorn was merely a population of Rocky Mountain bighorn sheep (*Ovis canadensis canadensis)* inhabiting low elevations east of the Rocky Mountains.

During the 1950s, the Pittman-Robertson Act afforded the North Dakota Game and Fish Department (NDGF) with the opportunity to reintroduce bighorn sheep to North Dakota. In 1956, 18 California-type bighorn were translocated from Williams Lake, British Columbia to a 160 acre enclosure in Magpie Creek, North Dakota. The purpose of the captive herd was to act as a source from which to establish additional populations throughout the badlands (Knue 1991). Eventually there were 3 captive herds utilized as source-stock; however, the captive management program was abandoned during the 1990s in favor of translocating free-ranging sources of bighorn from in-state and out-of-state populations, including British Columbia, Idaho, Oregon and Montana.

Bighorn inhabit rugged escape terrain that is ubiquitous throughout much of the Little Missouri National Grassland, with elevations ranging between 637 to 785 m above sea level. Substrates consist of highly erodible silts and clays and harder materials such as sandstone and scoria (Bluemle 1986). The climate in southwestern North Dakota is semi-arid, continental and windy, with very warm summers and very cold winters (Jensen 1974). Plant communities are comprised primarily of short-grass prairie, sedges, sagebrush, grama, saltbrush, juniper and green ash (Nelson 1961, Wali et al. 1980, Jensen 1988 and Fox 1989). Land ownership throughout North Dakota's bighorn range is 87% public and 13% private (per comm.-Arden Warm, USFS)

Following 6 out-of-state and 29 in-state translocations subsequent to the initial transplant in 1956, the state's population grew to approximately 300 by the mid-1990s. However, following a catastrophic all-age-class die-off in 1997 attributed to contact with domestic goats, the southern metapopulation was decimated to only 20 surviving individuals, with the state-wide population being only 140 (Stillings 1999).

The late-1990s epizootic precipitated a management partnership between NDGF and the Minnesota-Wisconsin Chapter of the Foundation for North American Wild Sheep (MN-WI FNAWS). Under the agreement, MN-WI FNAWS would provide funding for projects that were deemed critical for the recovery of the state's population by NDGF. Consequently, NDGF was able to radio-collar 30 bighorns within the remaining 7 sub-populations and successfully complete 3 out-of-state and 5 in-state transplants to reestablish herds decimated by disease and establish new populations in areas containing suitable habitat (Sweanor et al. 1994).

Wiedmann (2008) reported that by 2008 North Dakota's bighorn population had reached a minimum of 335 animals distributed among 15 sub-populations (Figures 1 - 4), likely the highest population total since the 1800s. Ram:ewe ratios from 1999 to 2008 have averaged 64:100 (Figure 5). Lamb recruitment rates from 1999 to 2008 have averaged 30.3% (12-37%) (Figure 6).

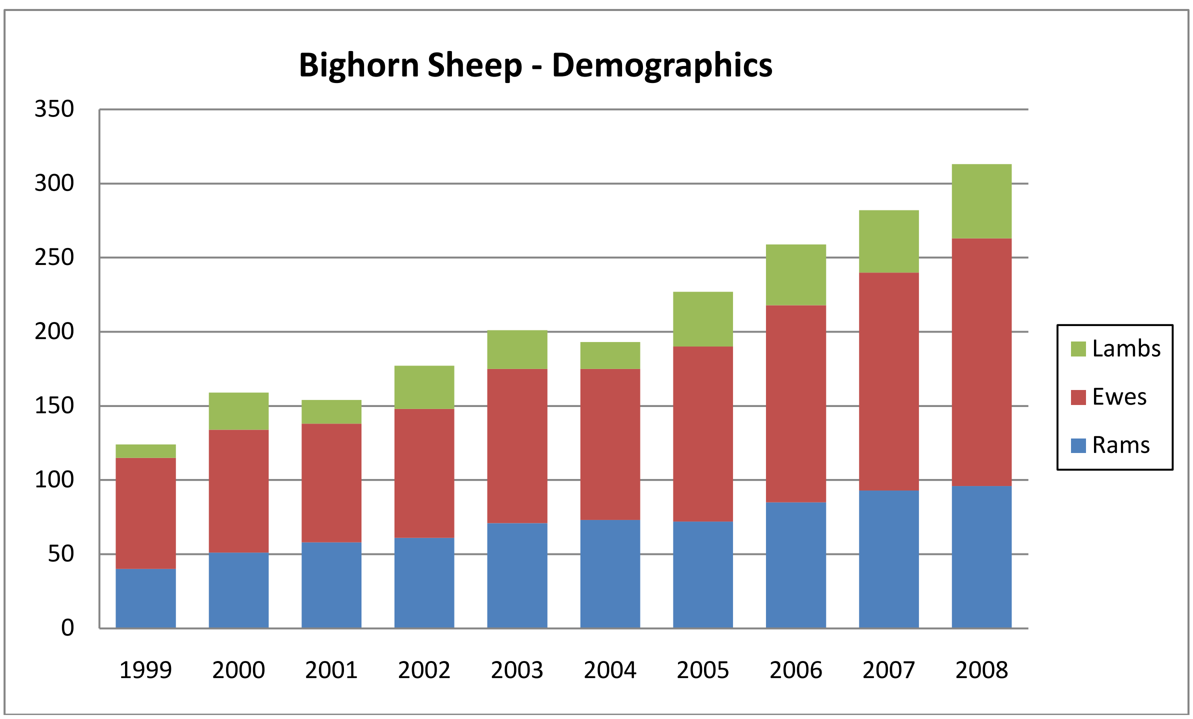

Figure 1. Bighorn sheep population demographics, 1999-2008.

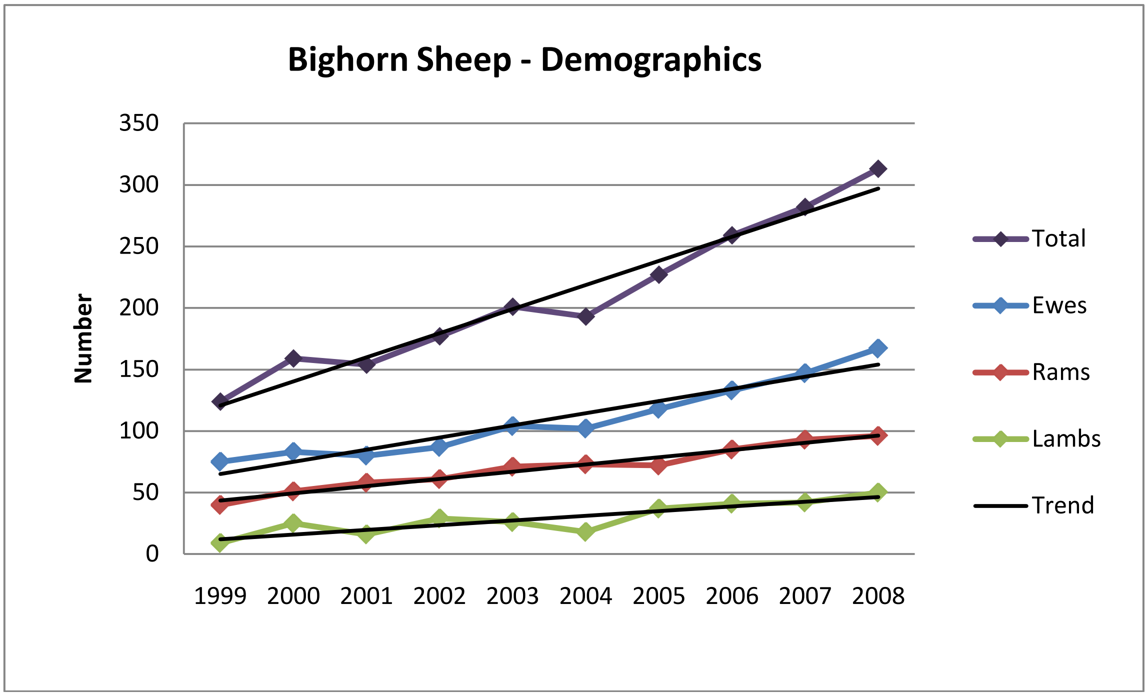

Figure 2. Bighorn sheep population, 1999-2008.

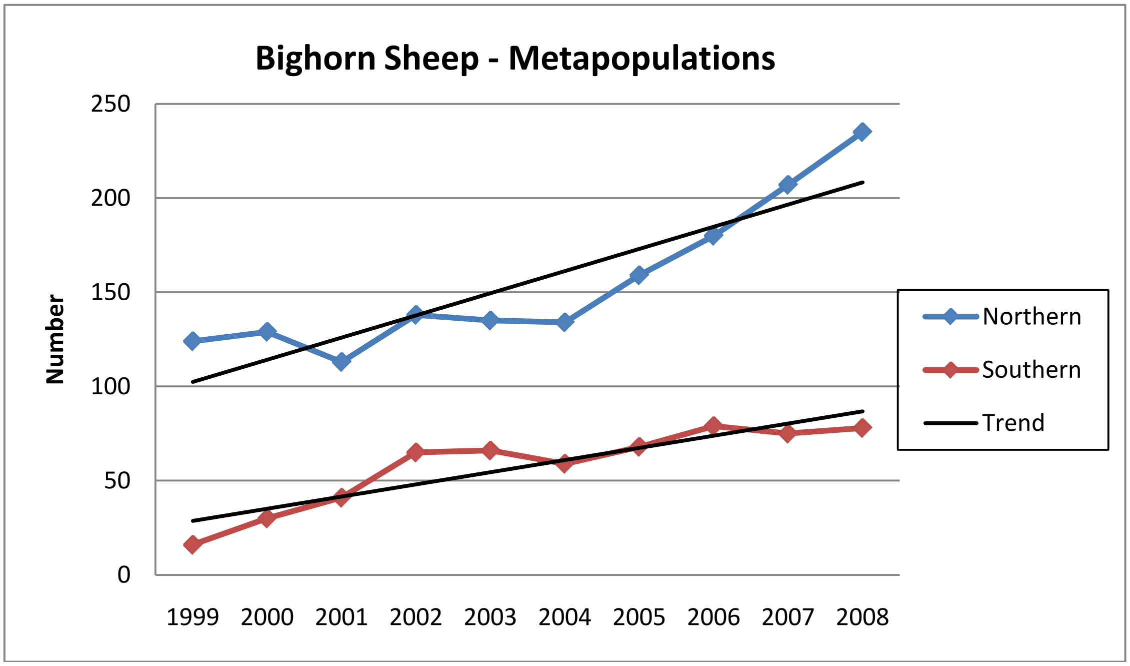

Figure 3. Bighorn sheep metapopulations, 1999-2008.

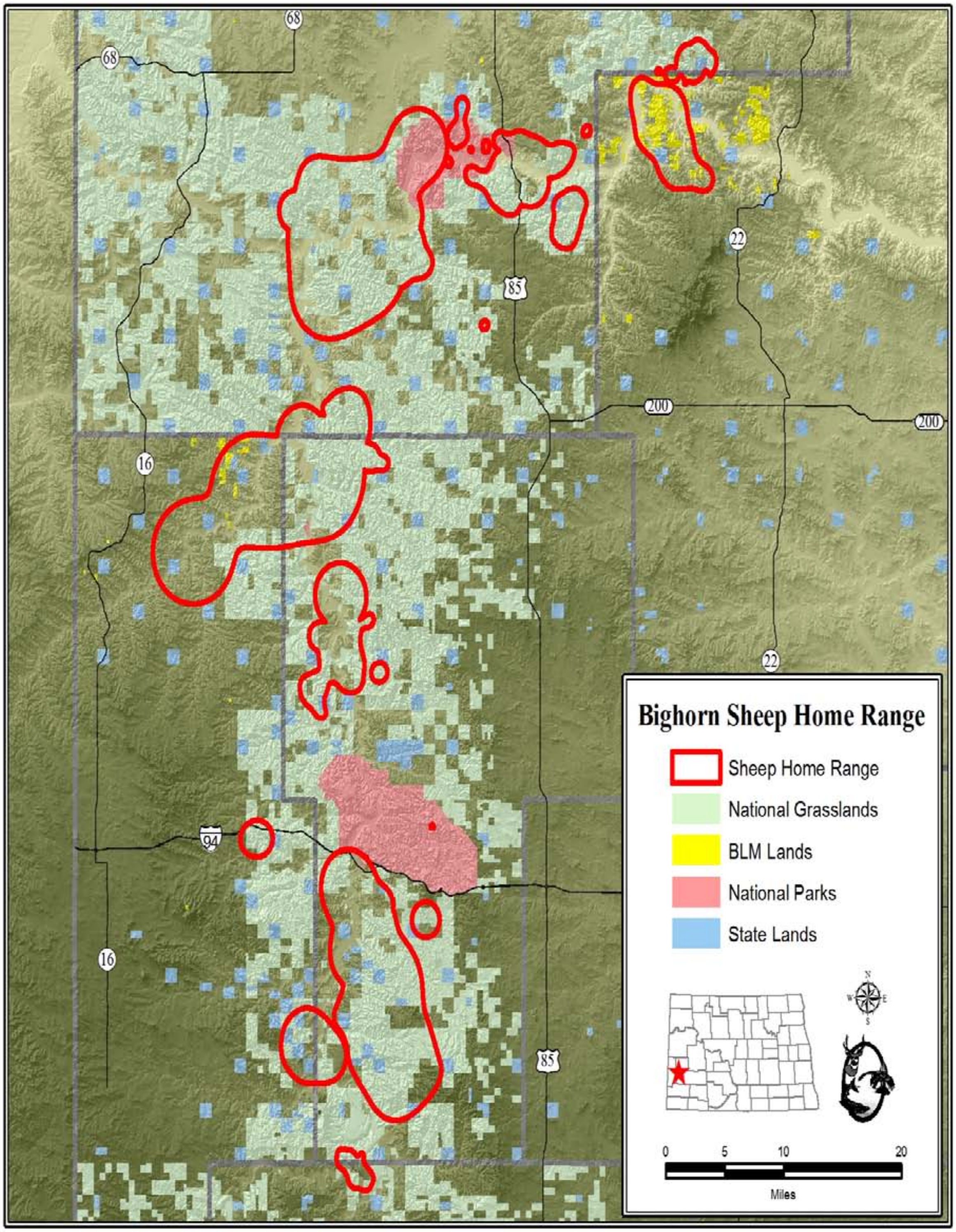
Bighorn Sheep Home Range
Sheep Home Range
National Grasslands
BLM Lands
National Parks
State Lands
0
5
10
20
Miles
68
68
85
22
200
200
16
22
94
16
85

Figure 4. Bighorn sheep distribution.

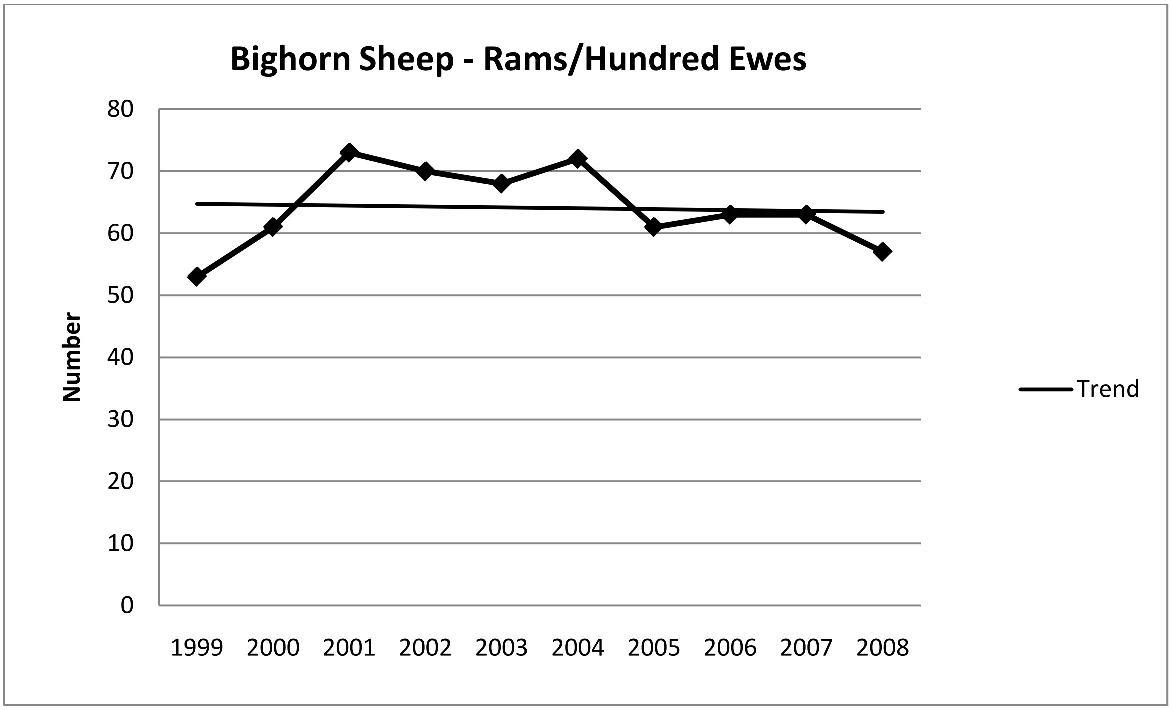

Figure 5. Bighorn sheep ram:ewe ration, 1999-2008.

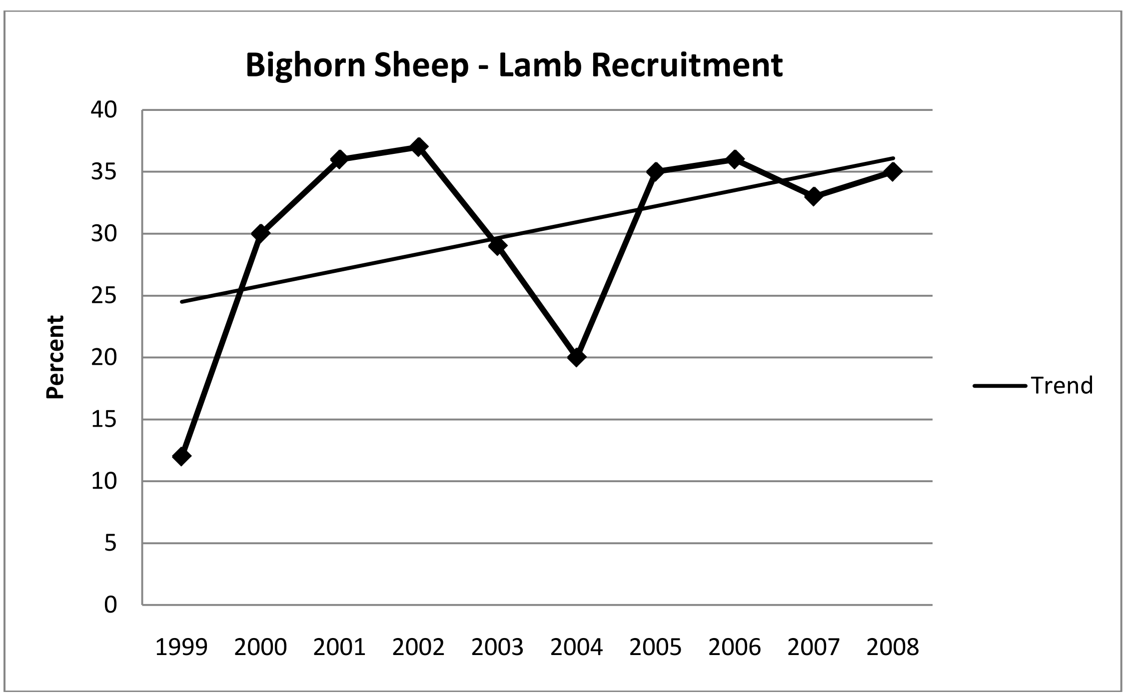

Figure 6. Bighorn sheep lamb recruitment, 1999-2008.

Bighorn were radio-marked in January 2000 primarily to collect population distribution, demographic and survey data. Therefore, VHF radio-collars were preferred in order to mark a greater number of individuals rather than collect significantly more locations from fewer animals using Global Positioning System technology (Girard et al. 2006). Consequently, supplemental analysis was also calculated, including adult survivability, cause-specific mortality and home range size.

Adult survivability (Heisey and Fuller 1985) from 2000 to 2008 averaged 84.1% (71-92%) and 86.1 % (74-97%) for rams and ewes, respectively (Figure 7). Mountain lion predation accounted for 25.6% of total mortality, including 15.4 and 30.8% for rams and ewes, respectively. The primary cause of ram mortality was hunting (53.8%); and, although a majority of ewe cause-specific mortality was undetermined/non-predation (46.5%), lion predation was the most significant cause of known mortalities. Age and winter stress were likely co-factors in a majority of undetermined/non-predation mortalities for rams and ewes. Other known sources of mortality included disease, poaching, vehicle collisions, fence entanglements, falls, coyote predation and rut injuries.

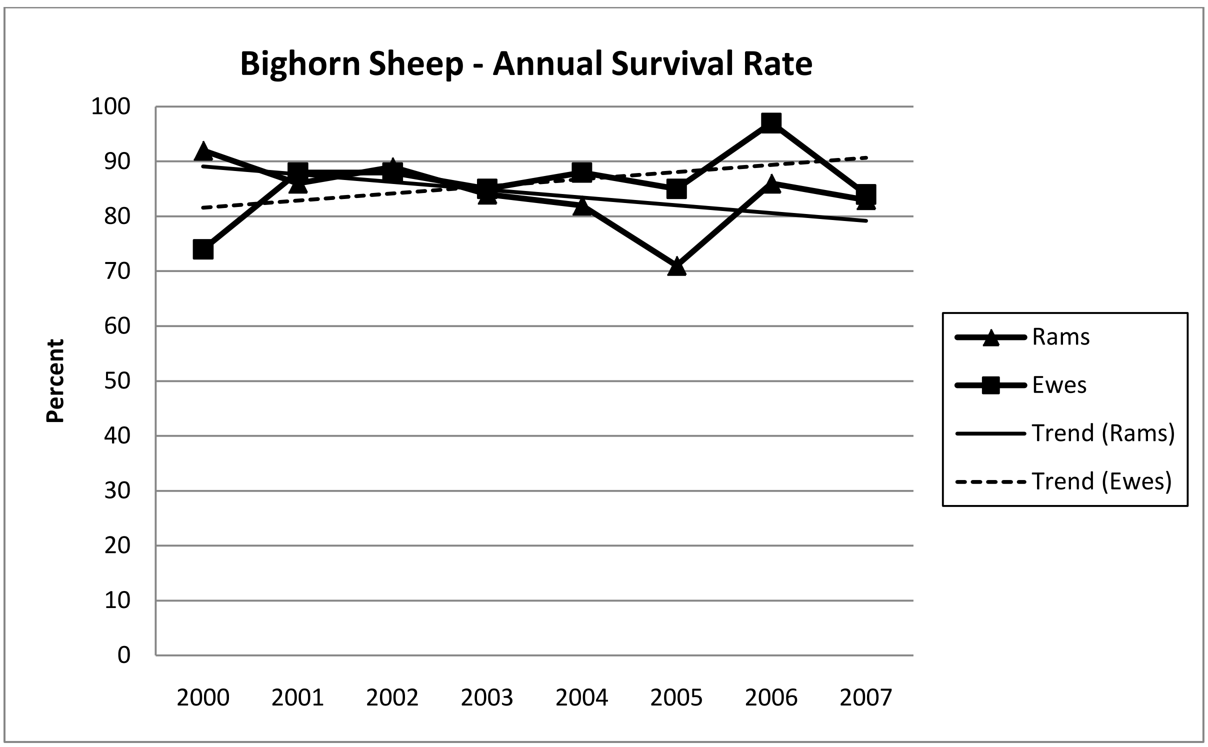

Figure 7. Bighorn sheep annual survival rate, 2000-2007.

NDGF presumed for decades that the state's bighorn herds occupied small home ranges, even less than 2 km^2. However, a preliminary Adaptive Kernel home range analysis (Rogers and Carr 1998) has revealed that home ranges are much larger than previously thought. Average home range size was approximately 81.3 km^2 for all herds. Home ranges within the northern and southern metapopulations averaged 85.2 and 77.4 km^2, respectively. Due to their migratory behavior, ram home ranges are typically twice that of ewes. The Ice Box Canyon (333.6 km^2) and Theodore Roosevelt National Park (14.2 km^2) herds had the largest and smallest home ranges, respectively. Lambing areas were also indentified for each of the 15 sub-populations, allowing NDGF to more effectively coordinate with federal agencies to protect these critical areas from disturbance and improve habitat. A more precise home range analysis of North Dakota's bighorn herds will be completed in 2009.

The first modern day hunting season was held in 1975 when 12 licenses were issued for rams having a minimum ¾-curl. However, the ¾-curl requirement was abandoned in 1990 in favor of an Any-Ram designation. From 1975 to 2008, 203 licenses have been issued with 198 rams being harvested (97.5% success). Licenses are allocated via a lottery system with no preference points being offered. In 2008, a record 10,425 individuals applied for 5 lottery licenses (Figure 8). In 1999, non-residents were allowed to apply for no more than one of the available lottery licenses. One license was authorized to be auctioned to the highest bidder beginning in 1986, resulting in $815,000 being raised for bighorn management through 2009. The average age of harvested rams since 1975 is 6.3 yr old, with no significant difference since the change from the ¾-curl regulation (6.2 yr old). No ewe seasons have been sanctioned in North Dakota.

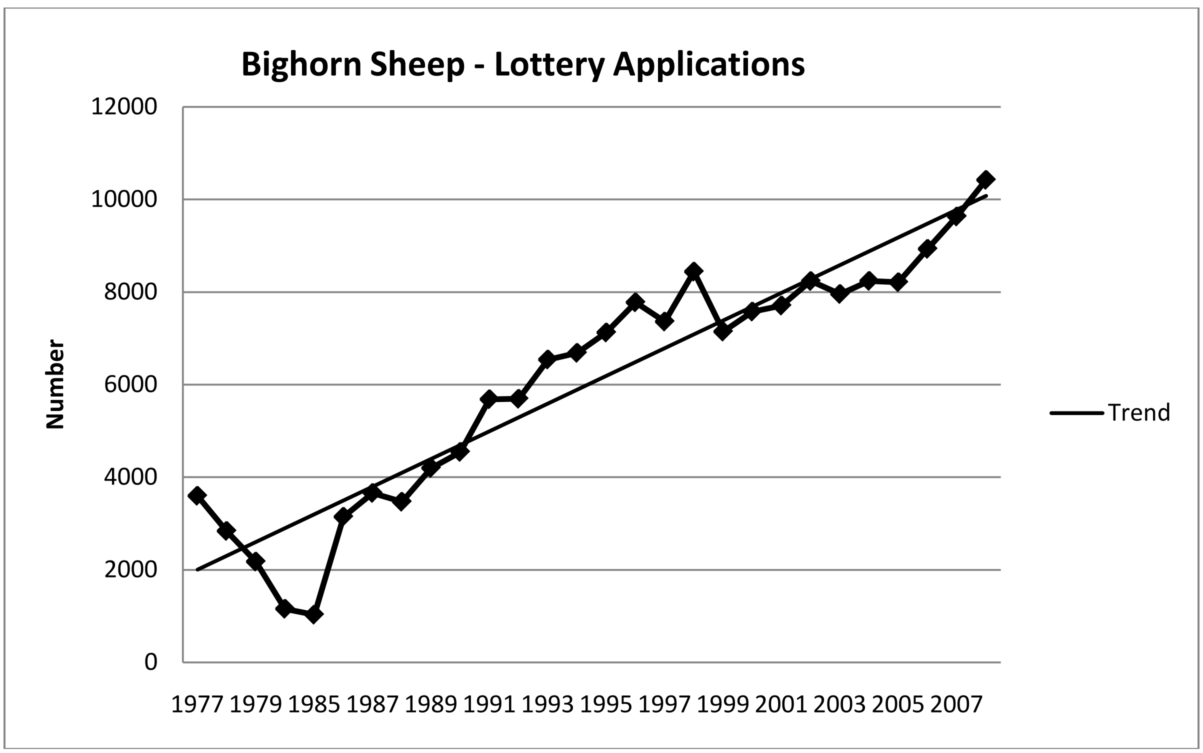

Figure 8. Bighorn sheep lottery applications, 1977-2007.

A paradigm shift occurred in North Dakota's bighorn management program in 2006 based upon revisions of Cowan's (1940) mountain sheep taxonomy by Wehausen, Ramey and Bleich (2000 and 2005). Because NDGF's initial transplant stock originated from an *O. c. californiana* source in British Columbia, the Department felt obligated to maintain this subspecies designation when conducting future translocations, even though it was believed low-elevation *O. c. canadensis* populations would much more readily acclimated to North Dakota's very similar habitat type. However, with Wehausen and Ramey's re-classification of *O. c. californiana* as synonymous with *O. c. canadensis*, NDGF translocated Rocky Mountain bighorn (*O. c. canadensis*) from Montana's Missouri River Breaks in 2006 and 2007. The Missouri River Breaks bighorn have surpassed expectations thus far, as annual lamb recruitment has averaged 70.9% the first 3 lambing seasons, far exceeding the 32.4% lamb recruitment achieved by the state's resident California-type populations during the same period. Furthermore, the incongruity in lambing success was also evident in an area where both resident California-type and translocated Montana Missouri River Breaks bighorn interact and occupy the same range. Future assessment and comparisons between these populations will continue so as to lend credence to the importance of translocating bighorn between similar habitat types when feasible.

Challenges facing North Dakota's bighorn population include contact with domestic sheep and goats due to interspersed private land ownership throughout the Little Missouri National Grassland (domestic sheep and goat grazing is prohibited within 16 km of known bighorn range on all federal and state lands), an increasing mountain lion population, increased mineral development (Sayer 1996, Feist 1997), disturbance from recreational trails constructed near critical lambing areas (Sayer et al. 2002) , habitat degradation due primarily to juniper encroachment, and persistence concerns due to a fragmentation and connectivity between sub-populations.

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South Dakota Rocky Mountain Bighorn Sheep and Mountain Goat 2008 Status Report

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BIENN. SYMP. NORTH. WILD SHEEP AND GOAT COUNC. 16: 28-29

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Rocky Mountain Bighorn Sheep

Audubon's bighorn sheep (*Ovis canadensis auduboni*) were native to the Black Hills and Badlands of South Dakota. Uncontrolled hunting caused the extinction of this subspecies by the early 1900's. Therefore, the four herds of Rocky Mountain bighorn sheep (*Ovis canadensis canadensis*) in South Dakota are a result of transplants from other state and provinces of Canada. Three herds are located in the Black Hills; Spring Creek/Rapid Creek herd, Elk Mountain herd, and Custer State Park herd. Another herd outside of the Black Hills is located in the Badlands National Park.

Spring Creek/Rapid Creek herd

This herd was established in 1991 with 26 bighorns from Georgetown Colorado. An additional 5 bighorns from the Badlands National Park were placed in the herd in 1992. The herd grew to 175-200 animals by 2000, the first year a hunting season was established for the herd with 2 "any bighorn" licenses available. Presently, the herd is at a stable population with approximately 200 animals. Licenses for this herd are at four "any bighorn".

Elk Mountain herd

This herd was established in 2001 when 20 bighorns from the Spring Creek/Rapid Creek were transplanted to Elk Mountain. An additional 7 bighorns ewes, were placed in the herd in 2004 from New Mexico. The herd has grown to approximately 100+ animals and in 2008 one "any bighorn" license will be offered.

Custer State Park herd

The present Custer State Park herd was started in 1965 with 22 animals from Wyoming. The herd grew to approximately 150 and stabilized. In 1999, twenty bighorns from Alberta, Canada were transplanted into the herd. During the 1990's and early 2000's licenses numbers ranged from 2 to 4 "any ram". By 2003 the herd had grown to approximately 180 animals. However, during the winter of 2003-2004 an all age die-off reduced the herd to around 50 animals. There has been no hunting season since that time. An additional transplant into that herd will be considered in the future to rebuild numbers.

Badlands National Park herd

The Badlands herd was originally started in 1964 when 22 bighorns from Colorado were transplanted into the park. The herd grew to approximately 160+ animals by the early 1990's when an all age die-off occurred during the winter of 1994-1995 and reduced the herd to approximately 52 animals. During 2004, 23 bighorns were transplanted into the park and the present herd has grown to around 100 animals. There is no hunting season within the park. Herd numbers will be controlled by removal of animals for transplanting in other areas of the state.

Rocky Mountain Goats

Rocky Mountain goats (*Oreamnos americanus*) were not native to South Dakota. In 1924, 6 animals were obtained from Alberta, Canada which were placed in an enclosure within Custer State Park in the Black Hills. Two escaped that day, and the remaining four escaped in 1929. This established the present herd in the Harney Peak range. In 1954, 6 goats were transplanted from this herd to Spearfish Canyon in the Northern Black Hills. That transplant failed, leaving the Harney Peak herd as the only herd of mountain goats in South Dakota.

By the late 1940's the herd size was estimated to be 300-400 animals. During the early 1980's an apparent decline in population numbers dictated a need for a basic population research study. During 1982 through 1984 the hunting season was closed. At the conclusion of the study, the population was determined to be 150+/- 22 animals. The hunting season was reopened with 4 "any goat" licenses. Population and license numbers remained stable until 2001, at which time mountain goat numbers began declining and license numbers followed suit. 2006 was the last hunting season with two licenses. At that time, aerial surveys results estimated the population to be at approximately 60 animals. During the winter of 2006-2007 eighteen mountain goats from Colorado were transplanted into the Harney Range to supplement the herd.

Rocky Mountain Bighorn Sheep Status Report - Alberta

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BIENN. SYMP. NORTH. WILD SHEEP AND GOAT COUNC. 16: 30-36

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Current Population Size and Trend

Rocky Mountain bighorn sheep are distributed across the contiguous Rocky Mountain range in the southern half of Alberta along the border with British Columbia as well as on an isolated mountain range – the Ram Mountain/Shunda Mountain complex. Sheep distribution and numbers are known fairly accurately (at least relative to most other wildlife species) through periodic surveys of key winter ranges. Seasonal distribution at other times of the year is less well understood except for a few intensively studied populations.

There are currently 60 well delineated winter ranges and most have been surveyed periodically since 1968 by fixed wing or helicopter. Sheep populations in the National Parks (Banff, Jasper, and Waterton) are not surveyed on any kind of a regular basis.

The total provincial population estimate including an estimate for the number of sheep in areas not part of the provincial survey and an estimate from the National Parks was 11,165 (Table 1). This represents an increase in the Provincial population of about 11% since 1989.

Table 1. Alberta Sheep Population Estimates, 1989 and 2008

	1989	2008
Surveyed Winter Ranges:	5215	5815
Unsurveyed areas:	785	870
National Parks: (Banff, Jasper, Waterton)	4000	4500
Totals:	10,000	11,185

In 2008, most of the winter ranges in Alberta were surveyed and subsequent preseason population estimates per Sheep Management Units (SMU) were determined using the minimum winter count from each of the respective winter ranges and factoring in the average productivity for that SMU. SMUs are groupings of winter ranges and Wildlife Management Units (WMU) that are used to try and manage on an individual herd basis in an effort to eliminate issues related to sheep movements across smaller unit boundaries (Figure 1). Estimates were compared to a similar count from 1989 to look at long-term trends in each of the SMAs. Between 1989 and 2008, counts of sheep within each SMU

Figure 1.
Sheep Management Units and Wildlife Management Units in Alberta

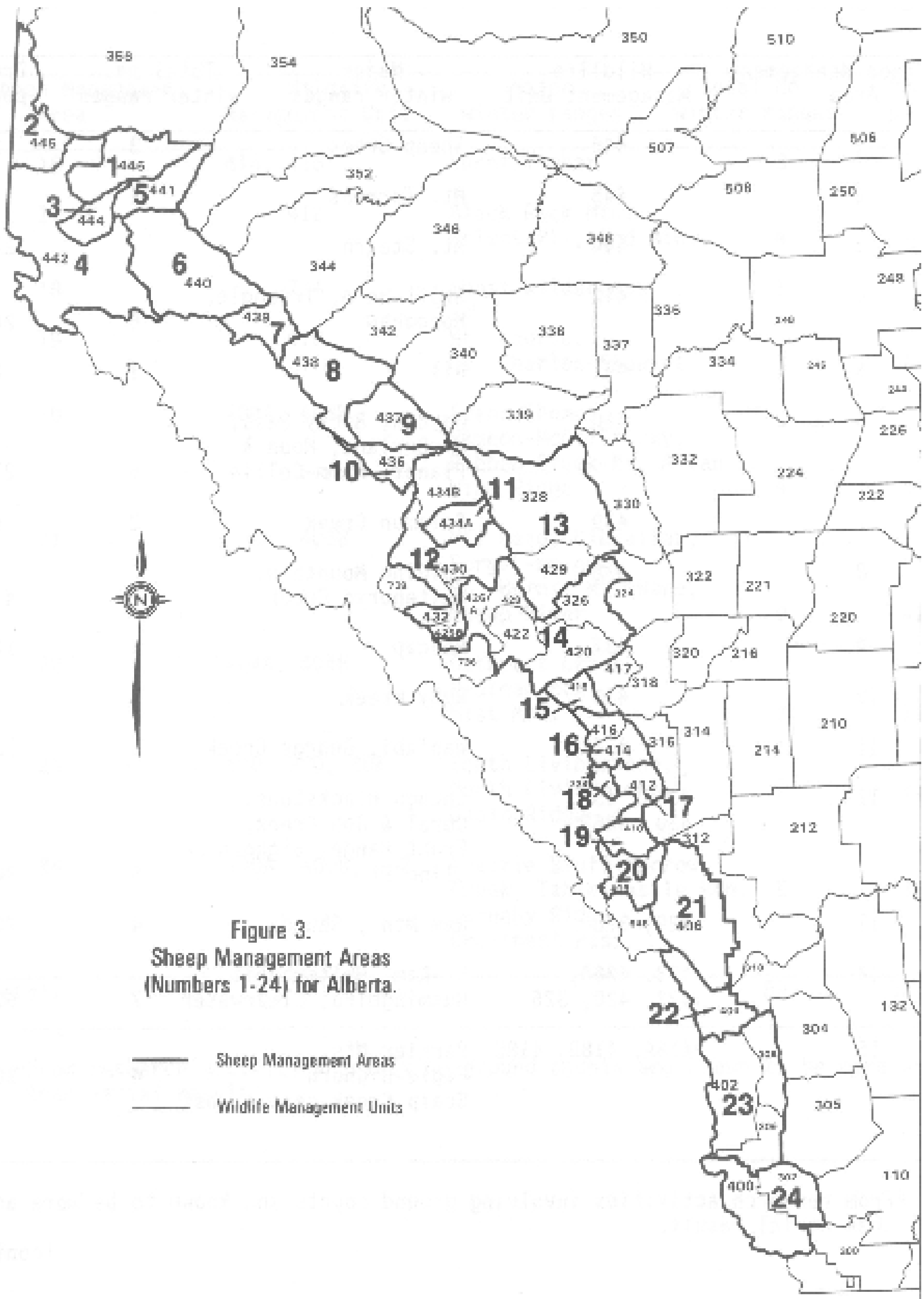
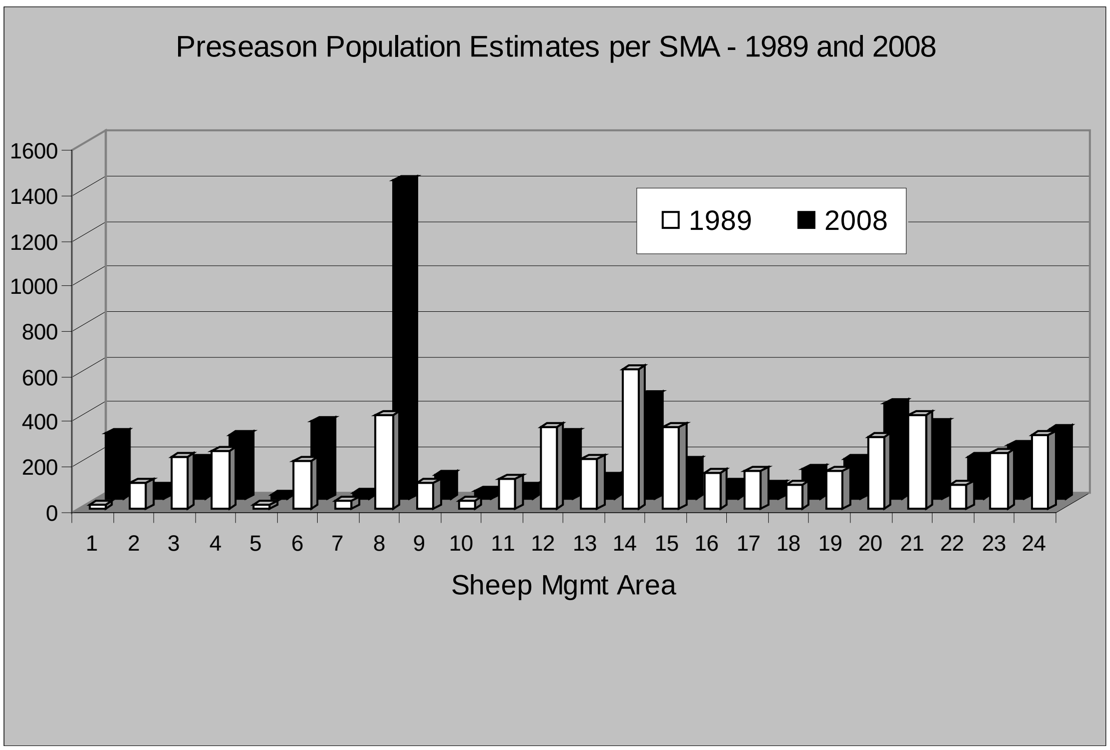


Figure 3.
Sheep Management Areas
(Numbers 1-24) for Alberta.

were similar except for SMUs 1 and 8 (Figure 2). In both these units, sheep numbers were significantly higher in 2008 especially in SMU 8 where the 2008 count was three times what it was in 1989. Most of the overall provincial population increase is almost entirely due to increases in these two SMUs which include populations at Cardinal River Coals and Smokey River Coals. Within both units there have been long-term open pit coal extraction operations with subsequent reclamation which has contributed to an increase in high quality bighorn sheep range. There have been declines in other populations e.g. Ram Mountain, Sheep River.

Figure 2. Comparison of sheep population estimates for each Sheep Management Area between 1989 and 2008.

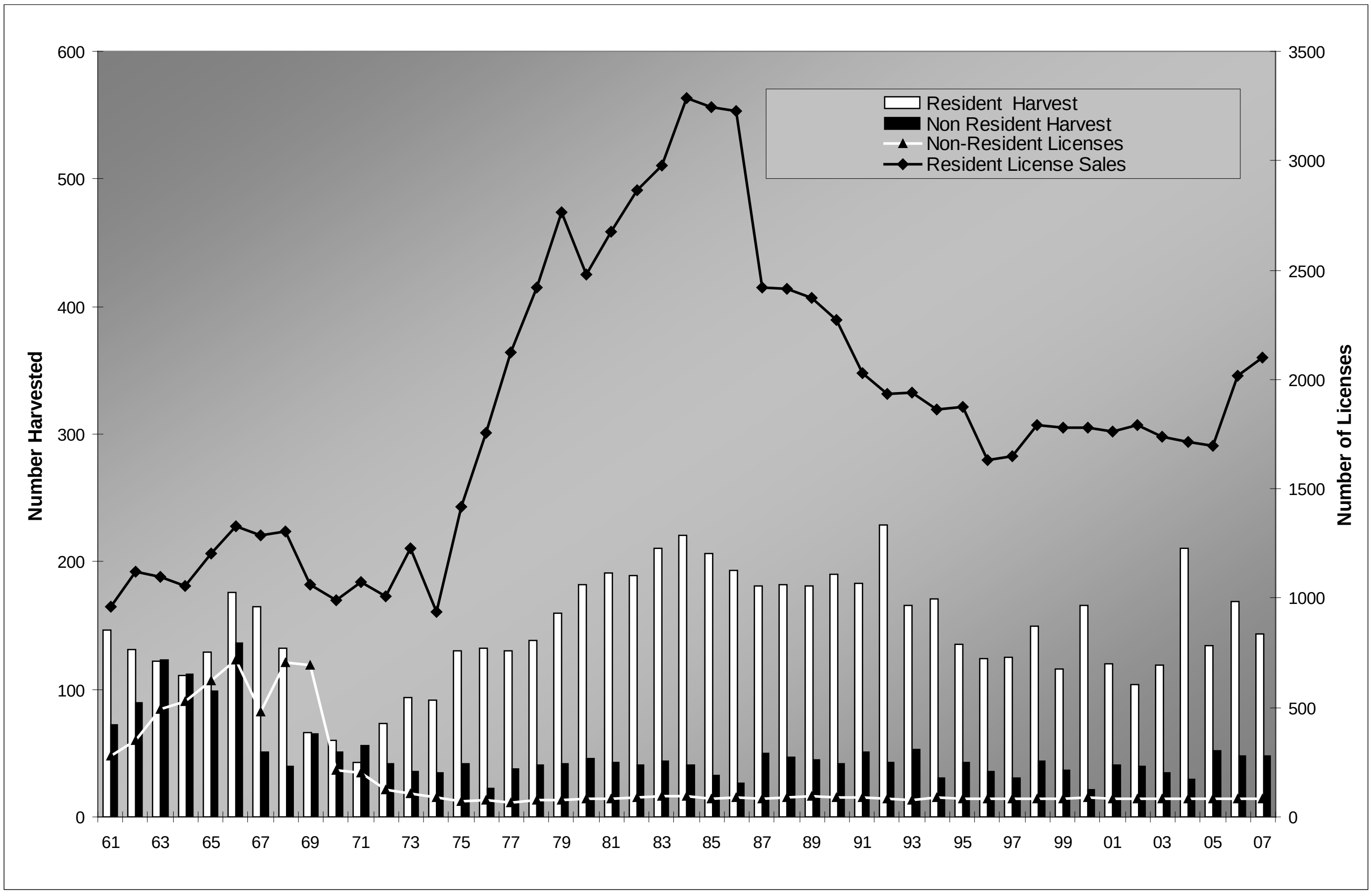


<u>Hunter Harvests</u>:

For hunting management, Alberta is divided into Wildlife Management Units (WMU) (Figure 1). There are 35 WMUs where bighorn sheep are hunted. Of these 35 WMUs, 33 have a general unlimited entry trophy ram season for residents that runs from either late August or early September to October 31. One of these units is an Archery only unit. The remaining 2 WMUs are on limited entry draw. Additional late-season opportunities are offered in 3 of the general season units in the form of a late November hunt to take advantage of animals moving out of protected areas later in the season. These late season hunt areas are all on a limited entry draw and two are Archery only. Non-resident opportunity is restricted by an outfitter allocation system and a shorter season. Outfitter guide allocations are only available north of the Bow River. All but 4 units hunt trophy rams under a minimum 4/5ths curl restriction. The remaining 4 have a minimum full curl restriction.

Over the last 10 years the number of resident licenses purchased for trophy sheep has averaged 1800 with about 85 additional licenses allocated to outfitters for non-residents (Figure 3). Annual average resident and non-resident harvest has been approximately 141 and 39 respectively (Figure 3).

Figure 3. License sales and hunter harvest of trophy rams in Alberta (1961 – 2007)



Alberta has had Non-Trophy (ewes and lambs) hunting seasons since 1968. There are currently 29 WMUs or subunits of WMUs with non-trophy seasons. All are hunted under a limited entry draw system with the annual number of permits adjusted each year according to desired harvest rates, population estimates and success rates. Approximately 250 permits are issues each year with a yearly harvest of about 65 sheep.

Transplant/Re-introductions

Since 1922, 659 Rocky Mountain bighorn sheep have been transplanted from various locations within Alberta to jurisdictions outside of the province as well as to some areas within (Table 2). Source herds have primarily been from the National Parks (Banff, Jasper, and Waterton) while Cadomin has been the principle source in recent years.

Research Programs

Ram Mountain:

Long term (30+ years) population dynamics study continues. Currently looking at the genetic and population dynamics consequences of an attempted genetic rescue. In 2007, have transplanted lambs from Cadomin herd. Will compare survival, productivity, and growth of sheep in future years according to proportion of introduced genetics. Expect the level of out breeding will improve growth, survival and reproductive success. Looking at how parasite load and parasite diversity are associated with individual heterozygosity and possible resistance to infection.

Continue with work on potential selective effects of trophy hunting. Wish to analyse long term dataset on harvested rams from both British Columbia and Alberta to look for any temporal changes.

Analyzing the long term data to examine what factors affect ewe reproductive strategy and reproductive success, focusing on senescence, causes and consequences of variation in age of primiparity, and the cumulative costs of reproduction under different environmental conditions, population densities, and phases in the population dynamics. . Population showed very strong density dependence between 1975 and1990 but not subsequently from 1991 onwards. Trying to determine why

Sheep River:

Continuing to look at the effects of weather, predation, and disease on the population dynamics of bighorn sheep at Sheep River. Population shows no evidence of density dependence but instead appears driven by pneumonia epizootics and cougar predation.

Looking at dominance hierarchies and reproductive strategies in male bighorns and how these correlate with testosterone and stress levels of individual rams. Also investigating the effects of free-range darting and capturing of bighorn sheep by measuring stress levels before, during and after captures.

Are also investigating the social structure of ram groups as well as female dominance and potential benefits thereof. Male dominance is directly linked to reproductive success but not in females. Nevertheless, females have well-established linear dominance hierarchies.

Table 2. Transplants and Relocations of bighorn sheep within and out of Alberta.

Year	No.	Origin	Destination	Reference
1922	12	Banff NP	Ntl Bison Range, Montana	Rognrud, 1983
1927	49	Banff NP	Spences Bridge (Thompson R.), B.C.	Stelfox & Stelfox, 1993
1927	50	Banff NP	Squilax, Chase, B.C.	Stelfox & Stelfox, 1993
1928	14	Banff NP	Wichita Mtns., Oklahoma	Stelfox & Stelfox, 1993
1932	6	Banff NP	Peco Wilderness, NM	Sand, 1967
1940	3	Banff NP	Sandia Mtns, New Mexico	Sand, 1967
1941	3	Banff NP	Sandia Mtns. New Mexico	Sand, 1967
1942	3	Banff NP	Sandia Mtns. New Mexico	Sand, 1967
1961	12	Sheep R.	South Dakota	Wishart, 1961
1964	10	Banff NP	Turkey Creek, New Mexico	Sand, 1967
1965	15	Banff NP	Pecos Wilderness, NM	Sand, 1967
1966	20	Waterton Lakes NP	Brigham City, Utah	Smith, 1988
1968	10	Banff NP	Wheeler Peak, New Mexico	Larsen, 1970
1969	12	Banff NP	Brigham City, Utah	Smith, 1988
1970	12	Jasper NP	Fraser Canyon, B.C.	Stelfox & Stelfox, 1993
1970	24	Banff NP	Challis Ntl. Forest, ID	Stelfox & Stelfox, 1993
1970	15	Banff NP	Brigham City, Utah	Smith, 1988
1971	20	Jasper NP	Upper Hell’s Canyon, Oregon	Stelfox & Stelfox, 1993
1971	20	Jasper NP	Lostine River, Oregon	Woody, 1971
1972	18	Waterton Lakes NP	Hall Mt. Washington	Johnson, 1983
1973	7	Waterton Lakes NP	Fort Wingate, NM	Sandoval, 1987
1973	12	Waterton Lakes NP	Desolation Canyon, Utah	Smith, 1988
1989	20	Cadomin	Ruby Mountains, Nevada	Alberta Nat. Res. Serv. Files
1990	25	Cadomin	Ruby Mountains, Nevada	MacCallum, 2006
1992	31	Cadomin	Ruby Mountains, Nevada	MacCallum, 2006
1995	49	Cadomin	Snake River, Oregon	MacCallum, 2006
1997	14	Ram Mtn	Picklejar Lakes, AB	Alberta Fish & Wildlife Div.
1998	31	Cadomin	Plateau Mtn., AB	Alberta Fish & Wildlife Div.
1999	20	Cadomin	Custer State Park, Sth Dakota	MacCallum, 2006
1999	20	Cadomin	Hells Canyon, Oregon	Coggins, 2000
2000	37	Cadomin	Hell's Canyon, Idaho/Oregon	Cassier, 2005:18
2000	7	Cadomin	Mt Baldy, AB	MacCallum, 2006
2001	22	Cadomin	Rock Canyon - Provo Peak,, Utah	MacCallum, 2006
2001	10	Cadomin	Grove Creek - Mt. Timpanogos Utah	MacCallum, 2006
2004	6	Cadomin	Ram Mtn., AB	Alberta Fish & Wildlife Div.
2005	6	Cadomin	Ram Mtn., AB	Alberta Fish & Wildlife Div.
2007	12	Cadomin	Ram Mtn., AB	Alberta Fish & Wildlife Div
2007	2	Cadomin	Calgary Zoo, Calgary AB	MacCallum, 2006
TOTAL	659			

Looking at potential benefits and costs of being a dominant ewe, such as priority access to limited resources, leading group decisions on when and where to forage, being at the head of the group while foraging but at the centre while bedded.

Investigating sexual segregation in winter and how population density, sex ratio, group structure and composition affect vigilance and activity budgets.

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The Status of Mountain Goats in Alberta, Canada.

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Abstract: Following a decline in many hunted herds of mountain goats, the hunting season in Alberta was closed in 1988 (Smith 1988). At that time the population on provincial lands (outside of National Parks) was estimated to be 1560 (Fig. 1). While populations recovered, a kid mortality study was completed (Festa-Bianchet et al. 1994) and a provincial management plan was developed (Glasgow et al. 2003). By 2000, the provincial estimate had increased to 1650 and in 2001 a limited hunting season was re-established in 3 management units in southern Alberta. A single tag is issued for each unit and to date the number of units (1 tag/unit) has increased to 8. Harvest has ranged from 1 – 7 goats annually. Hunters are encouraged to harvest only billies and an identification course is offered to each permit holder. If a nanny is harvested, the unit is closed to hunting for a year. However, since 2001, 39% (11/28) goats harvested have been nannies. The current population estimate on provincial lands is 1963 (Fig. 1; Table 1) and in the National Parks is 1430 for an Alberta total of 3393 (Table 1). There have been no mountain goat transplants since 1996 (Smith et al. 1996). Management research has focused on the Caw Ridge study area in west central Alberta including kid mortality (Festa-Bianchet et al. 1994), helicopter harassment (Cote 1996), reproductive success (Cote and Festa-Bianchet 2001) aerial survey efficiency (Gonzalez-Voyer et al. 2001), population response following hunting closure (Gonzalex-Voyer et al. 2003) and population dynamics and hunting strategies (Hamel et al. 2006). A summary of all Caw Ridge research activities has been reported in a recent book (Festa-Bianchet and Cote 2008). Management challenges in Alberta include resourcing systematic surveys, minimizing heli-seismic activity in mountain goat range and the encroachment of mining activity onto the Caw Ridge study area.

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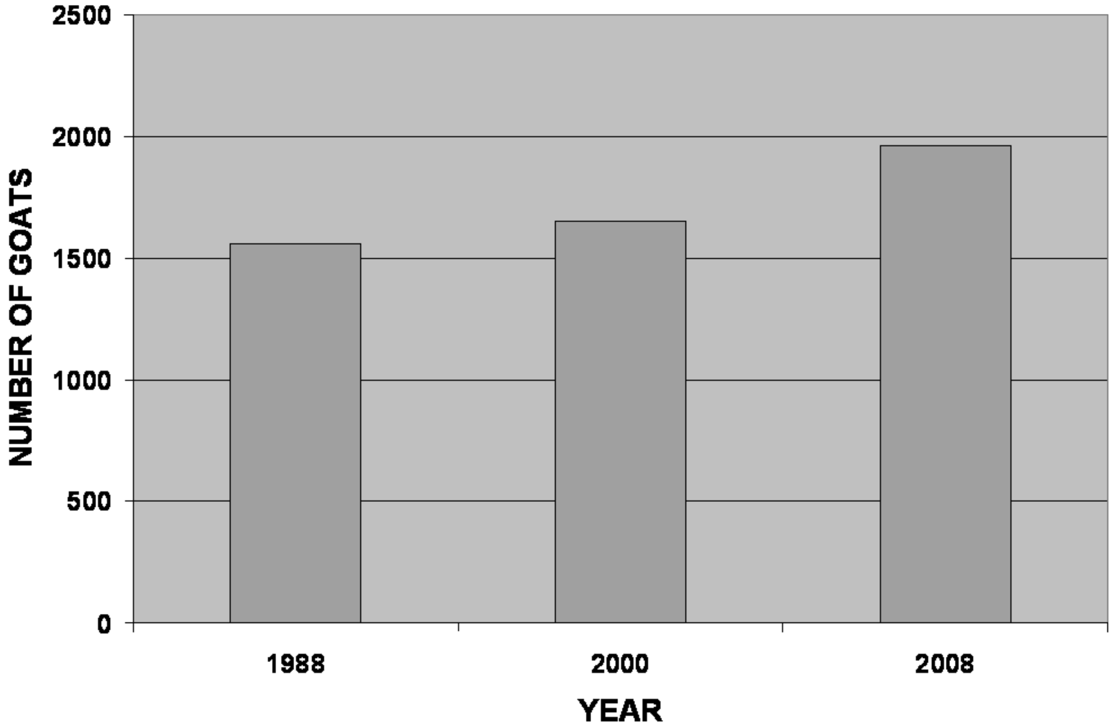

Fig. 1. Population estimates for mountain goats in Alberta (outside of National Parks), 1988 – 2008.

Table 1. 2008 mountain goat population estimates for Alberta, Canada.

GMA[a]	WMU	Area	Observed[b]	Source
A	400	Waterton , Carbondale and Castle	248	Bergman (2005)
	402	Crowsnest Pass to Mount Gass (Continental Divide)	93	Bergman (2006)
	306/402	Livingstone Range	14	Bergman (2006)
	402	Crowsnest Mountain	35	Bergman (2006)
	GMA Total	All Areas	390	
B	408/648	Area M, Kent Ridge and Opal Range West	100	J. Jorgenson (PC)
	404/406/408	Elk, Fisher, Elbow, Opal, Highwood, and Kananaskis Ranges	120*	J. Jorgenson (PC)
	410/412/734	Canmore, Devils Head and Ghost Wilderness Area	75	J. Jorgenson (PC)
	GMA Total	All Areas	295	
C	328	Shunda	12	Allen (1998)
	414/416	Burnt Timber Creek and Bruns Ridge	25*	E. Bruns (PC)
	417	Wilson Creek	4*	J. Allen (PC)
	418	Eagle Creek	10*	E. Bruns (PC)
	420	Peters Creek	5*	E. Bruns (PC)
	422	South Ram	18	Allen (1998)
	426/430/432	First Range and Cline Creek	39	Allen (1998)
	428	Kiska Creek	2*	J. Allen (PC)
	432	Whitegoat Peaks	45	Allen (1998)
	434	Blackstone-Wapiabi	2*	J. Allen (PC)
	736	Siffleur Wilderness	31	Allen (1998)
	738	White Goat Wilderness	2	Smith and Edmonds (1988)
	GMA Total	All Areas	195	
D	344	Pinto Creek	33	Hinton Wood Products 2006 report
	356	Kakwa/Smoky confluence	0	D. Hervieux (PC)
	436	Cardinal-Brazeau	5*	K. Smith (PC)
	437	Red Cap Range	0	K. Smith (PC)
	438	Whitehorse Creek	1	Sorensen (1999)
	439	Moosehorn	5	Hobson and Kneteman (2007)
	440	Berland-Hoff Range	40	Hobson and Kneteman (2007)
	440	Daybreak Peak	4	Hobson and Kneteman (2007)
	440	South Persimmon	51	Hobson (2002)
	440	North Persimmon	66	Hobson and Kneteman (2007)
GMA[a]	WMU	Area	Observed[b]	Source

D	441	Goat Cliffs-Grande Mt.	30	Hobson and Kneteman (2007)
	442	Sunset Peak	39	Kneteman PC
	442	Rockslide Creek	58	Hobson and Kneteman (2007)
	442	Monoghan Creek	45	Hobson and Kneteman (2007)
	442	Ptarmigan Lake	63	Sorensen (1999)
	442	The Triangle	8	Hobson and Kneteman (2007)
	442	Mount Deveber	61	Hobson and Kneteman (2007)
	442	Kvass	6	Hobson and Kneteman (2007)
	442	Cote/Trench/Bear Creek	12*	K. Smith (PC)
	442	Mount May/Francis Peak/La Creche Mtn	15*	D. Hervieux (PC)
	444	Llama/Turret	86	Hobson and Kneteman (2007)
	444	Mount Hamell	79	Sorensen (1999)
	445	Dinosaur Ridge	10*	D. Hervieux (PC)
	445	Narraway Valley	15*	D. Hervieux (PC)
	445	Sulphur Mountain	15*	D. Hervieux (PC)
	446	Caw Ridge	150	Steeve Cote (PC)
	GMA Total	All Areas	1100	
	Total on Provincial Lands		**1963**	
	Waterton National Park		80	R. Watt (PC)
	Banff National Park		1000*	A. Dibb and J. Whittington (PC)
	Jasper National Park		350*	M. Bradley (PC)
	Total on Federal Lands		**1430**	
	Alberta Total		**3393**	

[a] A = Southern Rockies Area – Pincher Creek B = Southern Rockies Area - Canmore
C = Clearwater Area D = Foothills and Smoky Areas

[b] These are the numbers of goats observed during the most recent aerial survey, except * (see below).

* These areas have not been surveyed recently so numbers represent estimates and are based on observations from the ground, information supplied by others and/or estimates by local wildlife managers.

PC = personal communication

Note: Many herds are shared with British Columbia or National Parks, but the numbers (other than those numbers beside the three National Parks) represent only those goats observed on Alberta provincial lands.

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The Status of Mountain Sheep and Mountain Goats in British Columbia

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Abstract**:** Approximately 2000-2500 Rocky Mountain bighorn sheep (*Ovis canadensis canadensis*) occur primarily in the Rocky Mountains of south eastern British Columbia (BC) and 2400-3300 California bighorn sheep (*O. c. california*) in south-central BC. There are 10,000-14,500 Stone's sheep (*Ovis dalli stonei*) in northwest and northeast BC and 300-400 Dall's (*O. d. dalli*) in the northwest corner of the province. Between 39,000-67,000 mountain goats (*Oreamnos americanus*) occur throughout the coastal, interior mountain ranges and the Rocky Mountains in BC. The harvest of bighorn sheep is limited to mature (8 years old or greater, or horn tips pass the bridge of the nose when viewed squarely from the side) or ¾ curl rams. One southern BC region has a limited entry lottery draw for any bighorn ram. Thinhorn sheep are regulated by a full curl restriction and this is generally managed by open season with limited entry draws primarily occurring in parks protected areas. The harvest of either-sex mountain goats is allowed, but the taking of females is discouraged. Public education, including an instructional video, is used to improve the success of male-only harvest. Mountain Goats are a highly sought-after trophy species in BC and harvest allocation between resident and non-resident hunters is a point of contention. Current management concerns for mountain goats include removal of forested winter range habitat, unregulated female harvest, increased backcountry access, and the unknown impacts associated with expanding helicopter recreation. Research is needed to determine survival rates, age structure and sustainable harvest levels for small (<100 animals) hunted populations of mountain goats. Mountain goat herds are declining in south-central BC from unknown causes while they appear to be stable in most of their range. The translocation of bighorns within the province is minimal with less than 100 animals moved for management reasons into historic habitat or to supplement herds in the past 5 years. Management of all wild sheep and to some degree mountain goats includes consideration for maintaining separation of wild and domestic sheep and goats. Local programs underway in 3 regions of British Columbia focus on collaborative efforts with livestock producers and private land owners. Research efforts are underway to assess the medium-long term effect of helicopter disturbance on mountain goats and the demographics and habitat use of a population of Stone's sheep as a prelude to planning for industrial activity.

Key words: bighorn, British Columbia, disease, harvest, thinhorn, mountain goat, Ovis, Oreamnos.

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Status of bighorn sheep in California

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Abstract: California supports 2 populations of federally endangered bighorn sheep. Sierra Nevada bighorn sheep (*Ovis canadensis sierrae)* are a unique subspecies that occupies portions of the southern and central regions of that mountain range where elevations are the greatest (>14,000 feet). They typically spend summers in the alpine above 11,000 feet and winters at lower elevations between 5,000 to 9,000 feet, yet some Sierra bighorn spend the entire year in the alpine. In 2008, Sierra Nevada bighorn sheep numbered 369 animals, including 200 adult females, and occupied 8 herd units; recovery goals are 305 adult females distributed among 12 herd units. Issues receiving particular focus in the Sierra Nevada are the disease risk posed by domestic sheep, use of prescribed fire to enhance bighorn habitat, use of translocations to augment and reintroduce herds, and efforts to limit predation by mountain lions. The disease risk posed by grazing of domestic sheep on public lands adjacent to bighorn habitat in the Sierra Nevada is receiving considerable attention and continues to be a challenging management issue. Peninsular bighorn sheep (*Ovis canadensis nelsoni)* occupy the Peninsular mountain ranges in southern California north of Mexican border and are recognized as an endangered distinct population segment of desert bighorn sheep. In 2008, Peninsular bighorn numbered 876 animals among the 9 units within the range but remain below recovery goals in at least 2 of those units. Disease outbreaks continue to limit population growth in at least 3 units. An effort is currently underway to identify the most appropriate approach for augmenting struggling populations in the context of population viability.

The majority of California's non-endangered desert bighorn sheep (*Ovis canadensis nelsoni)* occupy mountain ranges in the Mojave and Sonoran deserts and number close to 4,000 animals. Fifty-five of 67 desert ranges are currently considered occupied although many ranges have fewer than 50 animals. Numerous desert mountain ranges, that support bighorn, exist within the boundaries of National Parks and military properties where hunting is prohibited. Seven hunt zones exist within the desert ranges and provide the opportunity for 19-20 hunting permits annually. While many desert populations are stable or increasing, many also are threatened by a variety of factors including reduced connectivity from habitat fragmentation, disease risk posed by domestic livestock, and habitat loss through climate change. Currently there are no documented herds in northern California although there is interest in reintroducing bighorn to native ranges.

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Status of Rocky Mountain Bighorn Sheep in New Mexico 2006-2007

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Abstract: Rocky Mountain bighorn sheep (*Ovis canadensis canadensis*) numbers in New Mexico have nearly doubled in the last decade. In 2007, approximately 1,000 bighorn sheep occur in 8 populations, residing on state, federal, tribal, and private lands. There are 3 alpine populations located primarily in U.S. Forest Service wildernesses and 5 low-elevation populations that are primarily associated with river corridors. New Mexico Department of Game and Fish (NMDGF) has captured and translocated 245 bighorn sheep in 9 captures from alpine populations since 2001. An additional 23 bighorn sheep were captured and translocated by the Taos Pueblo. Since 2001, bighorn sheep have been translocated within New Mexico to start 3 new populations and augment 2 existing populations. In addition, bighorn sheep have been translocated to South Dakota and Arizona. Carrying capacity in the 8 extant herds is approximately 1,500. All known historical habitat will be occupied with 1 or 2 more translocations. Hunting permits have increased from 9 in 1998 to 19 in 2007, including 2 hunting permits on the Taos Pueblo. Management is guided by the "Long-range plan for the management of Rocky Mountain bighorn sheep in New Mexico 2005-2014". Primary concerns are woody vegetation encroachment in all habitats, keeping populations below carrying capacity in alpine habitats, minimizing contact with domestic sheep and goats, and mountain lion predation in low-elevation populations. View additional information about New Mexico bighorn sheep on our website at: www.wildlife.state.nm.us/conservation/bighorn/index.htm

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Status and Management Activities

Rocky Mountain bighorn sheep were never widespread in New Mexico, but by the early 1900s were extinct (Buechner 1931). Bighorn restoration began in the 1930s with bighorn from Alberta, Canada, and transplants continue today. In the late 1990s, the statewide bighorn population was estimated at 500 bighorn distributed in 5 populations. Between 2001 and 2007, the New Mexico Department of Game and Fish (NMDGF) translocated 159 bighorn within New Mexico to start 3 new populations and to augment 2 additional populations. Another 56 bighorn were transplanted to Arizona, and 29 bighorn were transplanted to South Dakota, to assist with their bighorn sheep management programs. By 2007, the statewide Rocky Mountain bighorn sheep population had grown to approximately 975. Carrying capacity of currently occupied ranges is estimated at 1,500 individuals, and there are few vacant bighorn sheep habitats left in New Mexico. The Long-range plan for the management of Rocky Mountain bighorn sheep in New Mexico 2005-2014 was approved by the State Game Commission, and guides New Mexico's bighorn sheep management strategies.

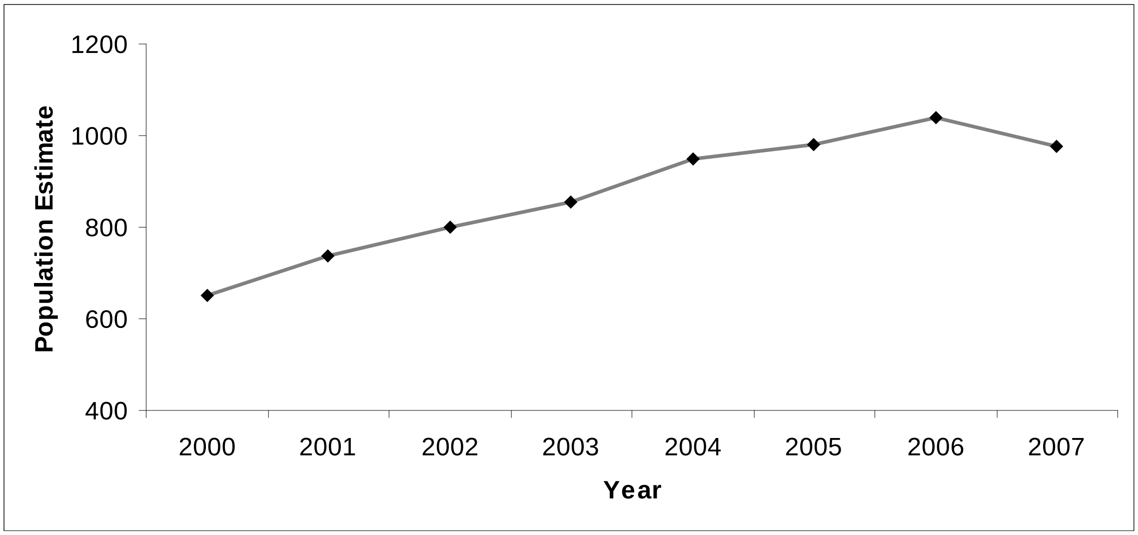

Figure 1. Statewide population trend of Rocky Mountain bighorn sheep in New Mexico, 2000-2007.

Alpine Populations

Three alpine populations are distributed in the Sangre de Cristo Mountains in north-central NM. Several dieoffs associated with large flocks of domestic sheep grazing in bighorn habitat limited or extirpated these herds historically. Conversion of allotments to cattle grazing has greatly reduced the threat of pneumonia transmission. All 3 populations are regulated by amount of available winter habitat, and are at or near carrying capacity. The primary management objectives are to maintain the populations below carrying capacity to decrease the risk of dieoffs, provide bighorn sheep for translocation, and to maximize trophy ram potential.

Pecos: This population was established in 1965 with bighorn sheep from Banff, Canada. This population lives entirely within the U.S. Forest Service's (USFS) Pecos Wilderness Area. It is estimated that this population fluctuates between 325-400 animals. Annual variation is based primarily on winter lamb survival and lamb production, suggesting that this population is at carrying capacity. To help regulate population numbers, bighorn are frequently captured out of this herd. Since 2001, 169 bighorn have been transplanted to augment or start new herds in NM and other states.

Wheeler Peak: This population was established in 1993 with a translocation of 33 bighorn sheep from the Pecos Wilderness. Currently this herd is comprised of 2 subpopulations. The main population lives within the USFS Wheeler Peak Wilderness, and on Taos Pueblo tribal lands. A subpopulation inhabits Gold Hill, within the USFS Columbine-Hondo Wilderness Study Area. Carrying capacity for this herd is less well understood than in the Pecos, but it is likely that current estimates of 325 bighorn are at or exceed carrying capacity. Recent creation of the Taos Pueblo Department of Game and Fish has resulted in an increasingly collaborative effort to survey and manage the population. Since 2001, a total of 71 bighorn has been transplanted out of this herd, and an additional transplant of up to 50 bighorn is planned for summer 2008.

Latir: This population was started with a transplant of 56 bighorn sheep from the

Pecos Wilderness in 2001. Bighorn habitat is primarily in the USFS Latir Wilderness, and a small portion is privately owned by the Rio Costillo Cooperative Livestock Association. The population quickly increased to an estimated 150 in 2005 and 2006, but declined to approximately 75 animals in 2007. We speculate that the population exceeded carrying capacity for several years and in combination with a high snowfall during the winter of 2006-2007 induced this decline.

Low-elevation Populations

Most low-elevation populations in New Mexico are associated with river corridors. These herds are not as robust alpine herds as they face increased risk from disease transmission from domestic sheep and goat contact, loss of habitat through woody vegetation encroachment, and cougar predation.

Turkey Creek and San Francisco River: Historically, these populations were likely comprised of desert bighorn sheep, but were reestablished in the mid-1960s with Rocky Mountain bighorn as desert bighorn numbers in New Mexico had declined such that they were not available for transplant. Habitat is primarily public lands on the Gila National Forest and Bureau of Land Management, with some private inholdings. Since 2001, 30 bighorn sheep captured from alpine populations have augmented the Turkey Creek herd.

Since 2001, 14 bighorn have been transplanted to augment the San Francisco River herd. In the last decade 2 large-scale dieoffs have been documented, with mortality patterns consistent with pneumonia outbreaks. In 2006, a confirmed pneumonia dieoff resulted in a loss of approximately 40% of the herd. While the source of pneumonia cannot be confirmed, we hypothesize that rams moving between NM and AZ have contacted a resident domestic sheep herd on private land in AZ.

Manzanos: This herd was started in 1977 with bighorn sheep from the Pecos Wilderness. This small herd faired poorly after a 1997 augmentation. It suffered from high average annual mortality rates from both cougar predation (mortality rate=0.11) and train strikes (mortality rate=0.13). We think this herd has declined to <30 individuals. The Burlington Northern Santa Fe Railroad has proposed building a second, parallel track through the main canyon where the bighorn reside. As part of the mitigation BNSF has proposed building a wildlife fence on both sides of the tracks for the approximately 13 km stretch of the canyon. Existing trestles would provide movement corridors under the tracks. Following the fence construction, NMDGF may consider implementing cougar control, and possibly a bighorn augmentation. A mechanical pinyon-juniper thinning project has been proposed on USFS and private lands in currently occupied bighorn habitat. This herd is in marginal habitat in the southern extent of their range.

Rio Grande Gorge: In 2006, the Taos Pueblo Department of Game and Fish (TPDGF) captured 23 bighorn in the Wheeler Peak herd, and transplanted them to tribal property on the east side of the Rio Grande Gorge. Bighorn were held in a temporary paddock in the Gorge for approximately 1 month prior to release. In 2007, NMDGF captured 25 bighorn in the Pecos Wilderness, and released them on BLM land on the west side of the Rio Grande Gorge. Although TPDGF deployed just 15 radiocollars, there has been no mortality on those bighorn. There have been 4 adult mortalities on bighorn released by NMDGF, and 4 of 5 lambs died within 8 months of release. A bighorn ewe returned to the capture site in the Pecos Wilderness, a straight-line distance of ~40km. Given the large movements, and presence of several small inholdings of domestic sheep, risk of a pneumonia outbreak appear high. The release has been very popular with the public as the Gorge is a destination for river rafters.

Dry Cimarron: NMDGF transplanted 34 bighorn to the Dry Cimarron in the far NE corner of NM in 2007. Bighorn sheep had been occasionally reported in this part of NM for several years. These were bighorn sheep from the Carrizo Unit in Colorado. Much of this area is characterized by broken mesas and the Dry Cimmaron River drainage. Much of the habitat has been invaded by pinyon-juniper. A recent fire killed this p-j overstory and opened considerable new bighorn habitat. Steep escarpments near the Cimarron River and associated mesas and draws provide sufficient habitat for a moderately sized population. The bighorn reside primarily on private lands and on small parcels of state land. Some bighorn have made temporary trips across the nearby Colorado border. Bighorn sheep from Colorado have also been observed in Oklahoma. Four adult bighorn sheep have died since the release – 1 in the first week after transplant, 1 from a cougar kill, 1 from a fall, and 1 of unknown cause. An augmentation is planned for summer 2008 to populate the remaining habitat.

Table 1. Population estimates of 8 Rocky Mountain bighorn sheep herds in New Mexico, 2000-2007.

Herd	2000	2001	2002	2003	2004	2005	2006	2007
Pecos	350	350	350	350	350	350	350	325
Wheeler	180	200	225	250	300	300	340	325
Latirs	0	56	85	106	128	150	150	75
TC	40	35	45	45	45	45	80	75
SFR	50	65	75	85	105	115	75	65
MZ	30	30	21	20	20	20	20	20
DC	0	0	0	0	0	0	0	35
RGG	0	0	0	0	0	0	23	55
TOTAL	**650**	**736**	**801**	**856**	**948**	**980**	**1038**	**975**

Table 2. Translocation history of Rocky Mountain bighorn sheep herds in NM, 2001-2007.

RELEASE HERD	TRANSLOCATION HISTORY						
	DATE	**SOURCE**	**RELEASE AREA**	**Rams**	**Ewes**	**Lambs**	**TOTAL**
Turkey Creek	2005	Latir Wilderness, NM	Watson Mtn.	0	2	3	5
	2006	Gold Hill, NM	Watson Mtn	14	4	7	25
San Francisco River	2004	Pecos Wilderness, NM	Sundial Mtn	2	12		14

Latir Wilderness	2001	Pecos Wilderness, NM	Latir Mesa	7	35	14	56
Rio Grande Gorge[b]	2007	Pecos Wilderness, NM	Vista Verde trail-head; w. Taos Jct Bridge	3	17	5	25
Dry Cimarron	2007	Pecos Wilderness, NM	S. of Wedding Cake Butte	4	28	2	34
Arizona	2003	Wheeler Peak, NM					16
	2003	Pecos Wilderness, NM					11
	2005	Pecos Wilderness, NM					29
South Dakota	2004	Wheeler Peak, NM	Badlands NP				30
TOTAL							**245**

Bighorn Harvest History

NMDGF manages bighorn hunts for trophy quality rams, and therefore has a conservative number of licenses issued each year. The high demand for bighorn licenses are reflected in the number of applicants each year (Table 3). Rocky Mountain bighorn hunting permits have increased from 9 in 1998 to 19 in 2007, including 2 permits sold by the Taos Pueblo for the Wheeler Peak population (Table 3). One youth license was added to the Pecos hunt in 2005. In 2007, the Pecos hunt was split into 2 different time periods to reduce the number of hunters on the mountain simultaneously. Two rams were legally harvested during the first Latir bighorn hunt held in 2007. This hunt has been cancelled until the population stabilizes following the substantial decline in 2007 and has older age-class rams to offer a consistent high-quality hunt. The state record Rocky Mountain bighorn was taken by a Taos Pueblo hunter in 2005 and scored 198 4/8. The average score of the 10 largest bighorn taken in New Mexico is 192 0/8. One license for either a desert or Rocky Mountain bighorn is auctioned annually through the Wild Sheep Foundation. Since 1990, the auction permit has averaged ~$104,000, and since 1999 the permit has averaged ~$130,000. The 2008 license sold for $90,000. One permit is available via a raffle; tickets are $20. Since 2000, the raffle has generated an average of ~$46,000 per year. In 2007, it generated ~$33,000.

Table 3. Number of licenses issued by NMDGF, Boone and Crocket scores, and draw odds for Rocky Mountain bighorn sheep in New Mexico, 2007.

Herd	**# of licenses available[a]**	**Average (range) B&C score of harvested bighorn**	**First Choice Draw Odds**
Pecos I	5	163 1/8 (144 6/8-176 6/8)	366:1

Pecos II	4	160 7/8 (156 5/8-169 0/8)	108:1
Pecos Youth	1	Included above	355:1
Wheeler Peak	4[b]	175 5/8 (172 6/8 – 180 1/8)	284:1
Turkey Creek	1	172 6/8	599:1

[a] An additional 2 licenses were issued: 1 purchased via auction, and 1 purchased via a raffle. The auction hunter chose to hunt in Wheeler Peak, and the raffle hunter chose to hunt desert bighorn in the Peloncillo Mountains.

[b] Two additional permits generally sold by the Taos Pueblo.

View additional information about New Mexico bighorn sheep on our website at www.wildlife.state.nm.us/conservation/bighorn/index.htm

Mountain Goat Management on the Kenai Peninsula, Alaska: a New Direction

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Abstract: Management of mountain goats (*Oreamnos americanus*) on the Kenai Peninsula has varied over the last 4 decades. A sanguine description of a past harvest-tracking strategy was described by Del Frate and Spraker (1994). Despite the stated goal of their management protocol to allow for gradual increases in population size, the current Kenai population of roughly 3,000 goats declined 30-50% from 1992 to 2006. The goat range on the peninsula is divided into 31 areas that are managed as discrete populations and vary greatly in goat densities, habitat type, hunter accessibility, and allocation of hunting permits. We review 4 decades of survey and harvest information, discuss some of the consequences of past management protocols, and describe a conservative strategy that has been recently employed to reduce the potential for overharvest yet still provide sustainable hunting opportunities. Specifically, our new protocols use explicit criteria to determine the number of hunting permits to issue each year in each area by considering past harvest rates, the sex and age structure of the harvest, population size and trends, the age of the survey data, access, ecotype, winter severity, and other factors. We also discuss a new approach for reducing the harvest of female goats.

Key Words: Alaska, Kenai Peninsula, harvest rate, mountain goat, *Oreamnos americanus.*

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Mountain goats (*Oreamnos americanus*) are the most understudied ungulate in North America. Past mismanagement of some goat populations stemmed from incorrect assumptions made about their population dynamics, which led to excessive harvests. Specifically, excessive harvests occurred because native goat populations lacked compensatory reproduction in response to harvests, survival was influenced by highly variable density independent events, population growth rates were lower than other North American ungulates requiring lower sustainable harvest rates, and populations were often not managed at the subpopulation level, which led to local extirpations (Kuck 1977, Herbert 1978, Bailey 1986, Kuck 1986, Glasgow et al. 2003). During the past decade, several studies have contributed greatly to our understanding of the ecology and conservation of mountain goats (Côté and Festa-Bianchet 2001*a*, 2001*b*; Festa-Bianchet et al. 2003; Festa-Bianchet and Côté 2008). Management protocols need to be reviewed periodically to incorporate new insights gained from field studies (Bailey 1982), especially considering the low growth rate of mountain goat populations.

The low growth rate in native populations of mountain goats (Festa-Bianchet et al. 1994, Côté and Festa-Bianchet 2001*b*, Côté et al. 2001) is more comparable to that of brown bears than other northern ungulates such as caribou or moose. For example, although there is regional variation, primiparity for native goat populations averaged 4.6 years (Côté and Festa-Bianchet 2001*b*) compared to 4-5 years in brown bears (Schwartz et al. 2003), 3.0 years in caribou (Adams and Dale 1998), and 2-3 years in moose (Boertje et al. 2007). The ≤2% sustainable harvest rate calculated for native mountain goats on Caw Ridge, Alberta, (Gonzalez Voyer et al. 2003, Hamel et al. 2006) is far lower than the 5.5-5.7% sustainable harvest rate for brown bears (Miller 1990, Van Daele 2006), and the 7-8% harvest rate for some moose populations (Boertje et al. 2007). The lifetime reproductive success of females is variable but studies on native populations showed a mean of 5.7 kids produced with 3.6 kids surviving to age 1 (Festa-Bianchet and Côté 2008:132). Contrary to density dependent responses found in some cervids (McCullough 1979, Sand et al. 1996, Boertje et al. 2007), there is little if any evidence of compensatory reproduction in native goat populations; mortality is primarily influenced by density independent factors (Smith 1988, Festa-Bianchet et al. 2003), and hunting mortality is considered additive (Kuck 1977, Bailey 1986). A slow growth rate coupled with additive hunting mortality creates challenges for sustainable management of mountain goats, especially native populations.

While introduced goat populations can grow and expand quickly and are often able to sustain relatively high harvest rates (Swenson 1985, Houston and Stevens 1988), native populations are sensitive to harvest (Côté et al. 2001, Gonzalez Voyer et al. 2003, Hamel et al. 2006). Indeed, native goat populations are the only ungulate in North America in the past 50 years to be extirpated from large areas due to excessive hunting (Smith and Nichols 1984, Glasgow et al. 2003). Aside from the intensively studied goat population on Caw Ridge, Alberta (Festa-Bianchet and Côté 2008), empirical support for most harvest strategies for mountain goats is weak (Bailey 1986). Annual differences in survival rates and reproductive success can be significant both across and within goat populations (Côté and Festa-Bianchet 2001*a*), so management actions need to be herd specific and based on many years of supporting data (Bailey 1986). Unfortunately, management of mountain goats across much of their range in Alaska is often compromised by a lack of information on herd specific dynamics and insufficient funding for adequate monitoring and research.

Past management protocols on the Kenai Peninsula may have negatively affected goat populations. The peninsula-wide population has declined 30-50% since the early 1990s. Our first objective was to review the past management protocols for goats on the Kenai Peninsula (Del Frate and Spraker 1994) by evaluating 4 decades of management actions that may have contributed to population trends. Secondly, we discuss new management protocols based on recently published studies on goat population dynamics and life history characteristics that will update our management strategy to help curtail the current population decline.

Study Area

The Kenai Peninsula (24,000 km^2), which lies between Prince William Sound and Cook Inlet, is in south-central Alaska (Fig. 1) and has over 12,000 km^2 of mountainous goat habitat. Over 90% of the habitat used by goats is within protected lands of the Kenai Fjords National Park (2400 km^2), Chugach National Forest (5000 km^2), Kachemak Bay State Park (1600 km^2), and the eastern portion of the Kenai National Wildlife Refuge (2100 km^2). Apart from the introduced population on Kodiak

Island, the Kenai Peninsula is the western most extent of the range of mountain goats. Goat habitat on the Kenai was described in Hjeljord (1973). The Kenai Mountains range in elevation from 1,300 m to 2,000 m. Alpine tundra (Viereck and Little 1972) covers most higher elevations but there is variation between coastal and inland areas. On the inland portion of the Kenai Mountains, goats are sympatric with approximately 1,000 Dall sheep (*Ovis dalli*). Both species have been present on the Kenai for centuries; native people hunted them long before Alaska was first settled by Russians in the late 1700s (Sherwood 1974) and large numbers were documented during early explorations of the area over a century ago (Bennett 1918). The total population size on the Kenai is currently about 3000 goats assuming our counts miss 20-40% of the goats present (Nichols 1980). For the purpose of controlling and distributing hunting effort, the Kenai Mountains were divided into 31 units, 25 of which currently have some level of goat hunting (Fig. 1). Although not completely panmictic, we know there is some level of movement of goats across these borders (Nichols 1985). Densities vary greatly; some units have over 300 goats, others fewer than 30.

Methods

Aerial Surveys.— Population counts were conducted annually from 1968-2007 using aerial fixed-winged techniques (Nichols 1980). Goats were classified as kids or older goats (yearlings and adults). Not all animals were observed and counted during aerial surveys, so this sightability bias underestimated goat numbers. Due to the inability to estimate goats not seen during flights, our survey techniques produced minimum counts and not population estimates. Although fine-scale and short-term trends cannot be detected from these types of surveys (Bailey 1986, Harris 1986), they are adequate for detecting broad trends in goat populations (Gonzalez Voyer et al. 2001). We assumed that our survey counts represented the individual goat populations. Goat surveys were conducted on only 20-40% of the Kenai Peninsula each year due to budgetary constraints. Surveys are not conducted in Kenai Fjords National Park (Fig. 1), where hunting has not been allowed since 1980.

Harvest Data.— Kenai specific data on hunter harvest has been collected since the early 1970s. The types of goat hunts have ranged from open hunts with no permit required, to hunts managed with drawing or registration permits. Drawing permits were limited in number, specific to a particular area (Fig. 1), and were issued on a lottery basis where hunters paid for the chance to win a permit. Registration hunts were typically unlimited, specific to a particular area (Fig. 1), and easily obtained at no cost. Registration permits allowed for in season management of harvest and hunter effort and could close early if harvest quotas were reached. In most years since 1976, successful hunters have been required to bring in the horns for sex determination, aging, and measurements (McDonough et al. 2006).

Results

Pre-1960s.— Fewer than 100 goats were reported taken statewide each year during much of the 1920s and 1930s (Klein 1953). Although native peoples hunted goats for hundreds of years (Sherwood 1974) and it is likely that early settlers and miners on the Kenai Peninsula hunted goats as well, Kenai specific harvest statistics before 1972 are unknown. Aerial counts were conducted in some areas in the 1950s (Klein 1953) but comprehensive surveys across the peninsula did not start until 1968.

The bag limit for hunting in the 1920s was 3 goats per year and was reduced to 2 goats per year from the 1930s through the 1960s. The seasons were typically August through December, no permit was required, and no restrictions on hunter distribution were in place. Unrestricted hunting caused the extirpation of some small populations that were likely unable to support even limited hunting pressure (Klein 1953).

1960s-1970s.— The yearly bag limit was reduced to 1 goat starting in 1971. The season extended from August through December until the late 1970s. The first effort to collect harvest data came in 1969 from volunteer questionnaires; however, the response was very low. Reporting hunt success became a requirement in 1972. Response in the first several years of required reporting was low, so the actual harvest in these early years was higher than reported (Fig. 2).

No permit was required to hunt Kenai goats before 1976; any licensed hunter could hunt in nearly any location. From 1976-1979, all hunters were required to obtain a registration permit, which allowed managers to assess hunting effort. However, there were no limits to the number of registration permits issued, and few restrictions were in place to control the distribution of hunters. During this period when many local goat populations were declining, managers learned that the hunting effort was very high; records are incomplete but in at least one year, over 1000 registration permits were issued for a population that numbered less than 2000 goats.

Certainly, winter severity, predation, and other limiting factors may have contributed to the population decline during this period. However, our retrospective analysis focuses on harvest rate because it is a factor managers can control and one that appears to have played a role in the population decline. When hunting pressure was first quantified in the early 1970s, the yearly harvest rates were well over 10%, occasionally reaching 15-40% in some areas. No native goat population has been found to sustain yearly harvest rates over 10% (Côté et al. 2001). The 25% population decline shown between 1968 and 1978 (Fig. 2) was likely the end of a long decline caused, at least in part, by years if not decades of overharvest. For example, unrestricted hunting in the early 1960s effectively extirpated the goat population on Cecil Rhode Mountain, an easily accessible area south of Cooper Landing. A reintroduction effort in 1983 was required to reestablish the population (Smith and Nichols 1984). Also, the highest nanny harvests recorded to date on the peninsula occurred from 1972-1975 (66-102 females taken each year).

1980s-early 1990s.— The population decline from 1968-1978 and the high hunting pressure documented during the registration hunts from 1976-1979 influenced managers to start a limited entry system in 1980. Also at this time, 31 discrete hunt units were established. A permit holder could only hunt in one of these predetermined units. This spread the hunting pressure across the landscape and decreased the chance of localized overharvest. The boundaries of the hunt areas established in 1980 are essentially the same ones currently used (Fig. 1). In the first 2 years of this limited entry system, only 185 drawing permits for the entire Kenai Peninsula were issued each year resulting in reduced yearly harvests (Fig. 2). This was a dramatic decrease in the allowable hunting pressure from the previous several years. The number of permits issued increased as goat populations rebounded.

The season for the drawing hunts varied in the 1980s but was typically August

10th through September or October. In 1982, late-season registration hunts were established. The registration season occurred after the drawing season, typically in October through November. Registration permits were issued in units ostensibly where the harvest during the drawing season was low and there was additional hunting opportunity available. Starting in 1989, in order to provide some protection to reproductive females, it became illegal to take a female accompanied by a kid.

We do not know exactly all the factors that may have influenced the population increase from 1980 to the early 1990s (Fig. 2). However, it is likely that the large increase in population size during this period resulted from the substantial reduction in the additive harvest mortality and by a density dependent response after unrestricted hunting reduced populations to low levels during the 1970s (Fig. 2). Although there has been little support for density dependent response to harvest in native populations (Smith 1988, Festa-Bianchet et al. 2003), there must be some density dependence at some point in growing populations (Hamel et al. 2006).

Early 1990s-2006.— When goat numbers were at their peak in the early 1990s, DelFrate and Spraker (1994) presented their paper at the Northern Wild Sheep and Goat Council symposium addressing the success of their management protocols. Steady declines throughout the 1990s were thought to be due to high winter mortality, a decline in habitat quality, poor recruitment, or competition with Dall sheep (Del Frate 1996, 1998, 2000, 2002). According to trend counts from aerial surveys, the goat population across the Kenai Peninsula declined >30% from the early 1990s to 2006 (Fig. 2). When using an index of the number of goats counted per hour, which corrects to some degree for variable survey effort, the decline during this period was 50%. There was also a significant long-term decline in kid to older-goat ratios (Fig. 3; $\beta = -0.29$, 95% CI: -0.19 to -0.39). Although there may have been landscape level changes influencing this decline, we cannot rule out that an overharvest of reproductive females contributed to the decline in the ratio of kids to older-goats and the overall population decline.

The drawing season from the early 1990s to 2000 was August 10-September 30 with a registration season from October 15-November 30. From 2001 to the present, the drawing season has been August 10-October 15 and the registration season has been the month of November. The number of drawing permits issued ranged between 350 and 450 permits per year and peaked in 1997. The number of registration permits issued exceeded the number of drawing permits issued in the early 1990s but have been greatly reduced in the past 5 years. In 2006, we initiated changes to the protocols of the harvest tracking strategy outlined in Del Frate and Spraker (1994).

Discussion

Management of mountain goats on the Kenai Peninsula has varied during the last 4 decades. Past harvest strategies may have played a role in influencing the large fluctuations in goat numbers. We outline new criteria used to manage goat hunting on the Kenai Peninsula in order to stem the current decline in goat numbers. The total number of goats counted in each unit during aerial surveys multiplied by the maximum allowable harvest rate gives a maximum allowable harvest, or quota. In order to keep the hunting mortality at or below the quota, we created specific criteria that provide guidance to managers for determining how many permits to issue for drawing and registration hunts (Figs. 4 and 5) along with a more conservative maximum allowable harvest rate. Factors that influence management decisions are discussed below.

Harvest rate.— Mountain goats have been established on the Kenai for centuries (Sherwood 1974) and, therefore, must be managed as a native population. Native populations of mountain goats are more sensitive to harvest than introduced populations (Festa-Bianchet and Côté 2008). Introduced populations of goats can sustain much higher harvest rates than native populations, especially during the initial increase phase when high food availability results in high fecundity and low natural mortality (Swenson 1985, Houston and Stevens 1988, Côté et al. 2001). While variable across areas and time since the introduction, introduced populations may sustain 7-16% harvest rates (Adams and Bailey 1982, Swenson 1985, Van Daele 2006; but see Côté et al. 2001) whereas small native populations may only sustain a harvest rate of ≤2% if the harvest targets males only (Gonzalez Voyer et al. 2003, Hamel et al. 2006). In native populations in Idaho and British Columbia, recruitment and productivity declined as harvest rates increased (Kuck 1977, Herbert 1978). Due to the difficult nature of goat hunting and the isolation of many units, the overall yearly harvest rate on the Kenai Peninsula has been under 5% for about a decade, but this is not the proper scale to measure harvest pressure. Each hunt unit (i.e., population) needs to be assessed individually. During the population decline of the 1990s (Figs. 2 and 3), the objective maximum harvest rate for mountain goats on the Kenai Peninsula was maintained at 7% (DelFrate and Spraker 1994; Del Frate 1996, 1998, 2000) and the actual harvest rate in some areas frequently exceeded 7%.

Currently, we determine the maximum allowable harvest rate for each individual hunt area (Fig. 1) each year based on 4-5% of the number of goats counted in each area during aerial surveys. A 4% maximum harvest rate is used for interior populations which are smaller and more vulnerable to density independent events (Hamel et al. 2006), whereas a 5% rate is used for the coastal zones where population sizes are typically greater (>100 goats), and weather and habitat conditions more favorable than inland areas (see *Coastal vs. inland populations* section below). A maximum harvest rate of 4-5% of the goats seen during a survey, (or 2-4% of the actual population size), is a conservative adjustment from the previous allowable harvest levels (Del Frate and Spraker 1994) and, coupled with the other criteria outlined below, should help keep hunting mortality within sustainable limits.

Age structure and female component of the harvest.— Sustainable harvest rates for small native populations are greatly influenced by the sex and age structure of the harvest (Gonzalez Voyer et al. 2003, Hamel et al. 2006). Specifically, the harvest of 1-2% of female goats of reproductive age (4-9 years old) can negatively impact small populations (Hamel et al. 2006). In order to give females added weight when assessing maximum harvest rates, a harvested female counts as two goat 'units.' For example, an area with 100 goats and an acceptable harvest rate of 4%, a maximum harvest level would be 4 males or 2 females. Kenai managers have used this system for over a decade. Despite this system, the yearly harvest rate of females often exceeded 3-4% in a hunt area. The establishment of a female quota for each population has been implemented in Alberta where exceeding the female quota one year may result in the complete closure of the area to all goat hunting the following year (Glasgow et al. 2003). New management protocols will access the sex and age structure of the harvest within each hunt area and may adopt similar measures if additional protections are needed.

Population size and trends.—The status of a population and what level of harvest can be allowed will be assessed by looking at historical survey trends within each hunt unit (Fig. 1). Populations that show a significant downward trend in goat numbers over the past 3 survey cycles (8-10 years) will have the maximum harvest rate reduced to 3% and a reduction in permits issued, or a closure of all hunting (Fig. 4). Because registration hunts are now managed more conservatively (see *Registration permits* section below), no registration permits will be issued in areas with declining populations (Fig. 5). In other words, management restrictions will not wait until a population is reduced to low levels before restrictions or closures are established. A population that is declining will be managed more conservatively than one that is stable or increasing.

Small populations.— In the 1990s, when limited entry was well established, hunts were often held in areas even when the goat population size was very low. Permits were issued in areas that had <20 goats, and many hunts took place in populations <50 goats (Del Frate and Spraker 1994). Small goat populations of <50 animals have a high probability of decline or extirpation even in the absence of harvest, and likely could not sustain a harvest greater than 1% of goats 2 years and older (Hamel et al. 2006). New management protocols will not issue any drawing permits in areas with <50 goats (Fig. 4) and no registration hunts will occur in areas with <100 goats (Fig. 5; see *Registration permits* section below).

Consecutive years of overharvest.— Throughout the period of population decline starting in the 1990s, if the harvest in a particular area exceeded the maximum harvest one year, harvest opportunities were often not restricted in subsequent years. This allowed for consecutive years of overharvest within the same population. New management protocols will restrict hunting opportunities if harvest limits were exceeded in the previous year, and additional restrictions if exceeded in consecutive years (Figs. 4 and 5).

Age of the survey data.— Management decisions are often made using aerial survey data that are several years old. A limited budget for goat management allows for only a portion of the range to be surveyed each year. High mortality and low recruitment due to severe winter conditions can reduce a population size in a local area so decisions on harvest levels need to be reduced when relying on survey data that is not current. Furthermore, the level of movement into and out of these units (Fig. 1) is unknown but does occur (Nichols 1985). Survey data that is >2 years old may not represent the current population. New management protocols will restrict hunting opportunities if the survey data is >2 years old especially when severe winters are believed to have occurred since the time of the last survey (Figs. 4 and 5).

Access variation and success rates.— The accessibility of goat habitat and success rates are quite variable on the Kenai Peninsula. Typically half of the permit holders hunt. Of those that hunt, success rates vary from 10-100% depending on access and other factors. Some areas are along highways that allow convenient access points or have trails that allow relatively quick access to alpine habitat. Other areas are very isolated and accessible only by airplane, boat, or very long hikes without trails. Although variable from year to year due to hunter diligence, weather, and other factors, the ease of access will greatly influence potential hunting success. New management protocols will use the degree of accessibility to determine the number of permits to issue for both drawing and registration hunts (Figs. 5 and 6).

Coastal vs. inland populations.— There are major differences in the goat habitat of coastal versus inland areas (Herbert and Turnbull 1977). Goat populations that inhabit these diverse habitats have major differences in sensitivity to harvest (Hjelford 1973) and should not be managed with a homogeneous protocol. Goat population declines on the Kenai since the early 1990s have been much sharper for inland populations (48%) versus coastal areas (21%). New management protocols discussed above have a lower maximum harvest rate for inland populations and added restrictions for small or declining populations. Highly productive coastal populations may be able to sustain higher densities and harvest than inland populations but are still be vulnerable to severe winters (Smith 1984).

Winter severity.— Mortality rates for mountain goats are influenced by density independent events, such as severe winters (Fox 1983, Smith 1984, Smith 1988); the variability in winter conditions should be considered in management decisions. The impacts of severe winters may vary substantially depending on the population's age structure (Coulson et al. 2000). Models of survival rates in Alaska were greatly improved when an index of winter severity was incorporated into the analysis (White et al. 2008). In other words, the degree of snow deposition can help managers categorize a severe winter that could impact goat survival. Although measures of icing events, which can reduce the availability of forage, are not available, historic and current databases of winter snow depths from locations in Alaska, and specifically throughout the Kenai Mountains, are maintained by the Natural Resource Conservation Service (www.ambcs.org). We constructed a winter severity index by averaging the snow deposition levels at several locations in the Kenai Mountain during late winter. New management protocols will use this index to restrict hunting if recent winter conditions may have compromised goat survival.

Registration permits.— Registration hunts are managed conservatively because they are held after the drawing season in units that may have often already had some level of harvest; therefore, the remaining harvestable quota is often small. Also, the late season registration hunts tend to have a higher proportion of females taken than during the earlier drawing season. This may be due to early snowfall pushing nanny groups to lower elevations during the November registration season making them more available to hunters, as well as inclement November weather influencing hunters to take the first animal they see.

In season management for a limited harvest is difficult unless limits are imposed on the number of permits issued. Registration permits have recently been valid for only 7 days after the date of issuance but there were still problems with hunt management. On the Kenai, the number of registration permits issued typically was unlimited and the hunt only closed by emergency order when the maximum harvest quota was met. Closures by emergency order typically took a day or more to enact and the closure declaration did not get to permit holders that were in the field or in route to the hunting grounds. Also, there is a requirement to report the success of a hunt within 5 days of a kill. The inherent lag-time associated with a 5-day reporting period and the potential of having many hunters in the field after an emergency closure was enacted, increased the chance for overharvest, especially when available harvest quotas were low. There were many examples of registration hunts where the maximum allowable harvest was

2 goats and over 100 permits were issued. New management protocols set clear criteria to be met before an area will open for a registration hunt, and, if met, the number of permits will be limited (Fig. 5).

Reducing female harvest.— Along with giving a harvested female added weight when calculating harvest quotas and the possibility of initiating a female quota outlined above, actually reducing the female portion of the harvest is a more proactive goal. Even a harvest of 1-2% of reproductive aged females in a population can have negative impacts (Hamel et al. 2006). Mountain goats are the only ungulate in Alaska to have no gender specific restrictions to harvests. Educational efforts to show hunters how to distinguish the gender of a goat and elucidation on why harvest efforts should focus on males have been available to Kenai goat hunters for decades. These efforts have resulted in no detectable decrease in the female proportion of the harvest for nearly 3 decades; the yearly female proportion of the harvest has ranged between 20-48% since 1980, averaging 34%.

We have a proposal that, along with continued and amplified educational efforts, might decrease the female harvest. Unlike many other states or provinces, goat hunting on the Kenai Peninsula is not a once in a lifetime opportunity. Over 97% of the hunters each year are Alaskan residents. Many Alaskan residents apply every year to win a drawing permit; the odds of winning depend on the area, the number of available permits, and the number of applicants but ranges between 2-25%. Furthermore, many hunters acquire a late-season registration permit in successive years. In other words, there typically is an opportunity for an individual to hunt mountain goats every year. Our proposal would encourage hunters to be more selective. Taking a female would remain legal, but the hunter would not be eligible to hunt mountain goats on the Kenai for 3-5 years. The hunter who took a female goat on the Kenai could hunt all other species and still hunt mountain goats outside of the Kenai Peninsula. We believe that this stipulation may cajole hunters to truly make an effort to educate themselves on how to distinguish the sexes and target only males. Hunters would be engaged in the sound management of their goat populations. If successful, reducing the female proportion of the harvest would increase hunting opportunities and could also promote population growth (Hamel et al. 2006).

Problems with timely decisions.— There are other time-related issues that present challenges to goat management on the Kenai Peninsula. Decisions for how many drawing permits to issue must be made in the fall for hunts that will occur the following year. Therefore, a severe winter could cause unusually high mortality after decisions of drawing permit allocations have already been made. This is yet another reason for conservative permit allocations. However, restrictions to registration hunts can be imposed in-season if the previous winter conditions call for conservative management.

A lack of timely hunt reporting also poses a management challenge. Specifically, decisions for late-season registration hunts (November 1-30) are made based on the success of the earlier drawing season (August 10 – October 15). However, many hunters fail to report their drawing hunts according to the required time limits; 10 days after a successful hunt or, if unsuccessful, by October 25. Typically, decisions for what areas to open for a registration hunt are made with only 60% of the reports submitted from the drawing hunts. A lack of timely reporting demonstrates additional need for conservative management of registration hunts.

Other factors.— There are many other factors that may influence goat populations on the Kenai Peninsula besides hunting. There has been growth in commercial heliski operations in large portions of the Kenai Mountains. These commercial operations are governed by the U.S. Forest Service on land within the Chugach National Forest. Many recommendations to mitigate impacts of helicopters on goats were presented to the U.S. Forest Service by local wildlife mangers. Concerns outlined were in response to known disturbance of goats by helicopters (Côté 1996, but see Goldstein et al. 2005) and recommendations were taken directly from those provided by the Northern Wild Sheep and Goat Council (www.nwsgc.org/StatementMountainGoats.pdf). Many of these recommendations aimed to reduce or limit negative impacts of heliski operations on wintering goat populations that were provided by local wildlife managers were rejected by the U.S. Forest Service and not incorporated into the permit conditions for heliskiing. It is unknown what level of impact heliski activities may be having on goat populations but the affects are not likely benign.

The Kenai Peninsula has shown significant effects of climate change through increasing elevation of treeline, wetland drying, and glacier retreat (Klein et al. 2005, VanLooy et al. 2006, Dial et al. 2007). Climate change may impact mountain ungulates by decreasing the time of forage availability (Pettorelli et al. 2007) and increasing the prevalence of disease (Jenkins et al. 2006, Mainguy et al. 2007). Despite the array of diseases endemic to some goat populations (Toweill et al. 2004), there has not been much disease monitoring on the Kenai Peninsula. We do not know how all the impacts of climate change might influence goat populations. However, an adaptive management plan, continued long-term monitoring, and future research must consider these potential landscape level changes.

In summary, the management issues outlined in this paper and the new protocols for issuing hunting permits (Figs. 4 and 5) will provide general guidelines to wildlife managers. There are often interactions among factors and unknown factors that make goat management challenging. If an area has multiple concerns, such as a high female harvest and a declining population, additional measures to monitor populations and restrict harvests will be taken. All the management issues outlined above will be assessed in each area (Fig. 1) individually, and management actions will be area specific.

Management Implications

The population dynamics and limiting factors for mountain goats varies across their broad range. Therefore, goat management must be herd specific (Gonzalez Voyer et al. 2003). The Kenai Peninsula certainly has unique characteristics that elicit conservative management protocols, most notably, the significant decline in goat numbers in the last 15 years. In response to this decline, the management protocols have changed to ensure hunting opportunities are sustainable. Managers need to respond to both long-term and short-term management issues (Smith 1984). Specifically, along with responding to long-term declines, managers need to close or limit hunting following years when an excessive number of females are harvested (Côté and Festa-Bianchet 2003). In this respect, hunters can help goat management and increase hunting opportunities by targeting males only. The management protocols outlined in this paper will be reviewed incrementally to assess success and allow for adaptive management changes based on the response of the goat populations. The management of Kenai goats could improve with increased budgets to survey populations more frequently and to conduct research to determine Kenai specific vital rates and limiting factors.

Acknowledgments

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Figure 1. Kenai Peninsula in south-central, Alaska, USA, showing 31 individual management units. Kenai Fjords National Park, where no hunting is allowed is hatched.

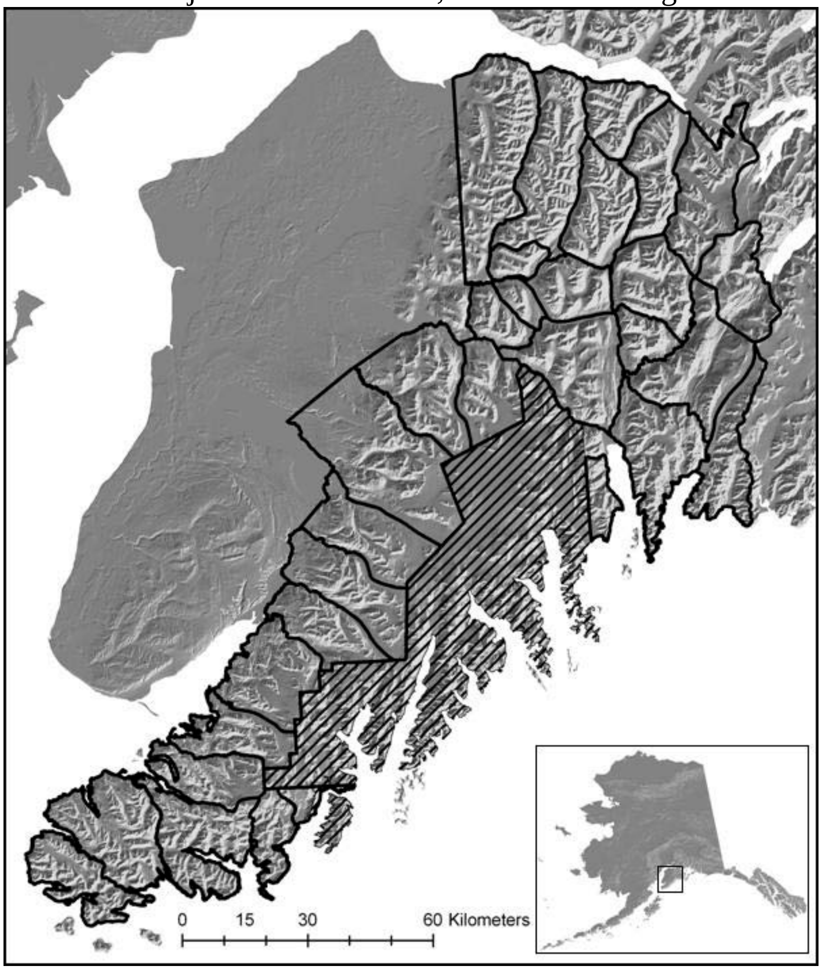


Figure 2. Mountain goat survey and harvest data from the Kenai Peninsula, Alaska, USA, 1968-2007. The yearly total of goats counted combines the most recent counts in 31 areas. Harvests occurred under varying management schemes.

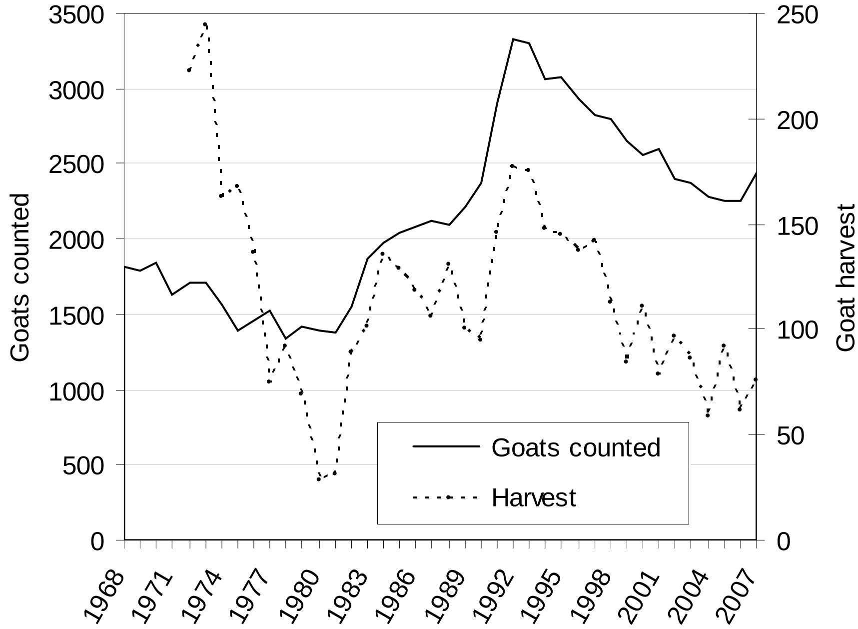


Figure 3. Regression of survey data showing decline in the ratio of kids: older-goats from the Kenai Peninsula, Alaska, USA, 1968-2007. Survey data is from 15 individual core areas. Surveys were conducted in each area once every 3-4 years.

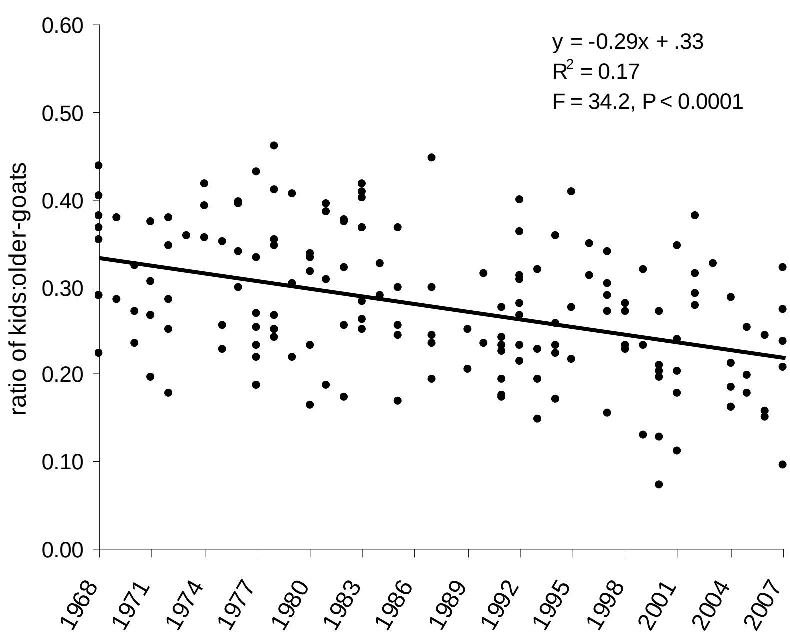


Figure 4. Flow chart for providing general guidelines for determining the number of drawing permits to issue for individual mountain goat hunts on the Kenai Peninsula, Alaska, USA. (Typically, less than half of the permit holders hunt).

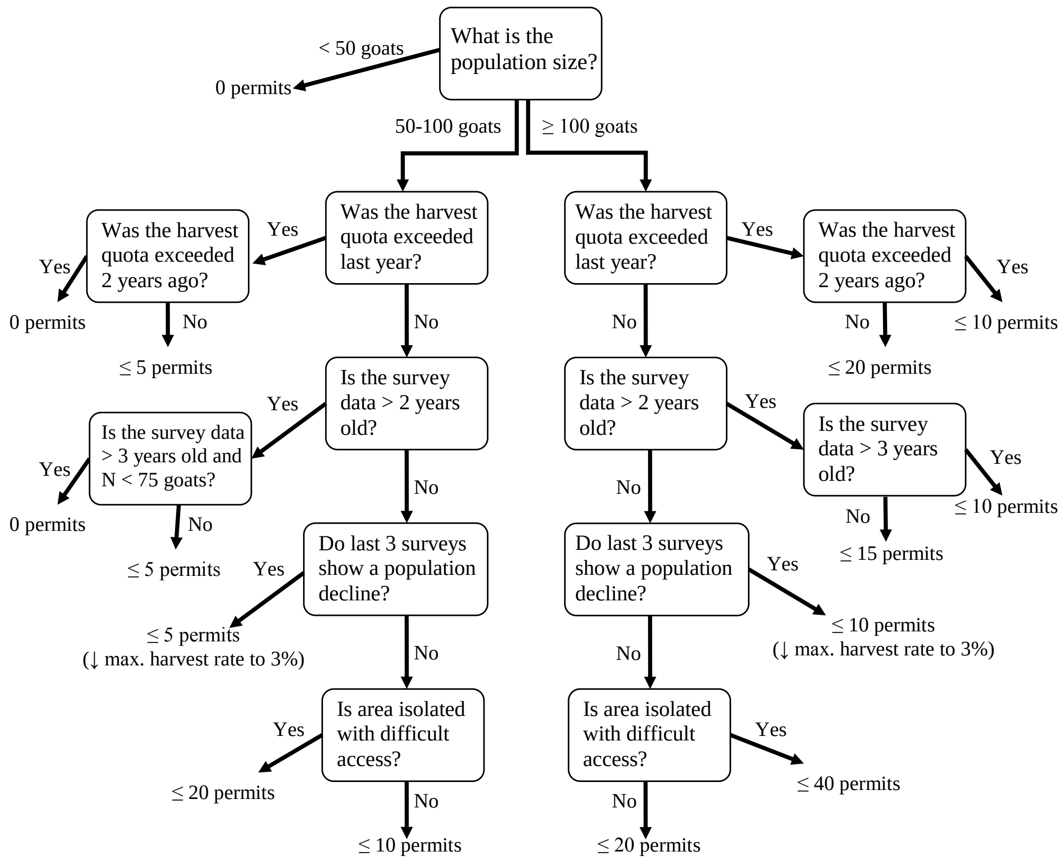
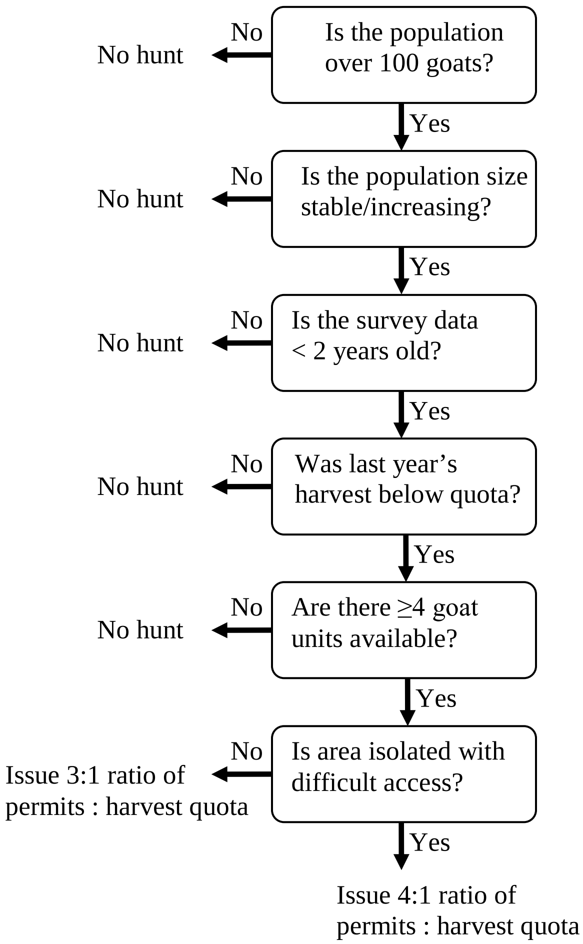


Figure 5. Flow chart of criteria that must be met for an area to open for a late-season registration hunt for mountain goats on the Kenai Peninsula, Alaska, USA. The survey count multiplied by a 4-5% harvest rate provides the harvest quota. A harvested male counts as one goat unit, a female is 2 units.



A Ground-Based Paintball Mark Re-Sight Survey of Mountain Goats

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Abstract: Mountain goats (*Oreamnos americanus*) were first transplanted to the Lone Peak area of northern Utah by the Utah Division of Wildlife Resources in 1967. The transplant was successful and mountain goats were subsequently moved to several sites around the state. They were transplanted to the Willard Peak area in 1994 with a supplemental transplant in 2000. Since its establishment, this herd has exhibited impressive growth. It is now one of the largest herds in Utah, and its growth and possible effects on the habitat have been a cause of both interest and concern. This study was conducted in the Willard Peak – Ben Lomond area of Box Elder and Weber counties in northern Utah. Mountain goats were marked using recreational paintball equipment and paintballs specifically intended for marking animals. We conducted 12 re-sight surveys between July 11 and August 31, 2007. Estimates of abundance were calculated using the Chapman-modified Lincoln-Petersen population estimate model. We concluded that marking from the ground can be both effective and feasible. However, conducting re-sight surveys from the ground can pose several challenges when trying to formulate accurate population estimates.

Key Words: Lincoln-Petersen population estimation, mountain goats, paintballs, Utah.

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One of the major challenges faced by wildlife biologists is the accurate estimation of population size. Population estimates are often used when creating population models and determining harvest recommendations. We wanted to explore the feasibility, utility, and accuracy of a method of population estimation known as a mark re-sight survey. In this particular case, we utilized recreational paintball equipment.

This method may seem unconventional, but it is increasingly being implemented by researchers as well as wildlife and natural resource management agencies to estimate species abundance (e.g., Cichowski et al. 1994; Pauley and Crenshaw 2006). Several studies involving mountain goats, including those from these aforementioned references, have evaluated the effectiveness of aerially marking and surveying. Yet efforts to determine the utility and accuracy of ground-based marking and surveying are lacking. During an extensive literature review of mark re-sight surveys using paintball guns, we could not find any examples of ground-based surveys that employed this method. In addition to exploring this method's feasibility and accuracy, we also wanted to determine the areas of mountain goat use and concentration in the study area, investigate whether they were intermingling and moving throughout the entire area, and gain a better overall understanding of the herd.

Recreational paintball equipment has been used to mark mountain goats to estimate population sizes (Cichowski et al. 1994; Pauley and Crenshaw 2006). Based on their aerial use of this technique, Pauley and Crenshaw (2006: 1354) concluded that the paintball mark re-sight method was effective in estimating abundance stating, “The paintball mark–resight approach provides significantly less biased abundance estimates than simple enumerations from aerial surveys.”

Cichowski et al. (1994) also conducted an aerial mark re-sight study utilizing paintball guns to estimate mountain goat abundance. They too felt that this method could be used for determining population estimates of other mountain goat populations. They concluded that their mark re-sight survey was cost effective and satisfied the assumptions associated with mark re-sight estimates. The assumptions for using this approach are:

1. All individuals have the same re-sighting likelihood

2. The population is closed: no emigration or immigration (static population size)

3. Individuals do not lose their markings during the course of the experiment.

Study Area

Mountain goats were first transplanted to the Lone Peak area of Utah by the Utah Department of Fish and Game (now the Utah Division of Wildlife Resources (DWR)) in 1967. The transplant was successful and individuals were then transplanted to several sites around the state, including Willard Peak. The Willard and Ben Lomond peaks herd was chosen for study because it is likely the most accessible in the state, making it ideal for observation. The herd is also well suited for study because most of its goats spend the majority of their time along the Skyline Trail in the summer (personal observations) (see Figure 1); this is the main path in the study area.

Willard Peak (coordinates: 41°22'59"N, 111°58'29"W) and Ben Lomond Peak (coordinates: 41°24′21″N, 111°57′36″W) are located on the Wasatch Range in northern Utah between Brigham City and Ogden (Figure 2). Their elevations are 2,976 meters and 2,960 meters respectively. In recent years, it has been common to see at least 70 goats concentrated just below the summit of Willard Peak in the early summer.

This area has apparently been ideal for the mountain goats. Since the herd was established in 1994, the region has experienced relatively mild winters. There are few predators, adequate escape terrain, and an ample forage base unexploited by other ungulates. This herd’s abundance has been estimated by the DWR primarily through the use of aerial surveys and subsequent population models that have been formulated.

The herd began with a transplant of six goats by the DWR in 1994. It received a supplemental transplant of four individuals in 2000, and increased to around 180 individuals by the fall of 2006 (DWR personal communication). One hunter-choice tag was issued for this herd from 2000 through 2004. Because of the herd’s rapid growth and increasing concerns about possible habitat degradation, the number of permits increased to three in 2005, and again to 25 in 2006 with 5 hunter-choice tags and 20 nanny tags being issued. Twenty-five permits were again issued in 2007.

In its management plan for this herd (State of Utah 2006) the DWR has identified 27 square miles of suitable mountain goat habitat between the North Ogden Divide and Willard Canyon. According to their management plan, the DWR has adopted the U.S. Forest Service's recommendation of 6 goats per square mile (which is the recommended density for southeastern Alaska). This density objective yields a population of approximately 160 mountain goats for the Willard Peak area. According to the Willard Peak management plan, if future monitoring shows that goats are using more area than was identified, or are not having detrimental effects on habitat, the objective could be raised (State of Utah 2006).

Methods

Two paintball guns were used to mark mountain goats numerous times with brightly colored, biodegradable, oil-based paintballs. We used 'Animal Mark' paintballs manufactured by Nelson Paint Company (Kingsford, MI). These particular paintballs are specifically intended for marking animals; ranchers and farmers use them on livestock. Their paint is thicker and tends to last longer than that of recreational paintballs. To recognize specific individuals, we used four different colors of paintballs in our marking: red, orange, green, and blue.

We used two Tippmann A-5 paintball guns (Buffalo Grove, IL) during the marking process. Each gun was modified for fully automatic firing and was equipped with an Apex barrel (Fort Wayne, IN) for increased shooting distance and accuracy. During pre-marking testing, the paintball guns were judged to be accurate to within about 30 yards. At the outset of this study, we were unsure if it would be possible to get close enough to mark the goats. We were also not sure how the goats would react immediately after being marked.

Compared with other various methods of investigation, this one appears to be relatively non-invasive; it seemed to cause minimal physical stress on individuals. The marking process did not appear to alter the animal's long-term behavior nor its overall health. It is conceivable that a goat's blood pressure, stress level, and heart rate may have increased immediately after being marked. Some bruising may have occurred. The animals that were marked were not unnecessarily pursued; individuals were quickly marked and left alone.

Based on discussions with DWR biologists, we determined that at least 20 goats needed to be marked to have an adequate sample size. This assumption was based on the 2006 DWR population estimate of 180 goats. We assumed that if we were able to get close enough to mark that many goats, that it would be an extremely time consuming process.

On June 29, 2007 the first attempt to mark goats was made around 5:00 AM. Christopher and Richard Schulze arrived at Inspiration Point near the summit of Willard Peak. As many as 6 or 8 goats could have been marked during this session but because of gun malfunctions, only 3 were successfully marked. Red paintballs were used. Marking stopped at around 10:00 AM because of the equipment failures.

On July 6, 2007 the second attempt to mark goats occurred. Darren Debloois (DWR District Biologist), Dax Mangus (DWR Biologist), Jim Christensen (DWR Technician), Christopher Schulze, and Richard Schulze arrived at Inspiration Point at around 5:00 AM and marked 14 goats below the summit of Willard Peak (see Figures 3 and 4). Red, orange, blue, and green paintballs were used; some of the goats were marked with multiple colors. Marking finished at around 11:00 AM.

The third and final attempt to mark goats was made by Christopher and Richard Schulze on July 7, 2007. We arrived at Inspiration Point around 5:00 AM. Heavy motorcycle traffic on Skyline Trail distracted the goats, making marking more difficult this day. Seven more goats were marked though, bringing the final number of marked individuals to 24. Marking was again completed by 11:00 AM.

We also observed two adult goats with radio collars and green ear tags from the supplemental transplant in 2000; these were counted as marked individuals. This brings the total number of marked goats used to derive our population estimate to 26. Fifty-two total person-hours (6.5 person-days) were spent attempting to mark goats, which was considerably less than what was originally anticipated.

The personnel involved in the marking process were able to get surprisingly close to the goats (4.5-27.5 meters). Because of the rugged and heavily vegetated terrain, those involved in marking the goats were frequently able to get within 27.5 meters; an adequate distance to successfully mark. This type of broken terrain made it possible to more easily stalk the goats. Because mountain goat kids are born between late May and early June, we determined that the kids were too young to include at the time of marking. Yearlings and adults of both sexes were marked. From July 11 through August 31, twelve re-sight surveys were conducted.

We used a Lincoln-Petersen population estimate model with the Chapman bias modifier to estimate the total number of goats in the population (e.g., see discussion about these techniques in White et al. 1982). The Chapman modifier corrects for low sample size (i.e., low re-sighting probability). The equation for the Lincoln-Petersen model is illustrated by the following formula:

$$\check{N} = \left[\frac{(n_1+1)(n_2+1)}{(m+1)}\right] - 1$$

Where:
$\check{N}$= total number of goats
n_1= number of marked animals present at time of survey
n_2= total number of animals (marked and unmarked)
m= number of marked animals observed during re-sight.

Results

Prior to formulating our population estimates, we concluded, based on our own knowledge of the herd, our field surveys from 2007, and the 2006 DWR population estimate of 180, that a population estimate greater than 300 was not realistic. The DWR's population growth models support this assumption and illustrate that even under the most optimistic conditions, the population could not be above 300.

Of our 12 surveys, 6 yielded population estimates between 180 and 300. If we eliminate the 6 population estimates that lie above 300, we arrive at a mean population estimate of approximately 249 goats for the six remaining surveys (Table 1).

In September 2007, DWR biologists conducted an aerial survey of the herd in which 181 goats were counted. The DWR estimates an 80% *sight ability* during its aerial surveying of mountain goats, yielding a population estimate of around 217 (DWR, personal communication). Based on the aerial survey, DWR biologists estimate that the 2007 population was between 200 and 225 individuals, making our re-sight survey population estimate of 249 goats 10-20% higher than the agency's.

There appear to be two main explanations for this difference. The simplest one is the fact that two different methods are being utilized to estimate population size. The second possible reason for a difference in the estimates is the likelihood that certain assumptions pertaining to mark re-sight analysis were violated during our surveys. The most obvious assumption which was violated is that all marked individuals had an equal chance of being re-sighted. We quickly concluded after our marking period that not all individuals had an equal chance of being re-sighted. We also determined that certain paint colors worked better than others for re-sighting. Further, some goats were marked more thoroughly than others; several were marked with too few paintballs and/or were marked on an area of the body that was difficult to view at certain times.

In addition, several of our surveys were conducted during or after rainstorms. These surveys produced what were concluded to be unrealistic population estimates (≥ 300 individuals). During these surveys, goats were often covered with dirt or mud, making the viewing of markings difficult.

During our surveys, it was difficult at times to distinguish the green and blue paint markings from shadows or soiled areas on the goats. This makes it likely that we missed some markings during our surveys. Orange and red paint appeared to be the most visible. We also were concerned about the longevity of the paint used. Last, those goats that were marked numerous times in the head and neck areas were consistently the easiest to re-sight.

The majority of the goats that were marked were on the west-facing slope just below the summit of Willard Peak. During our subsequent surveying, however, we observed marked goats throughout the entire study area. Therefore, we determined that goats were moving throughout the entire study area, exhibiting relatively little site fidelity. We observed that the goats utilize the entire study area with concentrations immediately west of Willard and Ben Lomond Peaks.

Discussion

We concluded that a ground-based mark re-sight survey utilizing paintball guns is feasible, cost-effective, and has the potential to produce reliable population estimates. Marks were probably missed at times, especially during surveys conducted in immediately after inclement weather. Despite this concern, we feel that with some modification and refinement, that this method can be reliable.

Ground-based surveying posed several challenges that may not occur if the surveying was done aerially. For example, goats were often observed to all be facing the same direction and it was not possible to gain a 360° view of every goat for possible markings. Also, at times some goats were simply too remote for us to distinguish any markings. It would not have been feasible to hike to every goat and obtain a 360° view of each one.

During this project, we gained a better overall understanding of this population. Many hours were spent in the field observing this herd. For example, over the years there has been some question as to the availability of water in the area. In previous years of surveying, goats were not observed to be utilizing any of the available water sources. However, during this project, we “discovered” a spring which goats were utilizing. Also, on one occasion we observed a goat being harassed and pursued by a golden eagle (*Aquila chrysaetos*). Such observations led to an increased understanding of this herd.

Management Implications

With some modification and refinement in methodology and surveying techniques we feel that this method could be an accurate tool for wildlife investigators. There are, however, several issues that should be considered concerning the accuracy associated with re-sighting. For example, several goats were marked with only one paintball or were marked with blue or green paint which proved to be extremely difficult to notice. Further, some goats were marked in almost unnoticeable locations on the body, which further complicated the likelihood of re-sighting.

For those contemplating marking mountain goats from the ground, we offer the following recommendations: the goats should be marked only with brightly colored red or orange paint. They should be marked as many times as possible; preferably towards the head, neck, and chest portions of the animal. Multiple re-sight surveys should be conducted within one week of their final marking to ensure a minimal amount of paint loss. A subsequent aerial re-sight survey should be done as soon as possible to gain more thorough survey coverage.

This type of mark re-sight surveying may be promising for concentrated and easily accessible mountain goat populations in which surveying the entire herd from the ground is feasible. This procedure could be utilized in instances where mountain goat populations are relatively dense, time and budgets are limited, and the population size is unclear and a more precise estimate is desired.

This type of project also can provide good public relations for wildlife management agencies. Our study area receives a significant amount of use from hikers, mountain goat and other wildlife enthusiasts, campers, and ATV riders. Our project appeared to be well received by the public. People were excited and pleased to see DWR personnel actively conducting research in the field. Many expressed an interest and offered to help were the project to continue next year.

Because of its extremely low cost (our entire project was conducted for under $1,200), relative non-invasiveness, and promising potential, we urge and recommend that wildlife managers and researchers explore and refine this method to capitalize on its potential as an effective tool in population estimation.

Acknowledgments

Richard Schulze has been instrumental in the establishment, subsequent management, and observation of this herd. Since its establishment in 1994, he has spent a significant amount of time monitoring this population. D. Debloois, J. Dolling, and R. Wood of the DWR, Drs. C. Hoagstrom and J. Cavitt of Weber State University (WSU), Dr. M. Wolfe of Utah State University, and Dr. L. S. Mills of the University of Montana offered vital insights regarding methodology and analysis of data. Dr. B. Trask (WSU) and the WSU Animal Care and Use Committee offered important advice. Dr. R. Chatelain (WSU) and J. Rensel (DWR, retired) provided pictures of marked goats that were used for this project. The project was funded by a grant through the WSU Office of Undergraduate Research.

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Table 1. Mark re-sight results from the Willard Peak study area in Utah, USA.

Date	NO	NM	Ň	95% Confidence Intervals
11-Jul	87	13	240	160-320
12-Jul	111	14	298	204-391
14-Jul	59	7	303*	143-462
20-Jul	109	7	519*	241-797
27-Jul	92	5	553*	199-906
31-Jul	49	13	180	121-239
3-Aug	61	2	764*	68-1460
10-Aug	46	6	308*	131-484
17-Aug	97	7	465*	216-713
22-Aug	56	6	296	127-465
24-Aug	71	9	291	160-421
31-Aug	24	4	193	63-324

Mean population estimate: 249

Where:

NO= Number of adults and yearlings observed

NM= Number of marked goats observed

Ň= Estimated population using Chapman-modified Lincoln-Petersen model

*Population estimates that were determined to be unrealistic

Figure 1. Willard Peak mountain goats below the summit of Willard Peak near the Skyline Trail

Figure 2. Willard Peak mountain goat study area

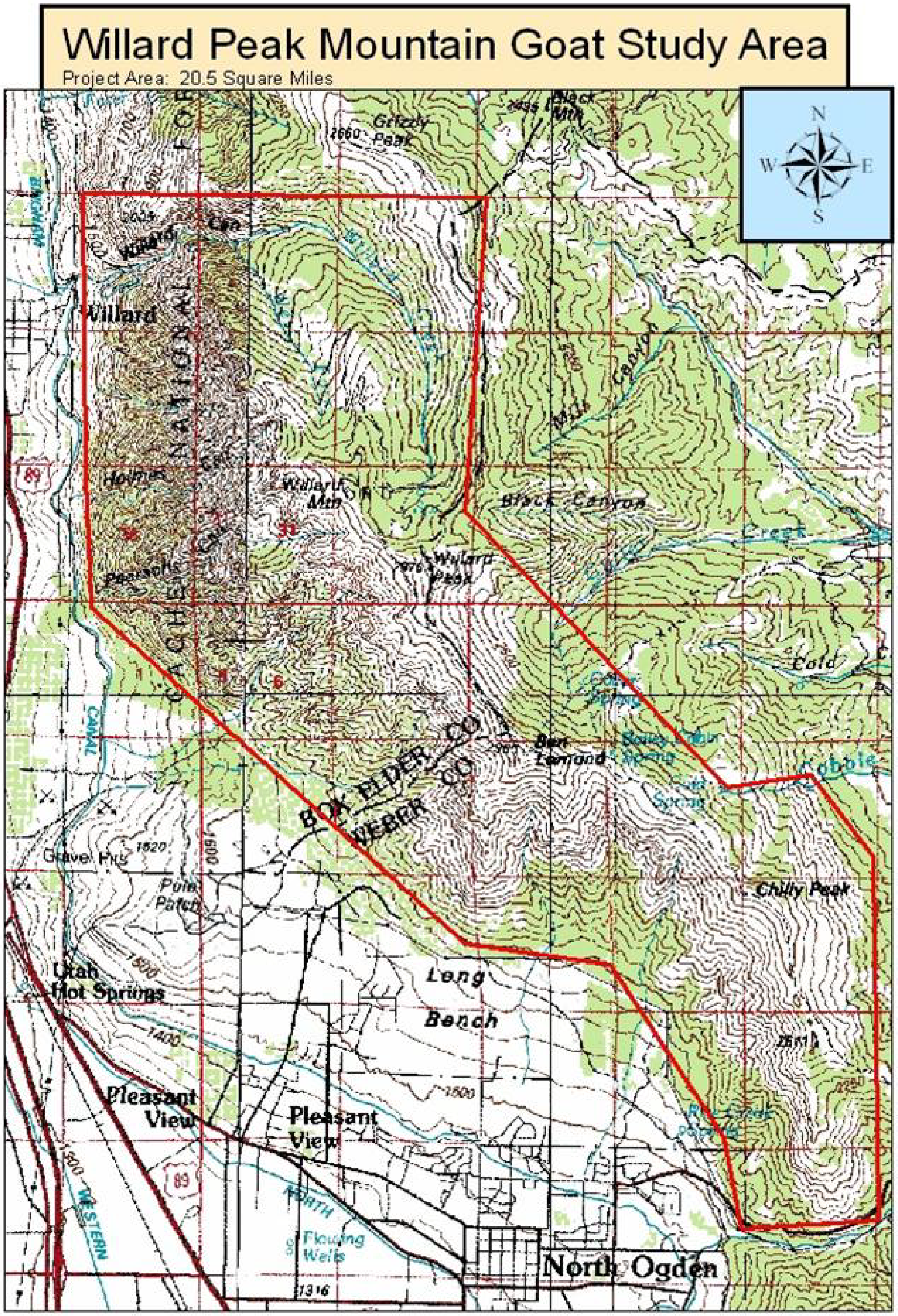

Figure 3. DWR biologists aiding in the marking process

Figure 4. Marked mountain goat at Willard Peak, Utah, USA

Survival of Mountain Goats in Coastal Alaska: Synthesis and Applications

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Abstract: Estimating survival is critical for modeling population dynamics and, ultimately, conservation of free-ranging wildlife species. Mountain goats are among the least studied large mammals in North America and, with few key exceptions, knowledge about patterns of survival is limited. In this study, we use data collected from 264 radio-collared mountain goats (116 males, 148 females) in 8 separate study areas over a 30-year period to characterize patterns of mountain goats survival in coastal Alaska. Specifically, we use Kaplan-Meier survival analysis to derive generalized estimates of sex- and age-specific survival for mountain goats. In addition, we assess how regional geography and variation in winter severity influence mountain goat survival. We further describe seasonal patterns and causes of mortality. Our findings are discussed in the context of life-history theory and, in addition, we explore how these data can be used in conservation and management applications.

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Investigating Genetic Diversity of Oreamnos americanus by Microsatellite Markers

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Abstract: For isolated species populations there is an inherent risk of small gene pools because of inbreeding. The genetic variability and configuration of Oreamnos americanus, populations were investigated using microsatellite markers. Both native and transplanted herds were examined for genetic variations at five microsatellite loci. Samples were collected by non-invasive gathering of scat and from donated tissue samples. The samples came from the Bitterroot, Beartooth, Absaroka, and Crazy Mountain ranges of Montana. The genetic variability based on number of alleles present in the sample population revealed low genetic variation for the loci used to date. Further examination of genetic diversity and statistical analysis using Popgene will help determine the existence of a genetic bottleneck. The finality of these results requires further assessment of sample population, and the studied loci. This study will make evident the need for management to maintain and diversify goat populations.

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Introduction

Oreamnos americanus, the Rocky Mountain goat, has inhabited the Rocky Mountains in Montana since the recession of the last ice age. As the result of environmental changes and human interaction, the natural goat habitats have been receding, restricting herds to smaller seasonal ranges. In a managerial effort, in the early 1940s, the Montana State Fish and Game Department began transplanting mature goat pairs from existing herds to stock ranges that had previously been uninhabited. In 1947, the estimated number of goats to inhabit two areas of study was 95 in the Crazy Mountains and 24 in the Beartooth Mountains. Populations in the Beartooth, Crazy, Gallatin, and Highwood have been isolated by geography from native goat herds because of both natural geology and by traditional goat ranges for almost fifty years. This separation of the transplanted herds makes genetic drift and low genetic diversity a possibility.

In 2005, a group of students began to study if it was plausible to determine the genetic diversity of Rocky Mountain goats by isolating DNA from scat. Taking the study a step further, the current aim is to examine the genetic diversity of a native goat herd as compared to goat herds that were transplanted in the 1940s. Using scat and donated tissue samples from the study areas, DNA has been isolated, amplified and studied using microsatellite markers. Gene lengths were examined at five loci utilizing electrophoresis.

Materials and Methods

Sample collection. The majority of sampling of Rocky Mountain goats was completed using scat samples obtained non invasively in the Bitterroot and Beartooth Mountain Ranges. Tissue samples were acquired from the Bitterroot, Beartooth, and Absorka Mountain Ranges through Fish Wildlife and Parks, and private donors. The location of where samples were collected

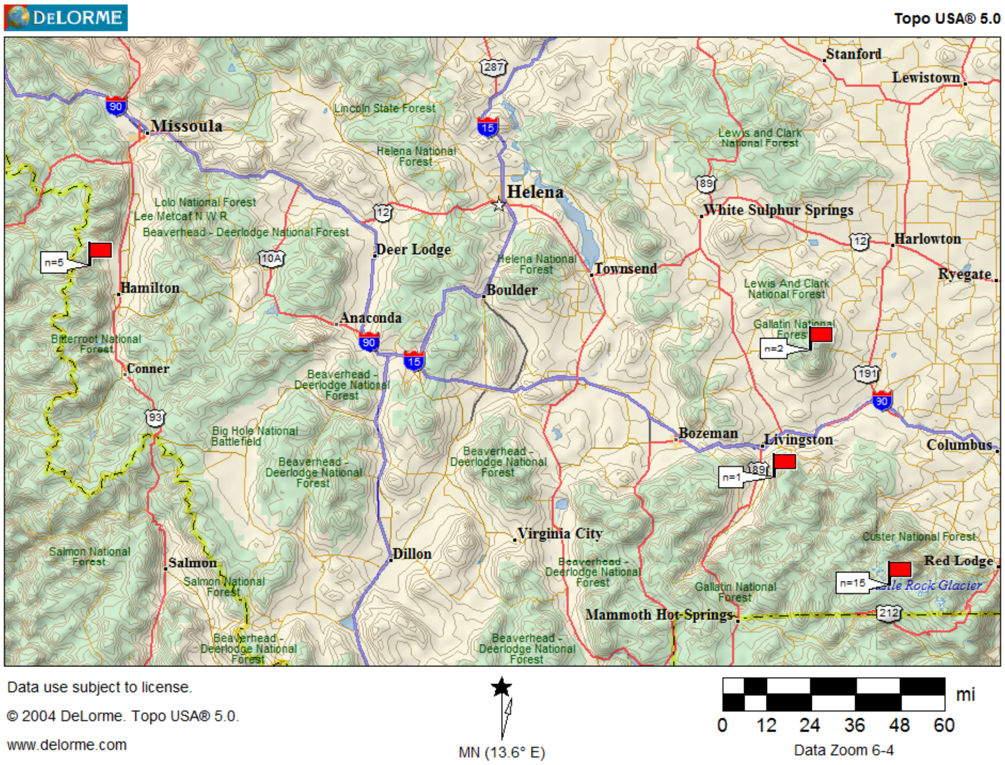

Figure 1: Location and number of samples per site used in the study.

are cataloged with GPS coordinates, date the sample was obtained, and the age of the goat if this information is known.

Molecular techniques. Genomic DNA was isolated using the procedure defined by the Qiagen Stool Sample and Qiagen DNeasy Tissue kits. To isolate DNA from scat required that a sample weighing 180-220 mg be prepared for the rest of the protocol. To obtain the most yield of DNA in each sample, four different methods were developed to isolate the epithelial cells from scat samples. (See figure 2). The selected method found that scraping the exterior of the goat pellet yielded the most positive samples of DNA. The weighed sample was then ready to have 1.6 ml Buffer ASL which is then homogenized with the sample. This buffer commences the refining of epithelial cells from plant and other inhibitors present in scat. The sample is centrifuged for one minute to pellet stool particles, 1.4 ml of the supernatant is pipetted into a 2 ml where one InhibitEX tablet is added. The solution is vortexed then incubated at room temperature to allow inhibitor to be absorbed by the Inhibit EX matrix, this solution is then centrifuged again for three minutes to collect inhibitors in a pellet form. The supernatant is then pipetted into a 1.5 ml microcentrifuge tube to be centrifuged again. 25 µl of Proteinase K is applied by pipette to a 2 ml microcentrifuge tube where 600 µl of supernatant is added. The tubes are then incubated at 70°C for ten minutes. When it is removed from the incubation

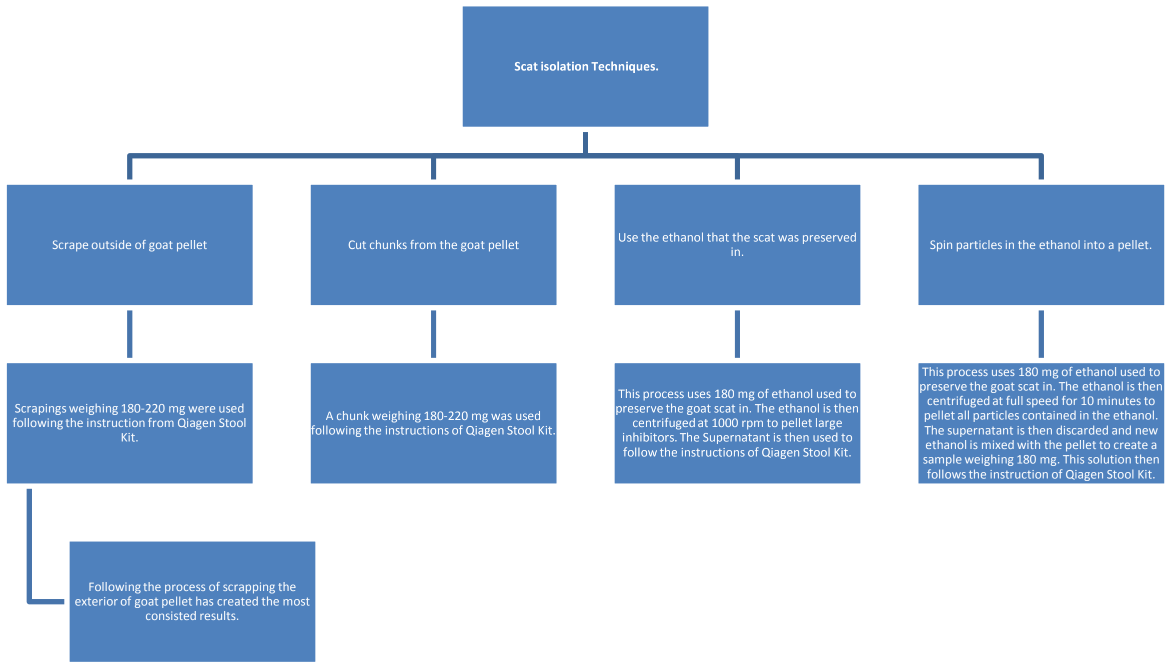

Figure 2: This chart depicts the different processes that were studied to determine the most effective procedure for isolating DNA from scat.

device, 600 µl of ethanol (96%-100%) is added and mixed with the lysate. 600 µl of this mixture is then pipetted into a QIAamp spin column with 2 ml collection tube. This collection is then centrifuged at full speed for one minute. The spin column is placed in a new 2 ml collection tube where 500 µl of Buffer AW1 is added, then centrifuged at full speed for a minute again. This step is repeated with Buffer AW2, centrifuging for 3 minutes. The final step to isolate the DNA is to transfer the QIAamp spin column to a 1.5 ml microcentrifuge tube where 300 µl of Buffer AE is applied directly to the spin column membrane. To elute DNA the column and tube are centrifuged at full speed for one minute. Isolating DNA using Qiagen DNeasy Tissue Kit follows similar steps of purifying DNA from the make up of cells. Using a 25 mg. portion of a goat sample the process begins by adding180 ml Buffer ATL to the sample. Before being place in a water bath at 55°C, 20 µl of Protenaise K is added. This mixture remains in the water bath for 2-3 three hours to allow for cell structures to begin breaking down. After the bath, the sample is mixed before 200 µl Buffer AL is added and then mixed again. The sample is again placed in the water bath, which is 70°C, and allowed to sit for ten minutes. When removed, 200 µl of ethanol (96%-

Locus	Primer Sequence	Ta°C	Allele Length Range	# of Alleles	
				Oreamnos americanus	Cervus canadensis
BM1818	F: 5'-AGCTGGGAATATAACCAAAGG-3'	50°C	250-280 bp	2	3
	R:5'-AGTGCTTCAAGGCCATGC-3'				
ILSTS005	F: 5'-GTTTCTTTGTTCTGTGAGTTTGTAAGC-3'	50°C	185-220 bp	1	5
	R: 5'-GGAAGCAATTGAAATCTATAGCC-3'				
TGLA122	F: 5'-CCCTCCTCCAGGTAAATCAGC-3'	50°C	130-256 bp	1	3
	R: 5'-AATCACATGGCAAATAAGTACATAC-3'				
BM4513	F: 5'-GCGCAAGTTTCCTCATGC-3'	50°C	140-160 bp	1	
	R: 5'-TCAGCAATTCAGTACATCACC-3'				
BM4208	F: 5'-TCAGTACACTGGCCACCATG-3'	50°C	150-175 bp	1	
	R: 5'-CACTGCATGCTTTTCCAAAC-3'				

Figure 3: This table expresses the number of alleles that have been observed in the study.

100%) is added and mixed together. This solution is then pipetted into a QIAamp spin column contained in a 2 ml collection tube to be centrifuged at 8000 rpm for one minute. When the spin column is placed in a new collection tube, 500 µl of Buffer AW1 is added. Again the spin column is centrifuged at 8000 rpm for one minute. After the spin column is secured in a new collection tube, 500 µl of Buffer AW2 is added before being centrifuged at full speed for three minutes. The final step to isolate DNA is to place the spin column into a 1.5 ml microcetrifuge tube and pipette 200 µl of Buffer AE onto the QIAamp spin column membrane. The tube and column should incubate at room temperature for 1 minute before being centrifuged at 8000 rpm for one minute to elute.

Polymerase Chain Reaction was then carried out for gene amplification and duplication. Five primers were utilized for comparison. These primers were BM1818, BM4513, BM4208, ISTLS005, and TGlA122. For all five primers the annealing temperature was 50°C. The PCR program had an initial denature cycle of 92°C for 1 minute followed by 40 cycles of 94°C for 30 seconds, 50°C for 20 seconds, and 72°C for 10 seconds. These cycles were followed by one cycle at 72°C for 10 minutes. 25 µl reactions volumes were used which contained 18 µl of purified water, 2 µl of a primer mix composed of forward and reverse primers, and 5 µl of the DNA template. The reaction tubes that were used were then run on a BioRad Gene Cycler.

Using the PCR reactions, allele length can be observed through the process of electrophoresis. Using an Invitrogen E-Gel and E-Gel 2% with SYBR Safe Starter Pak gels, the results was seen after 30 second pre-run and a 15 minute run time. Using a BioRad ultra violet light and a photographic filter, the results were recorded by observation and with camera.

Statistical analysis. Data that was attained was observed using five microsatellite loci to observe the heterozygosity and allele frequency of the representative goats. Bottleneck hypothesis will be used once 20-30 individual samples per population are available. With the bottleneck, the mutation-drift will be observed based on heterozygosity excess of

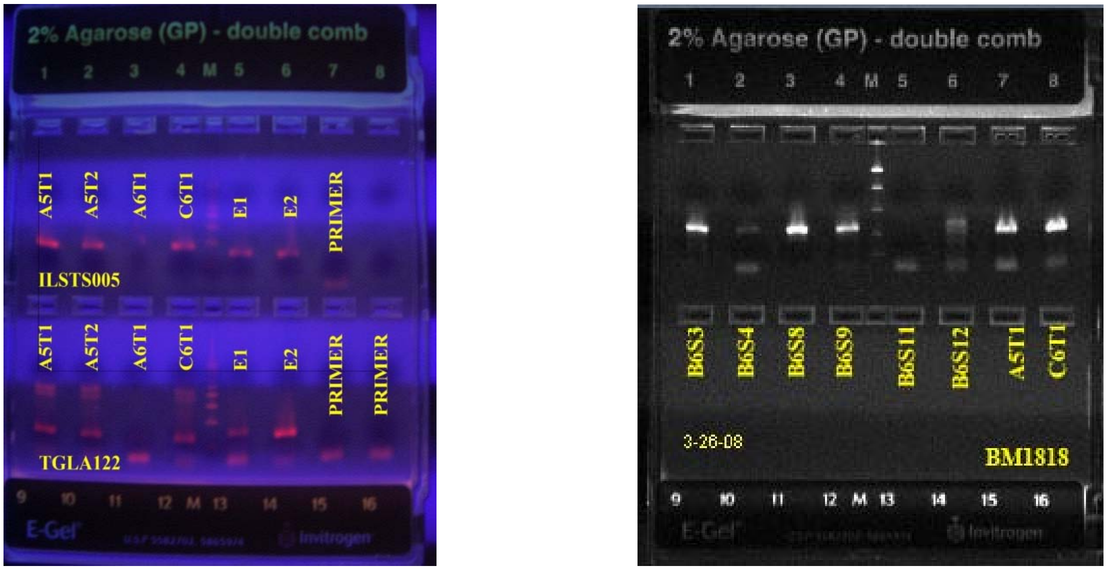

Figure 4: Two gel runs to reveal the genetic diversity of Montana mountain goats.

deficiency.

Results

The results to date using five microsatellite makers have revealed low allelic frequencies. Four of the five primers: BM4513, BM4508, ILSTS005, and TGLA122, rendered only one allele per samples tested. For BM1818 two alleles were present, one at 200-220 bp and another at 220-240 bp. To view all allele range data refer to Figure 3 for more information. The amount of samples observed with electrophoresis was fourteen, five from the Bitterroot Mountains, eight from the Beartooth Mountains, and one from the Absaroka Mountains.

Analysis

The results showed that current number of samples tested have low genetic diversity, but do not specifically indicate a low genetic diversity for the goat population as a whole. The genes present using the current microsatellite markers all run to similar lengths for the entirety of animals that have been tested. To make the results of this study more conclusive, the number of goats tested needs to be increased to twenty to thirty goats per sample range. When all samples have been tested a Genetic Bottleneck Analysis can be performed on the sample populations. Another element that needs to be evaluated to make the study more conclusive is the current microsatellite markers that are being used. It may be possible that the sequences coded for by the markers are genes that are unanimously similar for each goat. Once these quandaries have been assessed, a better picture will appear of the genetic diversity of mountain goat populations in the Montana Rockies.

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I would like to thank Tabitha Hooten for all the time she has spent with this project. I would also like to thank Jim Striebel and Art Rzasa for monitoring the experiment and answering pertinent questions. Thanks also to Coltman et al. for providing helpful resources. Finally, thanks to Corvallis High School for the funding and facilities.

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Multi-scale Habitat Modeling: Delineating Mountain Goat Habitat in the Washington Cascades

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Abstract: Historical declines in mountain goat populations in Washington State have spurred the need for understanding goat-habitat relationships for effective habitat management. GPS data from 42 collared mountain goats across the native ranges of Washington State were used to explore relationships between the use and availability of habitat. Our analysis represents one of the most extensive landscape-level habitat relationship studies conducted on Mountain Goats. Multi-scale path analysis methodology allowed us to test various ecologically informed relationships between landscape structure and pattern and the temporal movements of mountain goats at the home range scale. Our analysis compares available paths with random paths of matched identical spatial topology. We use matched case logistic regression to determine the spatially and temporally explicit scales that are the strongest predictors of seasonal mountain goat habitat. The methodology of this analysis is transferable and applicable to other studies that aim to predict mountain ungulate habitat. Additionally, the original use of path-level methodology in a case-control framework contributes to knowledge of statistical analysis of resource selection studies.

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Closing Comments: A Long-Time NWS&GC Member's Perspective on Wildlife Management

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Abstract: Throughout the history of the Northern Wild Sheep and Goat Council (NWSGC) the nature of what we've shared has ranged from what is happening, to what causes it, and what it should mean for wild sheep management. This progression of questions is illustrated by reference to bighorn pneumonia die-offs. In that area we moved from hypotheses relating forage competition with domestic livestock (including cattle), through the historic "lung worm-pneumonia" complex model, to our present understanding of domestic sheep and goats as reservoir/vectors of bacterial pneumonia as the most probable cause of bighorn pneumonia. Separation of domestic and wild sheep seems to be the present management direction. With respect to habitat protection and enhancement we've moved from strident advocacy of cattle exclusion to shifting grazing allotments from domestic sheep to cattle, accepted the idea of "foraging conditioning" and use of fire to enhance or restore wild sheep habitats subject to plant successions unfavorable to wild sheep. The progression from observational science to applied management is best typified by the working management hypotheses produced through these proceedings. There have also been significant technical advances from simple neckbands to radio collars. DNA work is presently "hot;" there's a present interest in genetics and evolving hunting strategies. Additionally, we've seen the creation of an unusually successful non-governmental organization (FNAWS) supporting sheep restoration and management followed by the "invention" and proliferation of "governor's permits," and greatly increased funding for wild sheep management programs. Bighorn populations (mostly due to transplants or reintroductions) have more than doubled, and harvests have increased dramatically as well. Thinhorn populations seem to have declined. The Council has published 23 volumes of research, management, and interpretive papers, and either sponsored or participated in four major collections of synoptic management papers and working management hypotheses for all species of North American Wild Sheep and Mountain Goats. We have also approved and presented a number of resolutions on current management topics. Nevertheless, implementing management programs indicated by our pursuit of "WHAT" and "WHY" questions is no less difficult than ever, and may be more so. Principles which, if applied, may lead to longer term success are presented.

Keywords: Dall sheep, wildlife management, working management hypothesis, Northern Wild Sheep and Goat Council.

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About 3,000 years ago, Solomon of Israel said, "As iron sharpens iron, so one man sharpens another." Throughout the history of the Northern Wild Sheep and Goat Council (NWSGC) symposia, we have tried to sharpen one another collegially. It seems likely this will be my last attempt to sharpen you. Should this be the case, I hope you will allow me the senior's prerogative of sharing some perspectives on life as a wild sheep manager in the hope that it will be of some use to you.

Methods

As a symposium, we have evolved in the way we approach sheep biology and management. I think this growth progression may be helpful to catalog. When I was first involved with the NWSC 37 years ago, we were exclusively asking the question, "WHAT?" This was appropriate at the time because the state of our documented knowledge allowed us to go no further. As time went by, those of us who survived in the wild sheep "business" began to ask the next logical question, "WHY?" Eventually, those of us who thought we might have a credible hypothesis relating to "WHY?" began trying to relate the answers to the "WHAT?" and "WHY?" questions in applied management. That is, we began to ask, "SO WHAT?"

Results

I offer two examples of this progression. The first example tracks the circuitous trails we have collectively followed to our present implementation of knowledge relating to bighorn pneumonia die-offs. I chronicled our progression from "WHAT?" to "WHY?" in some detail for the 2000 symposium in Rapid City (Heimer 2002). Our investigations first led us to a parasite-driven working hypothesis which could not be sustained experimentally. From that effort came our present understanding of bacterial pneumonia (the best answer yet to the "WHY?" question). Subsequently, we be began to ask "SO WHAT?" "SO WHAT?" took us into the realm of management.

Given that our hypothesis relating to domestic sheep bacterial involvement in bighorn die-offs remains seemingly robust, the answers to "SO WHAT?" suggest management action through separation of wild sheep from domestics. This action now optimistically appears likely to produce effective management actions, particularly on federal public lands.

The second example of this progression is best exemplified by the publication of synoptic working management hypotheses for all four subspecies of North American Wild Sheep published as the theme of the 2nd North American wild Sheep Conference (Heimer (a), Wishart, Toweill, Lee 2000). Four years later, this continuing effort produced a similar document for Mountain Goats during our seagoing symposium (Toweill et al. 2004).

As the working management hypothesis was defined at that time (Heimer 2000 b), these compilations represented the then-current synopses of answers to the "WHAT?", "WHY?", and "SO WHAT?" question progressions in wild mountain sheep and goat management. They were offered in anticipation that we could collectively make what we know and what we think about what we know relevant to management.

Discussion

In my bolder youth, I suggested taking this approach would heighten the prospects for successful management. However, at that time, I failed to appreciate the impact postmodern influences were having as they began to confound management success by defining "management" in ambiguous terms (Heimer 2004). These influences, as tacitly accepted by management agency leaderships to 'give the public a greater voice in management,' have obscured the meaning of "management." Currently "what it means to mange" is sufficiently vague that successful management no longer seems to require the formerly recognized requisites of answers to "WHAT is happening?" and "WHY?" In my advanced state as a curmudgeon, it now seems that we "manage" without any real consideration of the requisites formerly presumed to be the basis of modern wildlife management.

Being older, but perhaps not much more timid, I define "management" as "TWEAKING A SYSTEM TO PRODUCE A PRE-DEFINED HUMAN BENEFIT." In business management, this pre-defined benefit is profit. In human relations management, it is a happy cooperative workplace (generally defined to produce a pre-defined result pointing to production of goods or services). In wildlife management State/Provincial Constitutions/Charters define the benefit management is to produce. In Alaska, for example, the Constitution and the Alaska Statutes define the human benefit as manipulation of environments and populations to produce the maximal sustainable amount of human food. It was presumed that ecosystems would be "managed," i.e. manipulated to increase yields of this pre-defined benefit. Postmodernism seems to have attacked this basic presumption, and postmodern wildlife management has expanded the pre-defined benefit to include a wide spectrum of uses from viewing to existence value and even non-intervention in ecosystems as they exist at the moment.

At its inception, the illustration of ecological interrelatedness, the "web of life" was considered elastic. In postmodern terms, the web of life is now considered to have crystallized and become exquisitely fragile. When ecological interrelatedness was considered elastic tweaking a strand or two to increase production of human benefits was considered unlikely to cause the ecosystem to collapse. It would not look quite the same, but it would still be sustainable. The basic assumption of the need for continuous human manipulation was considered a given. Those laws have not been changed, but the postmodern influences defined by Heimer (2004) have basically defined intervention as inherently evil because it is "unnatural," and defined the web of life as delicately crystalline and fragile.

"So What?"

If we are to succeed in sheep conservation over the longer haul, I think it likely there are three principles of wildlife management which should serve us well. These are not what are taught as principles of wildlife management in colleges and universities. When we undertake to learn the art and craft of wildlife management, we are (or were) generally taught "Principles of Wildlife Management." Unfortunately, these principles (e.g. carrying capacity theory) were not principles of wildlife management at all. They remain the classic principles of wildlife science, but have little to do with successful management. I suggest the principles listed below are basic to success in contemporary wildlife management.

First, know and respect your pre-defined benefit. Generally, the predefined benefits are specifically enumerated human benefits, and are codified as guiding principles in Charters or Constitutions. These principles are defined in the statutes which give active force to principles. I find it particularly relevant that these guidelines define "SO WHAT" on the implicit assumption that the "WHAT?" and "WHY?" questions will be answered as a matter of course. In my casual look at non-Alaskan states and provinces, I've yet to see basic mandates to ask and answer the "WHAT?" and "WHY?" questions prescribed in law. I consider this "pre and end game" definition an example of modern (now considered archaic) wildlife management which has led to the outstanding success of wildlife restoration in the USA. The reluctance of management leaders to move from "WHAT?" and "WHY" to action seems, retrospectively, a natural consequence of postmodernism (Heimer 2004). I suggest it leads not only to "mission creep" but also to "mission slump." Things go well as long as we limit the scope of inquiry to the traditional "WHAT?" and "WHY?" questions. Where problems arise is with attempting to produce the basic pre-defined benefit which we, as managers, exist to pursue. Opposition to predator management is probably the best example. Studying "if" and "at what rate" predation occurs are socially acceptable. Applying findings to sustaining or increasing pre-defined human benefits from the same prey base is not.

The other consequence resulting from a failure to grasp or agree upon the predefined benefit as the reason for management is controversy. After spending several years agonizing over the stridently difficult exchanges chronicled in the last two proceedings of this symposium resulting from the Ram Mountain ram hunting controversy, the most benign hypothesis I can conceive is that the combatants had a basic difference or misunderstanding of the pre-defined benefit. The older school (modernists) seemed to consider, perhaps by default based on their history/philosophy, that the specter of possibly affecting genetic diversity in an isolated population of bighorn sheep was less terrifying than those with a different view of 'what management is really for.' The newer school (which look like postmodernists in setting aside the statutory definition of benefits for a more current understanding) seemed, possibly by default based on their history/philosophy, to suggest that human alteration of genetic diversity constitutes the most basic management mistake possible. In short, the unpleasantness manifested a conflict between schools of thought. We "oldsters" remained more focused on the traditional "prime directive," and did not graciously yield the field to the progressives. Both sides seemed to overlook the basic assumptions driving their interpretations of the data we think of as "scientific." I regret not being more introspective regarding the basic cause of the conflict than I was when I entered it, and more deeply regret the opportunity for offense I presented to my colleagues.

<u>The second principle</u> of wildlife management is related to science, but is more relevant to management *per see.* I suggest we will have greater success if we rely on modern science, not postmodern interpretations of data to inform the "rightness" of management actions. Because absolute certainty is unlikely to be defined in the plastic living systems in which we work, there will always be "nits to pick" about any generalized management hypothesis or unifying theory. Anti-management postmodern activists will always seize on these "nits" to advance their anti-management (i.e. their personal interpretation of 'benefit') agenda. "Science" used to be the default answer and basis for management when the goal was generally accepted. However, "science" (which is actually a method of problem solving) will be unable to bridge the schism which has developed over what management is actually to accomplish. Until the "prime directives" are altered to fit the common postmodern viewpoint, management actions will always be attacked as insufficiently grounded in science. Hence, I see no end to the present conflict. Still, good pre-thinking of "experiments," rigorous data collection and analysis will always be easier to defend than sloppy work. Do good work that is carefully considered in the larger societal context, and your life may be minimally disturbed by the inherently inevitable conflict over benefits produced.

Finally, we all need to realize we are managing resources which constitute a public trust. Consequently, politics will probably have a greater impact than empirical science. Hence, I suggest the successful manager of the future will have to work more productively in the political realm than has been required in the past. This goes well beyond knowing the predetermined benefit we are mandated to produce and the laws and regulations which have grown up to assure the benefit is produced. Operating politically is extremely difficult for those of us still employed by management agencies, which are defined as politically 'apolitical' by fiat. That is, agency employees, except those at the highest politically appointed level, are enjoined from conventional 'political activities.' This seemingly occurs as a matter of status protection (which defines the ability to exercise of power) by the elected officials who appoint the management agency leadership. If these folks are to function properly in their dominance hierarchy, they can't very well tolerate a bunch of subordinates challenging their social decisions. We're not much different than sheep in this regard (Heimer 1996).

It may not be a bad idea for this political agency social hierarchy to suppress the impulses of the passionate and inexperienced. Politics is an art/craft which is separate from that of agency management. Consequently, the manager who really wants to make a difference may be required to follow a path in which the "SO WHAT?" question really isn't satisfactorily addressed in the public arena till one has "graduated" from agency employment. This, of course, requires a perhaps-unhealthy commitment to management which extends even into "retirement."

In Alaska, we (retired agency folks) recently succeeded in getting the legislature to pass a law which should make citizen's initiatives/referenda a thing of the past. This we accomplished through political means using network connections established during our "agency careers." We could not have done it as "employees."

Alaska's publicly owned trust resources have always been constitutionally protected from allocation/appropriation by popular vote. This seems protective of minorities in rural Alaska, which could easily be "voted off the island" with respect to consumptive use of wildlife by the urban majority. Nevertheless, the postmodern popularity of "wildlife initiatives" had made these sorts of ballot propositions common. This, of course, lead to an unstable management environment because any management decision was subject to 'correction by referendum' (sold as 'initiative') by a sufficiently amoral cadre of activists (generally anti-managers) with the resources and expertise to "undo" almost any management action which they find personally repugnant. That is, the activists succeeded in making "SO WHAT?" a matter of personal definition rather than statutory response. With this correction (removing wildlife allocation from the initiative/referendum agenda) which could not possibly have been done by paid "public servants" because of the paradox of being politically designated as 'apolitical,' the management environment in Alaska should become more stable. This should be an advantage to traditional manipulation of living systems to yield higher (pre-defined) human benefits.

Thanks are due to the symposium for "sharpening" me over the decades.

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Ram Harvest Strategies for Western States and Provinces—2007

Authored by: Wild Sheep Foundation Professional Biologist Meeting Attendees (Biologists from all agencies that hunt wild sheep in the United States and Canada)

***Abstract**:* At the 2007 Professional Wildlife Biologist Meetings held in conjunction with the Western Hunting Exposition in Salt Lake, Utah, a review of the current harvest strategies for wild sheep rams was conducted. A questionnaire, designed to collect data on ram harvest strategies, was distributed to biologists from the 20 jurisdictions hunting sheep in 2007. Results from this questionnaire are presented in this manuscript. Most hunting of bighorn sheep is a function of limited entry drawings, although unlimited entry hunting occurs in much of Alberta and parts of Montana. Draw odds as high as >4000:1 exist for these rare permits. An estimated 1310 bighorn sheep (*Ovis canadensis*) and 1690 thinhorn sheep (*Ovis dalli*) rams were harvested in 2007.

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Introduction

The evolution of wild sheep hunting in North America has progressed from the market hunting days that pre-date the earliest game protection laws to the current regulations in place by all state and provincial wildlife agencies (jurisdictions). In this manuscript we review the regulations in place during the 2007 hunting season. A questionnaire (Appendix A) was developed and sent to 20 jurisdictions (Appendix B) that hunt wild sheep. The results from that questionnaire were presented at the 2008 Wild Sheep Foundation (WSF) Professional Meeting in Salt Lake City, UT and again at the 2008 Northern Wild Sheep and Goat Council Symposium held in Midvale, UT. An Excel spreadsheet with the data generated by each jurisdiction is included as Appendix C.

Harvest numbers varied substantially among jurisdictions, e.g., New Mexico issues a single public desert bighorn sheep permit compared with thousands of permits in Alaska and more than 900 rams harvested annually. Ram hunts were primarily permitted via a limited entry draw. More rarely, jurisdictions allowed over-the-counter, unlimited entry hunts. In addition, the results were partitioned between bighorn and thinhorn sheep. In 2007, both Montana and British Columbia were substantially redesigning their respective ram harvest regulations.

Results

Limited Entry Draw Hunts

Legal Ram

The majority of jurisdictions have gone to an 'any' ram regulation with neither a horn-curl or age restriction. Exceptions for bighorn sheep are California, Colorado, and Alberta where either ½-curl, ¾-curl, or *4/5*-curl restrictions are in place. Montana and South Dakota allow for harvest of either sex during the bighorn season.

In Alaska and Yukon full-curl or 8 years-old restrictions are in place. In Northwest Territory, a ¾-curl rule is applied.

Minimum Population Size

The minimum population size to hunt varied among jurisdictions. The general rule was a population between 50 and 100, although some jurisdictions hunted subpopulations as small as 25 if linked to a population in a 'protected' area such as National Parks, National Monuments, or military reservations. California requires a minimum female component of 50 ewes prior to hunting.

Boone and Crockett Scores

Most jurisdictions required that ram heads be sealed and Boone and Crockett (B&C) measurements are recorded at that time. Some jurisdictions only measured basal circumferences and horn lengths, i.e., not the quarter circumference measurements for a B&C score. Jurisdictions where thinhorns are harvested did not collect B&C measurements. This is primarily a function of the large number of rams harvested each year. In New Mexico ram age and B&C measurements are closely monitored in populations to allow maximum harvest without inducing long-term declines in either age or B&C scores.

Rams/100 Bighorn Sheep

One measure of ram harvest is the number of rams harvested/100 bighorn sheep in the population. Among jurisdictions this value ranged from 1.3-3.5 rams/100 sheep with a mean of 2.5 rams/100 sheep. The 2 jurisdictions with the highest harvest ratio were Montana and Wyoming at 3.5 rams/100 sheep. The jurisdictions with the lowest ratios were Texas and Arizona at 1.3 and 1.5 rams/100 sheep respectively. For thinhorn sheep the lowest ratio was in the Northwest Territory where 1.2 rams/100 sheep was harvested.

Colorado issues 1 license per 29 bighorn sheep in the population, which translates to 3.4 rams/100 bighorn sheep with 100% hunter success. Monitoring of age and B&C scores has allowed New Mexico Department of Game and Fish to increase the number of permits from ~1.3/100 bighorn sheep to ~2.7/100 bighorn sheep in the Pecos Wilderness.

With an estimated 72,000 bighorn sheep in the United States and Canada, and approximately 1310 rams harvested, the ratio would be 1.8 rams/100 bighorn (Appendix C). This number is substantially lower than the average across all jurisdictions because of a proportion of each jurisdiction's bighorn sheep are in protected areas, i.e., areas that are not hunted. The range of percentages for bighorn sheep in protected areas was <1% in Texas to 78% in California. Making an assumption that 25% of bighorn sheep are in protected areas in Canada and the United States would increase the ratio to 2.4 rams/100 bighorn.

A population estimate in Yukon was not available to create a species-wide estimate for thinhorn sheep. However, using the midpoint population estimates for Alaska, British Columbia, and Northwest Territory resulted in ratios of 1.6, 2.4, and 1.2 rams/100 sheep respectively. Using the 25% in protected areas assumption, the ratios would increase to 2.1, 3.2, and 1.6 rams/100 sheep.

Percent of Ram 8+ Years Old at Harvest

The percent of rams that were 8 years old or older at harvest ranged from 30-73%, with a mean of 51% (Appendix C). The lowest percentages were in Wyoming (28%) and Alberta (41%) and highest in New Mexico (78%) and Texas (64%). It was noted that California bighorn rams (race not state) rarely live to be 8 years old and therefore this may not have been the appropriate cut-off age to delineate 'mature' rams for that race of bighorn.

Harvested Rams as a Percent of Total Rams

There was the greatest amount of 'noise' in this variable. This may be because rams are more difficult to enumerate during helicopter surveys because of their predilection to move into timbered habitat. The range of values reported were 7-12% of all rams and 20-30% of Class III and Class IV rams (Appendix C). Because most herds are not surveyed just prior to hunts, the denominator in this ratio is inexact. Therefore most jurisdictions base this ratio on estimates generated from multiple sources including ground surveys, hunting guides, and long-term knowledge of the age structure. If ram harvests were based solely on number of rams *observed* during helicopter surveys, harvest ratios would generally be much more conservative.

Between 2000-2008, in the Pecos Wilderness in New Mexico, ram harvest is estimated to be about 7% of total rams using estimates from all sources to construct total rams. However, ram harvest based on rams *observed* during helicopter surveys alone was 21% (range=8-55%). The actual ram numbers were thought to vary little among years in this alpine population that has an asymptotic growth curve. Because rams, particularly large rams, are dominant at constricted winter feeding sites mortality rates for males during winter is hypothesized to be lower and more stable than for subordinate sex and age classes.

Number of Rams Harvested

Within jurisdictions the number of bighorn rams harvested annually ranged from 1-2 in Nebraska to ~200 in Wyoming (Appendix C). Approximately 1310 bighorn sheep rams were harvested in the United States and Canada in 2007.

For thinhorn jurisdictions the annual harvest was ~240 in Northwest Territory, ~250 in Yukon, ~300 in British Columbia, and ~900 in Alaska. Approximately 1690 thinhorn rams were harvested.

Success Rates

Success rates for jurisdictions with bighorn sheep ranged from 44-100% with a mean of 85% (Appendix C). Twelve of 17 jurisdictions with bighorn sheep reported success rates of $\geq$90%. The lowest success rates were in British Columbia (~65 for non-residents but only about 10% for residents) and Alberta (44%). Colorado reported a relatively low success rate (50%) but 80 archery licenses, which typically have a much lower success rate than rifle licenses, were included. Non-resident thinhorn harvest success averaged 62%, however the success rate for residents were substantially lower, e.g., in Alaska it is ~38%.

Over-the-counter Hunts

Two jurisdictions, Alberta and Montana, offer ‘over-the-counter’ hunts where unlimited entry can occur to hunt bighorn sheep. Most hunting for bighorn in Alberta is unlimited hunting with a 4/5th horn curl restriction. Between 1988 and 2007 there were an average of 144 rams killed in over-the-counter hunts and 25 in limited entry hunts. In a province-wide analysis this equated to 1.5 rams harvested/100 bighorn sheep. Using populations from just the hunted proportion of Alberta bighorn sheep results in 2.9 rams harvested/100 bighorn sheep.

Montana had 4 unlimited entry areas in 2007. Success rates are typically much lower than in draw hunts and Alberta averages just 7.5% and Montana ~6.5%. Montana sets a predetermined quota in these units and the hunting season is terminated when the quota is met, or in some instances approached. In 2005, 43% of hunter numbers were from the 4 unlimited entry units, however just 6% of the statewide harvest came from these units.

Acknowledgments

We would like to thank The Wild Sheep Foundation for hosting the annual Professional Wildlife Biologists Meeting.

Appendix A. Questionnaire sent to the 20 jurisdictions that hunt wild sheep in the United States and Canada.

Questions for Ram Harvest Management Strategies

A. Goal is trophy harvest (limited entry/draw hunt units):

1. Are there minimum population sizes/numbers of rams to hold hunts?
2. Hunts based on total population numbers or on total ram numbers?
3. Do you track ram age/B&C scores for herds?
4. What factors affect decisions to reduce permits or cancel hunts?
5. Using a 10-year average, what percentage of rams harvested are mature—8+ years old.
6. What is the mean success rate in these units?
7. On average, how many rams are harvested/100 bighorn sheep?
8. On recent average…how many rams are harvested annually?

B. Goal is high hunter opportunity (over the counter/open hunt units):

1. Are there different criteria for these open hunt units vs. draw units?
2. Do you track ram age/B&C scores for herds?
3. What factors affect decisions to reduce permits or cancel hunts?
4. Using a 10-year average, what percentage of rams harvested are mature—8+ years old.
5. What is the mean success rate in these units?
6. On average, how many rams are harvested/100 bighorn sheep?

Appendix B. List of 20 jurisdictions that hunt wild sheep in the United States and Canada.

- Alaska
- Alberta
- Arizona
- British Columbia
- California
- Colorado
- Idaho
- Montana
- Nebraska
- Nevada
- New Mexico
- North Dakota
- Northwest Territory
- Oregon
- South Dakota
- Texas
- Utah
- Washington
- Wyoming
- Yukon

Appendix C. Excel spreadsheet with the results from the questionnaire sent to each jurisdiction.

State	Representative	Ram	Ewe
Alaska	Becky Kellyhouse	X	X
Alberta	Jim Allen	X	X
Arizona	Brian Wakeling	X	
British Columbia	Chris Addison	X	X
California	Tom Stephenson	X	
Colorado	Bruce Watkins	X	X
Idaho	Dale Toweill	X	
Montana	Tom Carlsen	X	X
Nebraska	Todd Nordeen	X	
Nevada	Mike Cox	X	
New Mexico	Eric Rominger	X	
North Dakota	Brett Weidmann	X	
NW Territory	Alasdair Veitch	X	X
Oregon	Thompson/Torland	X	
South Dakota	Ted Benzon	X	
Texas	Calvin Richardson	X	
Utah	Kent Hersey	X	
Washington	Donny Martorello	X	
Wyoming	Kevin Hurley	X	
Yukon	Jean Carey	X	

State--subspecies	Pop. Est. BHS	
Alberta--RM	**11200**	
Arizona--DE	**4600**	
British Columbia	**4100**	
California--DE	**4400**	
Colorado--RM	**7000**	
Idaho--RM/CA	**4000**	
Montana--RM	**6700**	
Nebraska--RM	**220**	
Nevada--CA/RM/DE	**8800**	

New Mexico--RM/DE	**1400**	
North Dakota--RM	**300**	
Oregon--RM/CA	**4250**	
South Dakota--RM	**450**	
Texas--DE	**1200**	
Utah--RM/DE	**5500**	
Washington--RM/CA	**1600**	
Wyoming--RM	**6200**	
TOTAL	**71920**	

Ewe Harvest Strategies for Western States and Provinces—2007.

Authored by: Wild Sheep Foundation Professional Biologists from Alaska, Alberta, British Columbia, Colorado, Montana, New Mexico, and Northwest Territory

***Abstract*:** At the 2007 Professional Wildlife Biologist Meetings held in conjunction with the Western Hunting Exposition in Salt Lake, Utah, a review of the current harvest strategies for wild sheep ewes (*Ovis spp.)* was conducted. A questionnaire, designed to collect data on ewe harvest strategies, was distributed to biologists from 6 jurisdictions that hunted ewes in 2007. This product is a synthesis of the results from that questionnaire and/or oral presentations by biologists from Alaska, Alberta, British Columbia, Colorado, Montana, and Northwest Territory. These data were also presented at the 2008 Northern Wild Sheep and Goat Council Biennial Meeting in Midvale, Utah.

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Introduction

Female ungulates are regularly hunted in North America with hundreds of thousands of doe white-tailed deer (*Odocoileus virginianus*) and tens of thousands of cow elk (*Cervus elaphus*) harvested annually. A notable exception is wild sheep where just 6 of 20 jurisdictions harvest wild sheep ewes. Three jurisdictions, Alberta (n=~100), Colorado (n=~40), and Montana (n=~125) harvest fewer than 300 bighorn sheep (*Ovis canadensis*) ewes annually. Although Alaska issues >350 Dall's sheep (*Ovis dalli*) permits, <40 ewes are harvested annually. Because the harvest levels are so low in Northwest Territory (n=~20) and British Columbia (n=<10) they were not included in this analysis.

Although trapping and transplantation has been the primary population reduction strategy for most jurisdictions, many wildlife agencies have expressed an interest in the potential for ewe harvest as an additional population management technique. The expense of administering a hunt is generally a fraction of the cost of trapping and transplantation, particularly from wilderness areas requiring consider helicopter time. The questionnaire is attached as Appendix A.

Results

Criteria for a Herd to have a Ewe Hunt?

Rocky Mountain bighorn sheep ewe hunts are used as a population management tool and are often used in concert with translocation to reduce herd sizes below carrying capacity. In Colorado, primarily herds with >100 individuals are hunted. In Alaska and Northwest Territory ewe hunts also provide for subsistence needs.

In Alaska Dall's sheep ewes are hunted by draw, by subsistence, and in remote/restricted access areas. Some hunts are ewe-only while others are either sex or ewe or full curl restrictions. These are used as population reduction hunts as well as increasing sportsmen opportunity.

What are the Specifics for these Ewe Hunts?

The number of permits issued annually ranged from 95-374 among the jurisdictions. To establish the number of ewe licenses following formulas are used by Alberta and Montana:

Alberta—

No. of permits =

$$\frac{\text{Harvest rate (\%) * (winter ewe + yearling population estimate).}}{\text{Hunter success rate (\%) for that Sheep Management Area}}$$

Harvest rate will not exceed 18% unless a population reduction is needed. Hunter success rate is the average of the preceding 5 years.

Montana—

$$E(t+1) = (E(t) + (L(t) * 0.5)) * (0.95)(1 - (0.15 * 0.9))$$

- Where: E = number of ewes at (t) or (t+1)
- t = time of survey (March-April)
- Annual mortality of 0.05 or survival = 0.95
- L = number of lambs * 0.5 = female lambs recruited
- 0.15 = harvest rate
- 0.9 = Hunter Success

Draw Odds?

The draw odds for ewe hunts were substantially better than draw odds for rams. The probability of being drawn was Alberta 25%, Colorado 72%, and Montana 50%.

Total Number of Ewes Harvested?

In 2007, 4 jurisdictions, Alberta (n=~100), British Columbia (n<10), Colorado (n=~40), and Montana (n=~125) harvested just 277 bighorn sheep ewes.

In Alaska, an average of 374 ewe permits were issued but only about 32 ewes were harvested.

Success Rate?

The success rates were Alberta 44%, Colorado 39%, and Montana 75%. These success rates were substantially less than those reported for rams.

In Alaska, the success rate is only 9%.

What Percentage of Ewes Harvested in Herds?

None of the jurisdictions harvested >10% of the estimated number of ewes within the hunted populations. The highest proportion was in Montana (8.3%), with Alberta (3.1%) and Colorado (2.2%).

Other Issues

One concern is the potential accidental harvest of yearling rams. However all agencies reported few instances of immature rams being harvested instead of ewes. Some herds at carrying capacity do not have ewe hunts. These include herds in protected areas, some herds <100 individuals, and some herds that are limited by diseases. Some herds are not hunted because they continue to be used as transplant stock. In general, ewe hunts are an accepted management strategy to help maintain healthy bighorn herds.

Jorgenson et al. (1993) suggested that 12-24% ewes could be harvested or translocated annually to maintain stable population levels. The ewe harvest rates reported here are presumably too low to influence population demographics or result in increased horn basal circumference as documented by Jorgenson et al. 1993, although the harvest in some Montana herds is close.

Table 1. Synopsis of ewe harvest strategies in Alberta, Montana, Colorado, and Alaska.

	Alberta	**Montana**	**Colorado**	**Alaska**
No. of herds	29	15 of 48 (31%)	7 of 51 (16%)	~14 units

hunted				
No. of permits	231	169	95	374
Harvest success rate—percent	44	75	39	9
Draw odds--percent	25	49	72	?
No. ewes harvested	102	127	37	32
% of estimated ewe population harvested	3.1	8.3	2.2	?

Literature Cited

Jorgenson, J. T., M. Festa-Bianchet, W. D. Wishart. 1993. Harvesting bighorn ewes: consequences for population size and trophy ram production. Journal of Wildlife Management 57:429-435.

Acknowledgments

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Appendix A. Questionnaire sent to biologists in wildlife agencies that harvest female wild sheep.

QUESTIONS FOR EWE HARVEST STATES/PROVINCES— AB/BC/MT/CO/AK

1. **What are criteria for a herd to have a ewe hunt?**
    - Size?
    - Population estimate in relation to carrying capacity?

2. **How many herds have ewe hunts?**
    - What percentage is that of the total number of herds?

3. **What are the specifics for these ewe hunts?**
    - Number of permits issued state/province wide?
    - Percentage of estimated ewe population?
    - Success rates?
    - Draw odds—i.e., are any hunts 'under-subscribed'?
    - Are these 'any-weapon' hunts or 'primitive-weapon' hunts?
    - Issues w/ accidental harvest of immature rams?
    - Do you have herds at K that are not hunted? Why?

4. **General comments on the overall public response to these hunts?**

5. **How do these hunts fit into the overall trap and transplant plan for the province/state—i.e., do you hunt herds that are more difficult/ expensive to trap—e.g., wilderness herds vs. 'drive to' herds?**

6. **Does anyone have data on the hypothesized increase in basal circumference of rams born into herds that are below carrying capacity as a result of ewe harvest—*sensu* Jorgenson et al. 1993?**

Jorgenson, J. T., M. Festa-Bianchet, W. D. Wishart. 1993. Harvesting bighorn ewes: consequences for population size and trophy ram production. Journal of Wildlife Management 57:429-435.

Dall Sheep Management in the Chugach Range of Alaska

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Abstract: The past 20 years showed a steady decline in the number of animals taken in game Management Units 14A and 13D of the Chugach Range of Alaska. Changes in rams available for harvest, hunter success rates, and guided non-resident hunting pressure have created conflicts among user groups. In spring 2007 the Board of Game changed the hunting season in 14A and 13D from a general season hunt to a draw hunt to address these concerns. Sheep harvest data, survey information, hunter participation rates and hunter success rates for these areas were considered relative to historic trends and anticipated future hunting pressure. I will discuss the issues as they relate to the changes in management strategies and the associated controversy.

BIENN. SYMP. NORTH. WILD SHEEP AND GOAT COUNC. 16:103

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International Polar Year Project: Effects of Climate Change, Glacial Retreat, and Snowfield Loss on Wild Sheep Habitat, Nutrition, and Population Distributions in Polar and High Mountain Ecosystems in Alaska, Far Eastern Russia and Central Asia: A Comparative Study

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Abstract: The purpose of this study is to determine the effect of glacial and snowfield retreat on wild sheep habitat in selected study areas of Alaska, far-eastern Russia, and central Asia. We hypothesize that climatic changes are altering the traditional habitat for high-mountain large mammals, particularly wild sheep. Wild sheep are sensitive to environmental change and may be an indicator species regarding the effects of climate change in arctic and high mountain ecosystems. With predicted warming temperatures, the cold season is expected to shrink and may decline in severity, requiring herbivores to expend less energy to survive. For individual years, however, climatic extremes in arctic and alpine ecosystems could result in either shortened or lengthened vegetation growing seasons during which herbivores procure most of the extra nutrients needed for reproduction and the storage of fat for the next winter. For most herbivores, a longer forage growing season would be expected to increase total uptake of nutrients whereas a shortened growing season would reduce intake. In the case of wild sheep, which do not hibernate and are active throughout the cold season, the predicted outcome is less clear and higher population carrying capacities might be predicted for either or both of these simple hypothetical seasonal changes. For this study, wild sheep habitat is characterized using several types of remotely-sensed data. Landsat satellite imagery is being used to identify and map changes in glacial and snowfield extent and landscape change within the study area. Changes in snow and ice extent and distribution due to melting may impact the health and nutritional value of wild sheep forage in the study through increased release of water and trapped nutrients due to melting. Data resident in the Global Land Ice Measurements from Space (GLIMS) database will be used to fill in data gaps of snow and ice distribution. Historical aerial photography, topographic maps, and historical reports will be used for additional interpretation and to provide information on snow and ice distribution prior to unavailability of satellite data. MODIS satellite imagery is used to track phenology. Phenology integrates information on vegetation, species, and climate as reflected in the timing, intensity, and duration of greenness. Quickbird imagery is being used to capture vegetation pattern and structure, which allows mapping of generalized

vegetation types, including woody vs. non-woody vegetation. Various phenological, spatial and structural metrics will be derived from these data and summarized for the study area to define and characterize distinctive landscapes. In addition, wild sheep feces are being collected and analyzed for nutrient value, digestibility, and vegetation species composition. Analysis of remotely-sensed data will be coupled with fecal analysis to attach a measure of nutritional value, digestibility (stress), and forage species composition and change with respect to wild sheep. Collection of subsequently remotely-sensed data will then be used to map these landscapes through time, monitoring any changes in their extent and distribution. This permits evaluation of the overall quality of the habitat for wild sheep based on the inferred nutritional value of each landscape type, and provides a means to monitor habitat quality through time. Long term monitoring and analysis of changes in glacial and permanent snowfield extent may result in phenological changes in wild sheep habitat. These methods may provide long term monitoring tools for wildlife managers, and also be applied in similar environments in widely dispersed wild sheep habitat.

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Stone's Sheep Demographics in the Sulphur / 8 Mile Project Area, Northern British Columbia, Winter 2006/2007

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Abstract: One of the primary objectives of the S8M Stone's Sheep Project in northern British Columbia was to assess Stone's sheep (*Ovis dalli stonei*) population size, demographics, and stability, in order to provide a baseline for oil and gas pre-tenure plan management direction. Two population inventories were conducted, in December 2006 and March 2007. The censuses included all areas ≥ 1,400 m (approximate tree line) within the bounds of the S8M Project area. The presence of radio collared ewes enabled a sightability correction factor to be derived and applied to calculate confidence intervals around population estimates using the immigration/emigration joint hypergeometric estimator (IEJHE) in NOREMARK software. The project area is thought to include two populations, referred to as the Sentinel and Stone populations. Sightability varied between populations and censuses, but mean sightability was greatest in December at 83.5% compared to 71.9% in March. The IEJHE population estimate for the Sentinel was 627 (95% CI 532 - 781) sheep. The Stone population was estimated at 545 (95% CI 475 - 648) sheep. Lamb to ewe ratios for all sheep enumerated in the Sentinel and Stone populations were 0.67 and 0.73 respectively in December and 0.64 and 0.51 in March. Density ≥1,400 m in the Sentinel population (0.64 sheep/km^2) was approximately one-half that of the Stone population (1.38 sheep/km^2) in December and 0.62 sheep/km^2 and 1.00 sheep/km^2 respectively in March. A greater total number of sheep and a greater proportion of marked sheep observed in December suggest that conducting a population survey during the end stage of the rut while sheep are congregated in high elevation alpine ranges may be the best option to obtain a more precise total population estimate, especially if little is known about the population age-sex structure or if the marked sample population is sexually biased.

Key words: Census, *Ovis dalli stonei*, population demographics, Stone's sheep.

BIENN. SYMP. NORTH. WILD SHEEP AND GOAT COUNC. 16: 106-121

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Formally established in 2004, the Sulphur / 8 Mile (S8M) Stone's Sheep Project is a multi-stakeholder collaborative initiative focused on researching Stone's sheep (*Ovis dalli stonei*) ecology in the S8M area of northern British Columbia (BC), with a specific emphasis on evaluating the potential for resource development impacts on wild mountain sheep populations (Churchill 2005). Stone's sheep, considered to be an important species to hunters, naturalists and special interest groups, are of particular significance in the S8M Project area, and as such are being given special consideration in the S8M oil and gas pre-tenure plan (PTP), a planning process which is mandated under the Muskwa-Kechika Management Area (M-KMA) Act for areas which have high resource development potential (MSRM 2004). One of the primary objectives of the S8M Project was to assess Stone's sheep population size, demographics, and stability, to provide a baseline for PTP management direction. The BC Ministry of Environment (MoE) conducted aerial sheep inventories in the project area in 1977 and 2004, without the benefit of marked sheep to assess sightability and calculate confidence intervals around population estimates. In 2005 and 2006, ewes were radio-collared to obtain habitat use data and assess levels and causes of sheep mortality (Churchill 2005). A population inventory was planned for winter 2006/2007, to assess Stone's sheep distribution and demographic structure and trends, and to assess the benefit from the presence of radio-collars to calculate a sightability correction factor (SCF) and population estimate. Initially, a single inventory was planned and timed for the latter stages of the rut in late November – early December (Nichols 1978) to maximize the potential to enumerate rams, which may not be in the census area at other times of the year, but congregate with ewe groups during this time. Maximizing the potential to observe rams was a priority because males were not represented in the radio-collared sample population. The objectives were to:

- Design and implement a census methodology that is repeatable in the S8M project area and can be applied in other regions that support Stone's sheep;
- Obtain a total count of Stone's sheep in the census area, recording number of sheep, group sizes, age/sex classification, distribution, and habitat characteristics;
- Determine an SCF, population estimate and confidence intervals using sightability and distribution of radio-collared sheep;
- Map the distribution of all sheep sighted;
- Estimate lamb survival to early winter and compare this estimate to pregnancy rate of ewes marked and sampled in March 2006;
- Record number and distribution of competing ungulates and predators observed in the census area.

In March 2007, MoE conducted Stone's sheep inventories throughout the BC's North Peace Region, without the benefit of marked animals to calculate a sightability correction factor and derive a corrected Stone's sheep population estimate. To provide confidence estimates for their survey results, a second census was conducted concurrently in the S8M project area. The March 2007 late winter census enabled us to:

- Determine a SCF that can be applied to late winter Stone's sheep inventory results;
- Incorporate census results into a repeated count analysis to improve confidence of the S8M population estimate;
- Compare early and late winter distribution and demographics;
- Compare the efficacy of a rut census in December to those typically conducted in late winter-early spring (MSRM 2002).

Study Area

The S8M Stone's Sheep Project area (Figure 1) is centered about 150 km west-northwest of Fort Nelson, BC, Canada and is located within the M-KMA. The project area land base is approximately 4237 km^2 and encompasses the Sulphur / 8 Mile, Toad River Corridor, Toad River Hot Springs and Stone Mountain Resource Management Zones (RMZ) defined by the Fort Nelson Land and Resource Management Plan (MSRM 1997), and most of BC WMU 7-54. The project area is bounded by the Alaska Highway, Liard River Corridor, and the

S8M PTP boundary. The PTP areas resulted from an interest of industry to explore and develop the area, and consultation with public advisory groups. The outcome of this process led to the creation of a low elevation and high elevation zone in the eastern portion of the project area. The low elevation zone is not considered high value habitat for Stone's sheep and has been approved for the sale of oil and gas tenures. Tenure sales have been deferred in the high elevation zone, which has been identified to contain high value habitat, to allow for Stone's sheep research and management direction to mitigate the impacts of industrial activity on sheep.

The northern extent of the Rocky Mountains is bounded by the Liard River Corridor, and the transition to the boreal plateau occurs to the east, fostering unique land formations and diverse habitat types. Much of the area was covered by the Laurentide ice sheet during the Wisconsinian ice age and is responsible for giving the area its unique landform morphology (Millot *et al.* 2003). Deciduous and coniferous forest comprises the majority of vegetation cover. Biogeoclimatic zones in the project area are Alpine Tundra (AT), Spruce-Willow-Birch (SWB and SWBmk) and Boreal White and Black Spruce (BWBSmw1 and BWBSmw2) (Meidinger and Pojar 1991). Climatic normals at Muncho Lake from 1971-2000, obtained from Environment Canada (http://www.climate.weatheroffice.ec.gc.ca) indicate that the area has a dry climate with an average annual precipitation of 496 mm and 106 frost free days. From November through to February, the average temperature is -18°C and from June through August the average temperature is 15°C. The temperature in summer often exceeds 30°C and in winter it can fall to -40°C.

Known internationally for its exceptional wildlife and wilderness values, much of the area is undeveloped, with motorized vehicle access limited to routes designated by the M-KMA Act. The protected areas adjacent to the project area have international significance due, in part, to the diversity of wildlife that includes wolf (*Canis lupus*), grizzly bear (*Ursus arctos*), wolverine (*Gulo gulo*), moose (*Alces alces)*, Rocky Mountain elk (*Cervus elaphus*), deer (O*docoileus spp.)*, caribou (*Rangifer tarandus*), mountain goats (*Oreamnos americanus*), and Stone's sheep.

Because GPS collar and radiotelemetry data suggest that ewes belong to two subpopulations separated by the Toad River, we divided the S8M Project area into 2 subunits. One encompasses the Sentinel Mountain Range and is dominated by steep, rugged, alpine. This area extends northwest of the Toad River, and is hereafter referred to as the Sentinel population. The other subunit encompasses the less imposing Stone Mountain Range characterized by rounded peaks and increased vegetation cover at upper elevations. This area is southeast of the Toad River, hereafter referred to as the Stone population.

Methods

Capture and Radiocollaring

In March 2005 and 2006, 105 ewes >1 yr old were radiocollared in the project area. Sheep were captured by net-gunning from a Bell 206B helicopter, and fitted with either a motion-sensitive Very High Frequency (VHF) radiocollar or a Global Positioning System (GPS) collar with VHF transmitter. Progesterone levels from blood sera samples taken during March 2006 and March 2007 ewe captures were analyzed by the University of Saskatchewan Wildlife Health Centre. Serum progesterone levels >2 ng/ml indicated pregnancy.

Census Area Delineation

We stratified the project area according to ecosystem descriptions in Meidinger and Pojar (1991) who suggest that, although variable, alpine typically begins at an elevation of 1,400 m in north-eastern BC. We then correlated GPS location data from 9 collared ewes in our sample population with elevation, to discern if sheep were likely occupying open alpine habitats during the proposed time of the census. The census included all areas ≥1,400 m (approximate tree line) within the bounds of the S8M Project area (Table 1). The census area was mapped a priori using Geographic Information System (GIS) software to query Digital Elevation Model (DEM) data and produce census polygons for all areas ≥1,400 m.

Census Protocols

Census methodology and data collection conformed to provincial Resource Inventory Standards Committee (RISC) protocols for aerial ungulate inventories (MSRM 2002). Field data forms used followed RISC standards as well (MELP 1998). A Bell 206B Jet Ranger helicopter, equipped with two Yagi-Uda 2-element antennas mounted on opposing sides of the skid assembly, was used for both surveys. The crew consisted of a pilot, habitat/activity recorder, enumerator, and a navigator. The crew sat in the same seating arrangement in the aircraft throughout the census. All crew members actively participated in locating animals. The navigator employed blind telemetry (other members of the crew could not hear the radio collar VHF beacon) throughout the censuses to calculate sightability. If marked sheep were not observed, but heard by the navigator, the search for new animals was temporarily suspended at a natural break and the marked sheep were located using radiotelemetry.

Whenever possible, searches for animals began at 1,400 m elevation and, if necessary, subsequent passes were made increasing in elevation until the crew was confident the area was sufficiently searched. Tracks in snow, deemed relatively fresh, were followed as well. Although the focal species was Stone’s sheep, all animals sighted were recorded and geo-referenced during the censuses to provide some insight on inter-specific competition on winter ranges within the S8M Project area. The total number of each group was recorded first then each crew member was assigned a specific age class or sex to enumerate. Ram age classifications followed Geist (1971), grouped by degree of horn curl in relation to the bridge of the nose as class I (¼ curl), class II (½ curl), class III (¾ curl) and class IV (full curl). Individual tallies were then compiled by the enumerator.

Real-time flight tracking (MNDNR 2000) was utilized in concert with a GIS platform (ESRI 1999) at all times during the census to map flight lines. An on-board computer displayed the helicopter location relative to the census polygons. Additional GIS coverages, such as local hydrology and roads, complimented the census polygons to aid the navigator and pilot during flight by providing a visual reference of landscape features. The rationale for this was three-fold:

- To provide accurate reference points that allowed the census crew to determine if an area was surveyed previously and provide an opportunity to end the survey at natural breaks of contiguous areas. Also, to find unsighted, marked sheep with telemetry or refuel the aircraft, and then resume with minimal risk of double counting animals;
- To establish a repeatable survey protocol;

- To allow us to calculate true survey effort by excluding ferry time between polygons and to re-fuel.

Data Analyses

We made assumptions that all marked and unmarked individuals within polygons were independently distributed and had an equivalent probability of being observed, and that no errors were made differentiating a marked and unmarked individual. We used NOREMARK software (White 1996), which incorporates a joint hypergeometric maximum likelihood estimator for repeated counts (Bartmann *et al.* 1987) with an extension to account for immigration and/or emigration (IEJHE) of sheep to/from the census polygons (Neal *et al.* 1993), to calculate a population estimate for each sub-population with 95% confidence intervals using the survey data from December 2006 and March 2007. The IEJHE input data is based on observations within the census polygons but incorporates the proportion of collared sheep outside the polygons and the minimum number sighted to derive an estimate of Sentinel and Stone ewe populations.

The IEJHE was used to calculate the population estimate for ewes only. We accounted for sexual bias of the marked sample population to estimate total lamb, yearling, and ram numbers by multiplying the proportion of lambs, yearlings, and rams to ewes in December by our derived population estimate of ewes for each population. We used the December data for all elevations to derive the estimates for lambs, yearlings, and rams because the number of ewes sighted did not differ between censuses, but fewer rams were observed in March. Sheep observed incidentally or by radiotelemetry at elevations below 1,400 m were included in the lower limit population estimates but censored out for sightability correction.

Relative group composition and mean group size of each population were calculated as well. Groups were classified as being either a ram, ewe, mixed, or nursery group. Nursery groups were defined as ewes with lambs, yearlings, and class I rams while mixed groups contained at least one class II or older ram. The proportion of lambs to ewes observed within each population was calculated for both December and March using observations from all elevations.

True survey effort for each census was calculated using flight line data to determine only the time spent actively searching for sheep and excluded ferry time to refuel or search for sheep with radiotelemetry. Density calculations were derived based on the total area of ≥1,400 m census polygons within each population sub-unit. Slope, aspect, and elevation of Stone's sheep within census polygons were derived by plotting animal locations on a DEM grid and employing an Avenue script to populate the point file attribute table. After confirming assumptions of normality, differences in mean slope, aspect, and elevation utilized by sheep between populations and censuses were tested for significance using analysis of variance (ANOVA). Mean group size was calculated for the Sentinel and Stone populations. A Student's *t*-test was used to determine if there were differences in mean group size among populations and censuses. Mean values are reported ± Standard Error (SE). All tests of significance were measured against the 95% confidence interval (α=0.05).

Results

Survey Conditions

Censuses were conducted on Nov. 22-23 and Dec. 9-16, 2006 and Mar. 16-23, 2007. Very cold ambient air temperatures

(< -25 °C) required us to terminate the census temporarily on Nov. 24, 2006 and resume on Dec. 9, 2006. Areas previously searched that were spatially isolated, where the likelihood of animals emigrating or immigrating out of the area was low, were not resurveyed. Contiguous areas where there was increased likelihood of double counting were resurveyed in their entirety. With the exception of the cold temperatures in November 2006, weather conditions were generally favourable during both censuses. Frequent light snowfall overnight cleared in the morning allowing for good visibility. Strong winds made flying difficult at times but wind events were short lived and did not significantly hamper census activities.

Stone's Sheep Demography

Population size and structure - The total number of Stone's sheep counted within the S8M Project area in December 2006 was 939 and 875 in March 2007. True survey effort was 2.61 min/km^2 in December and 3.03 min/km^2 in March, and covered all census polygons. Sightability of marked ewes varied between populations and censuses (Table 2). Overall sightability was greatest in December at 83.5% compared to 71.9% in March. The IEJHE population estimate for adult ewes in the Sentinel was 224 (95% CI 190-279) and for the Stone was 202 (95% CI 176-240; Table 2). The Sentinel population was estimated at 150 lambs, 43 yearlings, 181 rams, and 29 unclassified for a total estimate of 627 (95% CI 532-781) sheep (Figure 2a). The Stone population estimates were 147 lambs, 26 yearlings, 156 rams, and 14 unclassified for a total population estimate of 545 (95% CI 475-648) sheep (Figure 2b).

Results of progesterone level analysis from blood samples collected during March 2006 captures indicate a mean pregnancy rate of 88.2 ± 0.7% among marked Stone's sheep ewes (n = 76). Pregnancy rates in the Sentinel and Stone populations were 88.9% (n = 36) and 87.5% (n = 40) respectively. Assuming all lambs were brought to full term, we observed an overall neonate to 6 mths survival rate of 79% and 65% survival to 9 mths (Table 3). Lamb survival to 6 mths was similar between Sentinel and Stone populations but differed between populations in March. There were similar lamb to ewe ratios between collared and uncollared ewes. We calculated lamb to collared ewe ratios at all elevations and populations at 0.70 in December and 0.60 in March. Overall ratios of lambs to uncollared ewes were 0.72 and 0.61 in December and March respectively.

Distribution, group sizes, and density - Large-scale distribution of groups did not appear to vary notably between censuses. However, we observed a 21% decline (n = 44) in the number of rams sighted within all census polygons between December and March. This decrease was most evident with respect to class II and III rams in the Stone population, with 59% (n = 48) fewer observed above tree line in March compared to December. The mean group size of Stone's sheep observed within the census polygons varied between censuses (Table 4). Mean group size was larger in the Stone population than the Sentinel population in March ($F_{1, 113}$ = 5.27, P = 0.024). Relative group composition was similar with only mixed and nursery groups changing notably from December to March (Table 4). In both December and March, 80% of all groups located at <1,400 m elevation were within 200 m of census polygon boundaries. Stone's sheep density within the census polygons was similar in the Sentinel population but differed in the Stone population between December and March. The Sentinel population density was 0.64 sheep/km^2 in December and 0.62 sheep/km^2

in March. Stone's sheep density in the Stone population was 1.38 sheep/km^2 and 1.00 sheep/km^2 respectively. Mean sheep density within all census polygons was 1.01 ± 0.37sheep/ km^2 in December and 0.81 ± 0.19 sheep/ km^2 in March.

Habitat associations **-** Mean slope, aspect, and elevation of Stone's sheep during December 2006 in the Sentinel and Stone populations were 32 ± 0.97 degrees, 189 ± 10.85 degrees, 1617 ± 9.47 m and 31 ± 1.15 degrees, 175 ± 13.27 degrees, and 1566 ± 12.33 m respectively. Mean elevation of sheep differed between populations in December ($F_{1, 163}$ = 7.40, P = 0.007). Mean slope, aspect and elevation occupied by sheep during March 2007 in the Sentinel and Stone populations were 32 ± 1.03 degrees, 196 ± 10.75 degrees, 1620 ± 15.78 m and 36 ± 1.45 degrees, 203 ± 9.60 degrees and 1536 ± 18.09 m, respectively. Mean slope ($F_{1, 113}$ = 6.79, P = 0.01) and elevation ($F_{1, 113}$ = 10.06, P = 0.002) differed between populations in March.

Discussion

Conducting two population censuses in a single winter provided an opportunity to establish a population estimate with a high level of confidence, and to assess the implications of early and late winter survey protocols for population estimation. The data suggest that there were approximately 1,200 sheep (minimum 939) in the S8M Project area in 2006/2007. By comparison, MWLAP (2004) conducted an aerial survey for Stone's sheep in the S8M Project area in March 2004. This total count survey of suitable winter habitat reported 888 sheep were observed; 507 in the Sentinel and adjacent ranges west of the Toad River, and 381 in the Stone Mountain Range, southeast of the Toad River. MWLAP (2004) also reported results for a similar survey in 1977, which found 997 sheep total.

Data summaries presented by AXYS (2005) indicate that MWLAP's March 2004 classification included 419 (47%) ewes and class I rams, 149 (17%) lambs, 80 (9%) yearlings, and 240 (27%) rams. The reported lamb: ewe ratio was 0.36 ('ewes' included yearling and Class I rams) and the ram: ewe ratio was 0.57. This is comparable to the March 2007 classification of 875 sheep that included 399 (46%) ewes and class I rams, 200 (23%) lambs, 54 (6%) yearlings, and 193 (22%) rams observed in the project area (all elevations), for both populations combined.

The estimated pregnancy rate of 88% suggests good population productivity as pregnancy rates of 75 to 100% are considered typical for thinhorn sheep (Hoefs and Bayer 1983, Nichols and Bunnell 1999). Lamb: ewe ratios reported for mountain sheep ranged from 0.08-0.82 (Nichols 1978, Harper 1984, MoE 1985, Douglas and Leslie 1986, Wehausen et al. 1987, Hass 1989, Corbould 2001, Wood 2002, Walker et al. 2006). Our data suggest favourable recruitment in both populations within the S8M Project area as our ratios tend toward the upper range of these values. Recent studies of Stone's sheep in northern BC reported spring-summer lamb to ewe ratios of 0.82 (Walker et al. 2006), 0.27 (Wood 2002) and 0.30 (Corbould 2001). Demarchi and Hartwig (2004) note that summer lamb to ewe and yearling ratios of 0.30 - 0.40 are generally considered sufficient for population stability, assuming normal winter conditions. Given approximately 15% annual mortality rate of ewes (S8M Stone's Sheep Project, unpublished data) and assuming an equal sex ratio in lamb production, late winter lamb to ewe ratios ≥0.30 should be expected to support a stable or growing population.

The general distribution of sheep observed in December 2006 and March 2007 did not change across the study area. With the exception of a decline in lamb to ewe ratios and the number of young rams in the Stone population, our age and sex classifications were also very consistent between the December and March censuses. This supports our assumption of geographic closure of wintering herds within the project area, and indicates good repeatability with respect to our census results.

Typically, aerial surveys of mountain sheep attempt to completely cover an acceptable number of survey units or strata and strive to enumerate every sheep in these strata (Neal et al. 1993, Bodie et al. 1995, Udevitz et al. 2006). Survey effort reported from thinhorn sheep inventories in Alaska ranged from 0.30 - 1.34 min/km^2 using fixed-wing aircraft (Strickland et al. 1994, Udevitz et al. 2006). Our survey effort is similar to helicopter surveys of mountain sheep in Colorado (2.60 min/km^2) and mountain goats in northern BC, which occupy similar habitats to sheep (3.80 min/km^2; 3.1 min/km^2) (Neal et al. 1993, Poole et al. 2001, Hengeveld 2004). However, the detection rates reported were lower in all but one inventory cited than the means of both of our inventories.

It has been suggested that detectability of mountain sheep can be influenced by group size and composition, activity, habitat, weather, and the relative location of the animal to the aircraft in complex topography (Strickland et al. 1994, Bodie et al. 1995). We agree that larger group size increases sightability (Eberhardt et al. 1998, Udevitz et al. 2006) but only to a degree as large groups (>20) were much more difficult to enumerate and class than smaller groups and marks can easily be missed. We contend sightability was considerably reduced in the Sentinel population in March as sheep appeared to elicit a flight response to the helicopter less often in March than in December, and were dispersed within expansive, rugged alpine that enabled sheep to retreat for cover against the rocks and remain relatively motionless, effectively lowering their detectability to observers.

Our assumption that there was an equivalent probability of sighting all marked and unmarked individuals was likely a source of error. Given the gregarious nature of sheep, their tendency to site fidelity, the presence of more than one marked sheep in some groups, and that group characteristics can affect detection probabilities, it may be argued that sightability should based on the number of marked groups observed, rather than the number of marked individuals. Based on these assertions, we calculated sightability of marked ewes both as an individual and by groups during analyses. Our findings agree with those of Neal *et al.* (1993) that population estimates that use groups for calculations rather than by individuals results in an overestimation of the target population, especially if the population is large. As well, a decrease in confidence due to the reduced number of marks available for sightability correction emerges when calculating population estimates using marked groups rather than on marked individuals sighted.

Udevitz *et al*. (2006) reported a high mean detection rate (88%) of marked collars and stated that confidence in annual population estimates increased due to the number of marked sheep sighted and not due to refining estimates of detection probabilities. In some instances, marked ewes in the S8M area were not sighted in the open alpine during the surveys and were subsequently located outside of census polygons using telemetry, often using tree canopy near the polygon boundaries for refuge. However, due to the relatively large sample size and using proportions of sighted marks over both surveys, the reduction in precision of the estimate is likely small (Neal *et al.* 1993).

The results in relative group composition between surveys were somewhat surprising. As mountain sheep are typically sexually segregated throughout most of the year and interact only during courtship (Geist 1971, Seip 1983), we expected greater separation of ram and ewe/nursery groups in late winter. High ram to ewe ratios and similar relative group composition between surveys suggest we likely sighted most rams, and they appeared to be occupying the same ranges as ewes. The increase in mean group size coupled with the decrease in the number of groups in late winter may suggest limitations in optimal winter ranges within the project area (Shackleton *et al.* 1999). If limitations of optimal winter range exist, this appears more evident in the Stone population where late-winter group aggregation is more pronounced, and overall densities are approximately double that of Sentinel sheep. Over-winter lamb survival was lower in the Stone population than in the Sentinel population. This may suggest that there are density-related limitations of optimal winter habitat in the Stone population at elevations ≥1,400. Further, limited optimal winter range and higher density may cause sheep to utilize habitats that may increase the chance of predation or reduce nutritional resources, increasing winter mortality (Douglas and Leslie 1986, Wehausen et al. 1987, Festa-Bianchet 1988, Portier et al. 1998).

While the two populations appear to differ somewhat demographically with density potentially being the key factor, broad habitat associations were similar, with sheep favouring south-facing, moderate-steep slopes in winter. Differences in mean elevation may be due to the topography and elevation range between mountain ranges or snow depth as Stone's sheep may stop excavating for forage when snow depths exceed 30 cm (Seip and Bunnell 1985) or when snowpack conditions hinder forage efforts (Geist 1971). Habitat data for both December and March agree with that reported from other Stone's sheep studies where winter range typically consists of steep, south-facing cliffs (Wood 1995, Corbould 2001) and wind-blown alpine ridges (Backmeyer 1991). Use of these areas by competing species varied between censuses, with moose and elk potentially significant competitors in the eastern Stone area, particularly at elevations at or near tree line, and caribou more prevalent in the Sentinel area.

Management Implications

Results from both censuses indicate little use of the northern half of the S8M High Elevation Zone PTP area by Stone's sheep. Only one group of 4 sheep (including a radiocollared ewe) was observed during the December 2006 and March 2007 surveys. Both ewes and rams are known to use ranges in the southern half of the High Elevation Zone PTP area, south of the Toad River. Of particular interest with respect to our analyses is that we counted similar numbers of ewes, but less than half the number of 3-6 yr old (approx.) rams above tree line in this area in March compared to December. In the Sentinel Range, we counted about the same number of rams in December and March. This suggests that rams and ewes may differ in their use of the southern portion of the PTP area, with rams possibly using lower elevation habitats in late winter or moving to different ranges. Habitat use data collected with GPS collars on ewes and rams will be used to quantify habitat values, and help to identify the importance of the PTP area to Stone's sheep.

Because the oil and gas industry has significant interest in developing the area, the impetus to capture current, accurate demographic and distribution data on the sheep population residing within the Sulphur/8 Mile Project area provided the rationale to conduct intensive inventories during the baseline phase. Designing a repeatable census methodology, utilizing on-board, real-time flight tracking with GIS and marked ewes for sightability correction, enabled an accurate population estimate. A greater total number of sheep and a greater proportion of marked sheep observed in December provided justification for using December ratios of ewes to lambs, yearlings, and rams to estimate total population size. As such, conducting a population survey during the end stage of the rut while sheep are congregated in high elevation alpine ranges may be the best option to obtain a more precise total population estimate, especially if little is known about the population’s age-sex structure or the marked sample population is sexually biased.

Acknowledgments

I wrote in the first person plural throughout this paper to acknowledge the contributions of the following people and organizations. The December 2006 census was conducted by Pamela Hengeveld (Synergy Applied Ecology), Clint Cubberley (Synergy Applied Ecology), Conrad Thiessen (Ministry of Environment), and Tara Anhel (Quest Helicopters). The addition of a late winter census in March 2007 was made possible by Brian Churchill (S8M Stone’s Sheep Project Science Advisory Committee chairperson) and Andy Ackerman (Ministry of Environment). The March 2007 census was conducted by Pamela Hengeveld (Synergy Applied Ecology), Clint Cubberley (Synergy Applied Ecology), Kathleen Dyke (biologist), and Sean Rickards (Yellowhead Helicopters). This work was primarily funded by the Muskwa-Kechika Trust Fund and Advisory Board, with helicopter support in March 2007 funded by the Ministry of Environment and reporting supported by the BC Oil and Gas Commission Science and Environmental Knowledge (SCEK) Fund.

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Tables

Table 1. Total area (km^2), census area (km^2; ≥1,400 m elevation) and elevation (metres above sea level) of the Sentinel and Stone subunits within the Sulphur / 8 Mile Stone's Sheep Project area, northern British Columbia.

Subunit	Census area	Total area	Elevation range
Sentinel	579	2460	450-2350
Stone	257	1777	450-2100
Total	836	4237	450-2350

Table 2. Mark-resight parameters for females marked with radiocollars in two Stone's sheep populations enumerated during the December 2006 and March 2007 censuses in the Sulphur/8 Mile Project area, northern British Columbia. The census polygons were limited to alpine areas (≥1,400 m elevation); sheep sighted at lower elevations (<1,400 m) were located incidentally or found by telemetry of radio-collared sheep. The total number of females was estimated using NOREMARK software for repeated counts, incorporating a joint hypergeometric maximum likelihood estimator with an extension to account for immigration and/or emigration (IEJHE) of sheep to/from the census polygons.

	Total marked	# marked in census area (% of total)	Marked seen (% sightability in census area)	Unmarked females sighted in census area	IEJHE estimate for total number of females (95% CI)
Sentinel					
December	32	24 (75.0)	21 (87.5)	110	224
March	32	29 (90.6)	17 (58.6)	117	(190 – 279)
Stone					
December	45	39 (86.7)	31 (79.5)	102	202
March	42	27 (64.3)	23 (85.2)	97	(176 – 240)

Table 3. Estimated Stone's sheep lamb survival to 6 and 9 months calculated using observed lamb to ewe ratios for the Sentinel and Stone populations in the Sulphur/8 Mile Project area, northern British Columbia. Pregnancy rates were estimated from blood progesterone levels of 76 adult ewes during March 2006 capture.

Date	Sentinel	Stone
Pregnancy rate	0.89	0.88
December 2006 census		
Lamb:ewe	0.67	0.73
Lamb survival to 6 mths	0.75	0.83
March 2007 census		
Lamb:ewe	0.64	0.51
Lamb survival to 9 mths	0.72	0.58
Overwinter lamb survival (Dec - Mar)	0.96	0.70

Table 4. Mean group size and relative group composition of Stone's sheep enumerated within the census polygons (≥1,400m) during the December 2006 and March 2007 censuses in the Sulphur/8 Mile Project area, northern British Columbia. Nursery groups were defined as ewes with lambs, yearlings and class I rams while mixed groups contained at least one class II or older ram.

Census date	# groups	Mean	Ewes	Mixed	Nursery	Rams	Unclassified
December							
Sentinel	93	3.98 ± 0.34	0.03	0.41	0.30	0.24	0.02
Stone	71	5.00 ± 0.47	0.04	0.54	0.21	0.21	0
Combined	164	4.42 ± 0.28	0.04	0.46	0.26	0.23	0.01
March							
Sentinel	78	4.64 ± 0.53	0.06	0.36	0.29	0.24	0.04
Stone	36	7.14 ± 1.12	0.05	0.28	0.44	0.22	0
Combined	114	5.43 ± 0.52	0.06	0.33	0.34	0.23	0.03

Figures

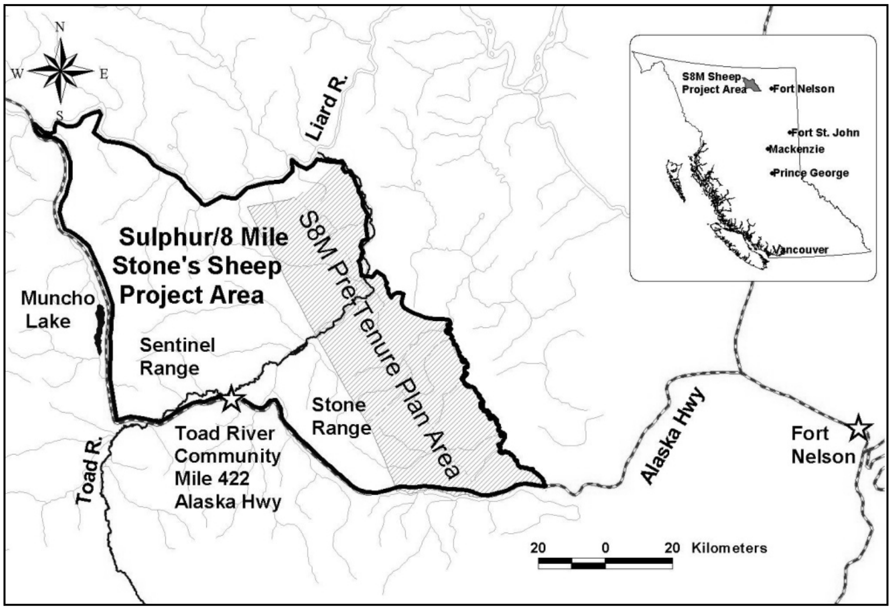

Fig. 1

Figure 1 Location of the Sulphur / 8 Mile (S8M) Stone's Sheep Project area in northern British Columbia, Canada. The Toad River divides the project area into the Sentinel (north) and Stone (south) subunits. Boundary of the S8M oil and gas pre-tenure plan area is shown.

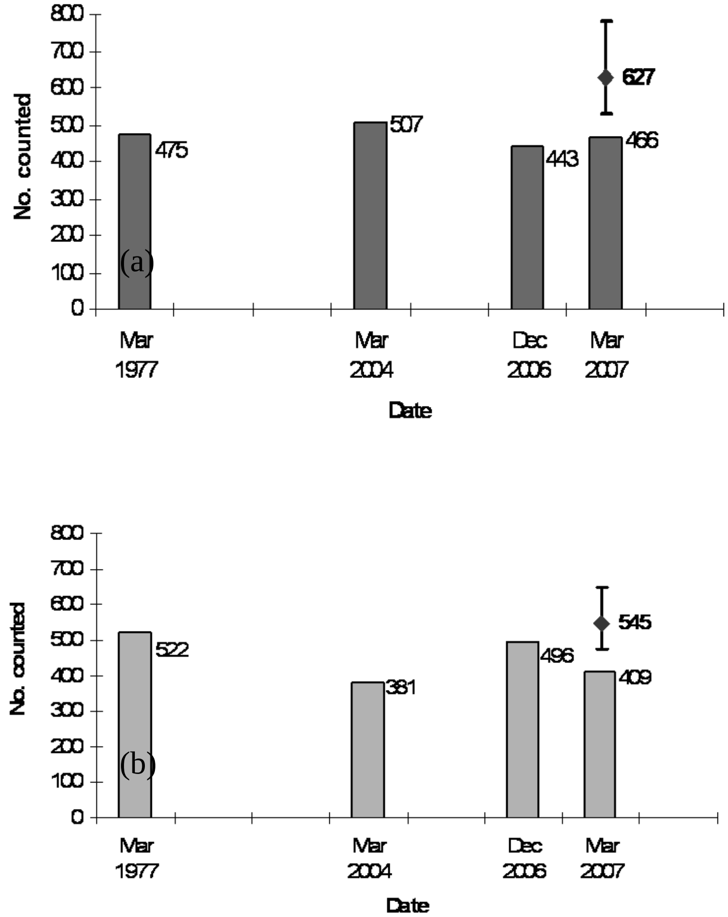

Figure 2. Winter 2006/2007 population estimates (red diamond) for the Sentinel (a) and Stone (b) populations with 95% confidence intervals, based on sightability of marked ewes and the total number of Stone's sheep observed in the project area. Using December 2006 and March 2007 survey results, ewe estimates were calculated using NOREMARK software for repeated counts incorporating a joint hypergeometric maximum likelihood estimator with an extension to account for immigration and emigration from census polygons. Lamb, yearling and ram estimates were calculated using the proportion to ewes counted in December. March 1977 and 2004 counts are from inventories conducted by MoE without the benefit of marked sheep (MWLAP 2004).

A Study of Bighorn Sheep Diet Composition and Home Range on the Pine Ridge Region of Northwest Nebraska

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Abstract: The Fort Robinson Nebraska Rocky Mountain bighorn sheep (*Ovis canadensis*) Herd was established in 1981and has slowly expanded its range overtime to encompass the majority of the Fort property. As the herd expanded its range, its population also increased to roughly 120 individuals, but went through a die off in the winter of 2004-2005, though it is currently on the rebound. The objective of this study is to determine if this is a sedentary herd and if diet or competition with other herbivores is a limiting factor affecting this herds overall health. In January and February of 2007, 19 ewes and 5 rams were captured via net gunning and marked with VHF collars. Each individual will be observed one or more times a week for two calendar years. During these observations, bite count and fecal samples will be taken (10 per month and 10 per week, respectively) to determine the diet composition. Any observations of direct or indirect competition with livestock (cattle, bison, donkeys, and horses) or other wildlife (pronghorn, mule deer, or elk) will be documented. The home range will be established by comparing three home range modeling techniques (modified convex polygon method, fixed kernel method, and adapted kernel method) to determine the model that best represents the observed locations.

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Comparison of Bighorn Sheep Forage, Hair, and Feces Using Stable Isotopes

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Abstract: Stable isotopes have been used to document diet history in black bears (Mizukami et al. 2005), short term diet changes in horses (West et al. 2004), and to determine the diets of various African ungulates and bovids (Sponheimer et al. 2003a, Sponheimer et al. 2003b, Codron et al. 2007). We collected samples of forage, hair, and feces from bighorn sheep (*Ovis canadensis)* in 6 areas during summer and autumn in 2005 and 2006 in Utah, USA. We observed foraging locations of bighorn and collected fecal samples as well as plant species eaten by these animals. Similarly, we collected forage samples from nearby random locations for comparison with plants eaten by bighorns. We also collected hair from animals in one population. Mass spectrometry was used to analyze each of these samples for $\delta^{13}C$ and $\delta^{15}N$ isotope ratios. We are looking to see if the difference in ram and ewe diets is quantifiable using isotope rations and to determine diet differences between seasons. Our preliminary results indicate that there is a difference between ram and ewe diets. Analysis of stable isotopes can be a useful tool to identify plant species that are consumed by bighorns. This technique can be used by wildlife managers to reseed in bighorn habitat after fires or treatment.

Key Words: bighorn sheep, stable isotope analysis, forage selection

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Introduction

Rocky Mountain bighorn sheep (*Ovis canadensis canadensis*) have been an integral part of the natural history of Utah. Their original range covered all but the southeastern and southernmost parts of Utah. Their depictions are common in native art and are mentioned in the annals of the earliest explorers of what is now Utah. These animals were mostly extirpated from the state by the 1960's (Rawley 1985) because of factors relating to interactions with settlers and their livestock and livestock management practices (Shields 1999). This includes direct competition for forage resources and diseases, especially lungworm from domestic sheep.

Current practices of bighorn sheep management in Utah include the reintroduction of animals from Montana and Colorado into local historic ranges. The primary purpose of these releases is for sheep conservation, but it also provides wildlife viewing and hunting experiences for people. Currently, Rock Mountain bighorn and California bighorn (*O. c. californiana*) have been used to reestablish populations of these animals in northern Utah. California bighorns have been released on Antelope Island and the Newfoundland Mountains (Jericho Whiting, personal communication 2007). All other areas in our study received

Rocky Mountain bighorn. In southern and southeastern Utah mostly desert bighorn have been translocated. California and Rocky Mountain bighorn sheep should not be considered separate subspecies (Wehausen and Ramey 2000); therefore, in this paper, we treat them as a single species (UDWR Statewide Management Plan for Bighorn Sheep 1999).

Bighorn sheep reintroductions are not uncommon and have been used throughout the western United States (Krausman 2000). Indeed, of 100 sheep reintroductions 70 of these were either successful or moderately successful (Singer et al. 2000). The Utah Division of Wildlife Resources has exerted much effort reintroducing bighorn sheep to their native ranges in Utah including Flaming Gorge and Cache Valley in the north, the Newfoundland Mountains west of the Great Salt Lake, Antelope Island, the Stansbury Mountains, and the Wasatch Mountains (American Fork Canyon, Rock Canyon, and Mt. Nebo).

The management plan for bighorns in Utah indicates that research is needed to increase lamb survival and to “initiate vegetative treatment projects to improve bighorn habitat lost to natural succession or human impacts” (UDWR Statewide Management Plan for Bighorn Sheep 1999). Before performing range improvements, such as reseeding of desired plant species, both for existing wildlife populations and prior to wildlife introductions it is critical to understand the diets of each animal to be released. Previously this required many man hours and time consuming practices such as direct observation of bite counts and captive rearing of wild ungulates (Dailey et al. 1984 and Goodson et al. 1991). Now, new technology involving mass spectrometry makes it possible to determine the chief components of an animal’s diet simply by analyzing hair composition (West, et al. 2004, Schwertl et al. 2003). The ratio of $\delta^{12}C$ to $\delta^{13}C$ and $\delta^{14}N$ to $\delta^{15}N$ is standard in different plant species. When consumed, these ratios remain constant and are used in the growth of the animal, or in other words, there is a set differential offset between diet and hair, and because this value is set and does not fluctuate, the offset value can be used to indicate the forage signature (Todd Robinson 2008 personal communication). By determining the presence of these ratios, hair can indicate which plant species or types are consumed. By decreasing the amount of time and funds spent to determine plant use wildlife management agencies will be better able (both in time and money) to enact range improvements.

Methods

We observed bighorn sheep foraging various locations across the Great Basin, including the Newfoundland Mountains, Stansbury Mountains, Antelope Island, American Fork Canyon, Rock Canyon (Provo), and Mt. Nebo. We located sheep that had been equipped with radio collars before and during the 2005-2006 using radio telemetry and observed for at least 20 minutes while grazing using spotting scopes and binoculars. A detailed map of the foraged area was made by hand showing plants and locations the sheep foraged. After sheep had left the site, either later the same day or the next day researchers returned and using the map made previously, we would locate exactly where sheep had foraged, based on evidence of bites on plants. When a use site was found, a 1 m. plot was centered around the bite site and all plant species within the plot were cut to ground level and separated by species, bagged, and weighed. We also recorded percent cover, percent use, and dominant phenotype for each plant species found in the plots. Five such use plots were collected for each day of sampling. For each use site a random site was also sampled following the same protocol. If a plant species that was consumed was found in the random site it was collected and processed in the same manner as in the use site. If the species was not found in the random site then the nearest plant was found and at least 20g was collected. After collection each plant sample was dried in an oven in 60°C for 24 hours and then reweighed (Flinders and Hansen 1972). Furthermore, we entered all information that was collected into a database based on location and date and whether the group of sheep was composed of rams, ewes and lambs, or a mix. Additionally, we collected fecal samples from foraging locations. These samples were dated and labeled based on the use group (ewe, ram, lamb).

These plants and feces are now being ground using a 0.425 mm mill, to produce a fine homologous sample. Like species from each sample day were ground together, keeping plants from use sites separate from those in random sites. From these ground samples a 600-700µg sub sample will be collected for stable isotope analysis in a mass spectrometer. To date the focus has been on processing samples from Antelope Island.

We also collected hair samples from sheep on Antelope Island to determine if the stable isotope ratios of different plant species of known use collected from Antelope Island appear in the hair after stable isotope analysis. Hairs were labeled according to the sex of the animal and the date it was extracted. We cut hairs in 1 mm segments starting at the proximal end (Sponheimer et al. 2003). To obtain a sufficiently large sample (350-550µg) more than one hair from each individual will be used. Hair samples will then be run on a continuous flow mass spectrometer to determine isotope ratios.

Values gained from the mass spectrometer were used to determine each plant species fraction in the diet based on the fecal values based on the equation $[(\delta^{13}C_{feces/hair} + 1000) / (\delta^{13}C_{forage} + 1000) - 1] / 1000$ = diet fractionation. This provides an estimate of the short term diet. The results from the hair analysis will provide a better look at the long term and seasonal diets.

Results

The correlations gathered from stable isotope analysis of bighorn sheep hair and forage from Antelope Island will be paired with a nutritional analysis of the Antelope Island forage. This information will detail which plant species are preferred by the sheep and which provide the best nutrition. These findings will then provide the state with the focal species that should be used to reseed areas of ewe and lamb use. The same analysis on other forages in the other bighorn locations will provide the same information for each of the different locations sampled by researchers.

As can be seen in Figure 1, C3 and C4 plants are easily identified by their different isotope signatures. Then in Figure 2 the diet fractionation of different plant species in ram and ewe diets is expressed. Values that are positive or near zero are relatively abundant in the diet, whereas negative values make up small proportions of the diet. These results are preliminary and not yet refined or compared with the other sheep populations along the Wasatch Front and Great Salt Lake Desert of Utah. Four more populations of bighorn sheep will be compared with the same techniques and will result in a description of the differences in diet over short distances.

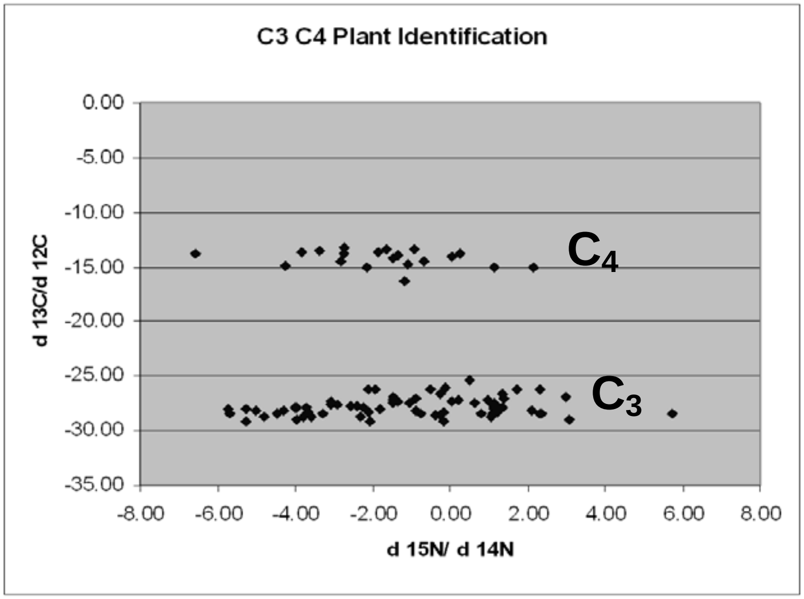

Figure 1. A comparison of C3 and C4 plants types found in the diet of bighorn sheep on Antelope Island, Utah from 2005 to 2006.

	Ram	Ewe
Eriogonum divergens	1.66	-0.13
Carex spp.	1.64	-1.28
Artemesia ludoviciana	1.21	0.09
Lactuca serriola	0.58	No use
Helianthus annuus	-0.02	-1.23
Compositae spp.	-0.15	No use
Epilobium brachycaulum	-0.16	-15.05
Bromus tectorum	-1.74	-13.67
Erodium cicutarium	-13.94	-0.54
Aristida purpurea	-14.08	0.51

Figure 2. Fractionation values of different plant species in the feces of rams and ewes from Antelope Island, Utah. Values that are positive or near zero denote a higher proportion in the diet.

Discussion

Rams and ewes separate into separate groups, except during breeding season. During segregation rams stay in bachelor herds and will move around looking for the best feed (Bleich et al. 1997). Ewes, however, tend to stay near escape terrain (cliffs and steep slopes), where they and their lambs can more effectively avoid and/or escape from predators. These areas offer the best opportunity for safety, but do not allow access to the best available forage. While bighorn sheep have a highly variable diet, one that is difficult to quantify by species (Krausman and Bowyer 2003) stable isotope analysis will cheaply register plant types consumed. Any reseeding projects can focus on the local plant species best suited for ewes and lambs and be located near escape terrain. Since the survival of young and their recruitment, or their addition to the breeding population, is of vital importance to the sustainability and growth of bighorn sheep herds, increasing the vigor of lambs without removing them from escape terrain will allow the bighorn sheep herds in the Great Basin to grow.

By knowing the best plants to revegetate range with, based on use and known nutrient content, management agencies will be able to determine which species to reseed based on a nutritional and foraging preference basis. Currently the methods used to determine forage use in wild ungulates is to observe foraging behavior. This is time consuming and costly. Using hair samples (even from harvested animals or carcasses) could simplify and cut the costs associated with determining forage use. This method can then be replicated with other wildlife species to help in other revegetation projects, or during reseeding after wildfires.

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Response of Bighorn Sheep to Restoration of Winter Range: Revisited

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Abstract: Winter range for bighorn sheep (*Ovis canadensis*) in south-eastern British Columbia has declined in both quality and availability due to forest ingrowth. In 2003 we applied mechanical treatments to a 200 ha portion of traditional bighorn winter range near Radium Hot Springs, British Columbia in an attempt to improve habitat suitability. In 2005 we applied prescribed fire to a portion of the previously treated area. We monitored bighorn sheep response to these treatments by deploying GPS radio collars on 10 sheep each year from 2002 to 2007 and collecting daily location points for each animal. Study animals increased their use of the treated area from 1.0% of daily locations in 2002 to 8.9% in 2004 and 4.3% in 2007. We plan to apply additional mechanical treatments and prescribed burning to nearby areas of winter range and mid-elevation transitional range, and to continue to monitor bighorn sheep response.

Key words: bighorn sheep, British Columbia, GPS, habitat, Kootenay National Park, *Ovis canadensis*, prescribed fire, radiotelemetry, restoration, winter range.

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In winter, most populations of bighorn sheep (*Ovis canadensis*) in southeastern British Columbia depend on low-elevation open forest and grassland habitats that were formerly maintained by frequent, low-intensity ground fires (Demarchi et al. 2000) or by mixed fire regimes of frequent low-intensity fires with occasional stand-replacing fires (Gayton 2001). Fire suppression has altered the natural disturbance regime and these habitats have declined due to the resultant forest encroachment (Davidson 1994). Additionally, the quality, extent and effectiveness of critical winter range have been affected by competing land uses, including urban and rural settlement, agriculture, resource extraction, and off-road motorized recreation (Demarchi et al. 2000; Tremblay 2001; Tremblay and Dibb 2004). At Radium Hot Springs, British Columbia the bighorn sheep population consists of about 200 animals (Dibb 2006). In the last several decades, deteriorating range conditions on traditional winter habitats of this herd have been implicated in the partial abandonment of these ranges in favour of artificial grasslands such as golf courses, residential lawns and highway rights-of-way within and adjacent to the town (Tremblay and Dibb 2004). This has increased habituation of bighorns, exposed them to harassment by dogs and humans, and increased mortality of bighorns along highways. Consequently, Tremblay (2001) recommended restoration of portions of historic bighorn winter range in the Radium Hot Springs area.

We carried out mechanical treatments on a 200 ha site in 2003, including timber removal with retention of clumps of veteran trees, brushing, piling and burning, and noxious weed control. We began global positioning system (GPS) radiotelemetry monitoring of a sample of bighorn sheep in January 2002 and therefore acquired one full year of pre-treatment data. We previously reported on the response of the Radium bighorn sheep to restoration treatments as indicated by telemetry results from 2002 through 2004 (Dibb and Quinn 2006). Since that time we have completed a prescribed fire within the previously treated restoration area, and have continued to monitor bighorn sheep response. The purpose of this paper is to provide an update on sheep response including the period of 2005 through 2007.

Methods

Radiotelemetry monitoring methods were the same as those reported in Dibb and Quinn (2006). The Parks Canada Agency Animal Care Committee approved animal capture and handling methods under Research and Collection Permits LLYK02-01, LLYK02-35, LLYK03-15, LLYK04-02, and KOONP-2005-3518.

For each study animal we selected one GPS location per day, and then used a Geographic Information System (GIS) to determine which locations were inside the perimeter of the 2003 restoration area and which were outside. We determined the average number of locations inside the restoration area per animal per year, and also determined the total number of points inside and outside the restoration area in each year with all study animal locations pooled. We conducted chi-square analyses on the pooled animal locations to assess the magnitude and significance of between-year differences. We also summarized animal use of the restoration area by month and by sex.

We carried out a low intensity prescribed fire on 21 and 22 April 2005 by deploying ground crews with drip torches. The burn covered approximately 110 ha of the 200 ha area previously treated using mechanical means (Figure 1). Burning days were chosen according to a suite of weather and soil moisture parameters such that the predicted fire intensity would be sufficient to achieve objectives of burning slash, surface litter and duff while not causing widespread mortality of desirable native bunchgrasses. No mechanical treatment took place after 2003. We assessed bighorn sheep response to burns by considering use levels of the restoration area in pre-burn years compared to post-burn years. In addition, we examined all sheep locations within the original 2003 restoration boundaries in 2 periods: 2003-2004 (pre-burn) and 2006-2007 (post-burn), and determined the proportion of locations within the burned zone of the restoration area versus the unburned zones of the restoration area. We then used a chi-square analysis to assess the significance of differences of pre-burn and post-burn use of the burned and unburned areas.

Results

Bighorn sheep made more use of the restoration areas in each of the post-treatment years (2003 through 2007) than they did during the pre-treatment year (2002) (Figure 2). Differences in use levels, assessed by comparing each post-treatment year to 2002, were all significant to $P < 0.001$, except for 2006 (Table 1). Highest use levels were in 2004 and 2005, and lowest use levels were in 2006.

Most use of the restoration area occurred in March through June, prior to the sheep migrating to their lambing or summer ranges, and in October, when the sheep were moving between summer and rutting ranges (Figure 3). Female use declined rapidly after the middle of May because nearly all females migrated to lambing range at high elevation between mid- and late May. Male use levels were relatively high in June, but declined to near zero in July after the males moved to their summer ranges. Most sheep use of the restoration area in October was by males. Use levels by both sexes were low in November through February.

The increased use of the restoration area was distributed among nearly all study animals in the post-treatment years (Table 1). In 2002, prior to treatment, 5 of 7 animals were recorded on at least 1 day within the boundaries of the restoration sites (range = 1-5, SD = 1.5) for an average of 2.4 days per animal. In the post-treatment years, 2003-2007, 41 of 43 animals were recorded within the restoration area on at least one day (range = 1 - 56, SD = 13.1) for an average of 10.4 days per animal.

Subsequent to the initial treatments, the lowest levels of sheep use occurred in 2006 and 2007, the years immediately following the 2005 prescribed fire. In 2003 and 2004, 20.8% of locations inside the treatment area occurred within the perimeter of the future prescribed burn area. In 2006 and 2007, only 7.0% of locations inside the treatment area occurred within the burn perimeter, a significant difference compared to the pre-burn years ($\chi^2 = 10.8$, P = 0.001).

Discussion

Although use levels in all post-treatment years were higher than in 2002, the pattern of rapidly increasing sheep use from 2002 to 2004, as reported by Dibb and Quinn (2006), did not continue in subsequent years. However, we do not believe that the decline in sheep use after 2005 can be attributed to vegetation change within the restoration area. Page (2006) monitored a suite of indicator plants in the restoration area over the period of 2004 through 2006 and reported that forage plants generally increased in cover over the period of her study (only non-native species failed to increase). The same study also monitored plant responses on burned versus unburned sites. These results showed that most forage plants increased their cover on both burned and unburned sites. For non-native plants, cover decreased in unburned sites but increased in burned sites, although these differences were not statistically significant at the P = 0.1 level. The increase in percent cover of non-native species was from approximately 3% (2004) to 7% (2006), however we do not expect that these differences would have resulted in an observable decline in bighorn sheep use of the burned sites. We are not aware of vegetation changes at the shrub or overstory level that would have influenced bighorn sheep habitat selection.

Human activity has generally increased in the Radium Hot Springs area in recent years, with rapid growth in the human population (British Columbia Stats 2006) and strong demand for recreational opportunities. Human activity levels in the restoration area are of concern, but at present no on-going monitoring is occurring, and we have no evidence that recreational use of the area is limiting sheep use. Future monitoring of the patterns of human use within and near the restoration area would be valuable in helping us to understand the potential impacts of human activity.

Although sheep appeared to avoid the restoration area during the months with highest average snow depths (December through February), preliminary investigation showed no apparent relationship between sheep use and either winter snow depth or the date of disappearance of the winter snow pack. For example, snow disappeared from the restoration area relatively early in 2006, but sheep use levels were lower than in other years. Sheep use did not appear to be closely related to plant phenology in the restoration area. Much of the use in March and April occurred prior to plant green-up, even though green-up occurred earlier within the nearby winter ranges at slightly lower elevation.

We speculate that sheep may have adjusted their use of the restoration area in response to the presence of predators, particularly cougars (*Puma concolor*). The low levels of use of the restoration area in March through April of 2006 coincided with a period in which at least one cougar was known to be active, one of the few periods during our study in which repeat sightings of cougar were made (Parks Canada, unpublished data). Harassment by humans and dogs, either within the restoration area or in the Village of Radium Hot Springs, may have influenced sheep behaviour. It is also likely that arbitrary movement and habitat selection decisions by dominant animals played out differently in different years, contributing to the changing patterns of sheep use observed through our study.

Our monitoring confirmed the seasonal pattern of sheep use of the restoration area reported by Dibb and Quinn (2006). Most post-treatment use of the restoration area by Radium bighorn sheep occurred in October, and in March through June, periods when, prior to treatment, the sheep were still on winter range elsewhere in the Radium area. This may have alleviated some grazing pressure on winter range, as well as slightly reduced the various risks the sheep take in living near highways and within the village of Radium Hot Springs. However, this restoration site appears not to have the inherent capability to serve as core winter range for bighorn sheep, primarily due to its flatness and the resultant winter snow retention. The Parks Canada Agency currently has prescribed burn plans for the southwest and west facing slopes of Redstreak Mountain above the restoration area. This site, pending removal of thick forest cover through burning, appears to have a potentially suitable combination of habitat, slope, aspect, interspersion of escape terrain, and proximity to occupied sheep habitat. We plan to continue to monitor bighorn sheep response to these prescribed fire and other treatments in order to assess effectiveness, to adapt future treatments on the basis of this new knowledge, and to develop bighorn sheep habitat restoration prescriptions with broad applicability throughout bighorn sheep range in southeastern British Columbia. Our results demonstrate the value of long term monitoring, since some patterns of sheep response were not observable within the first 2 or 3 years of post-treatment monitoring.

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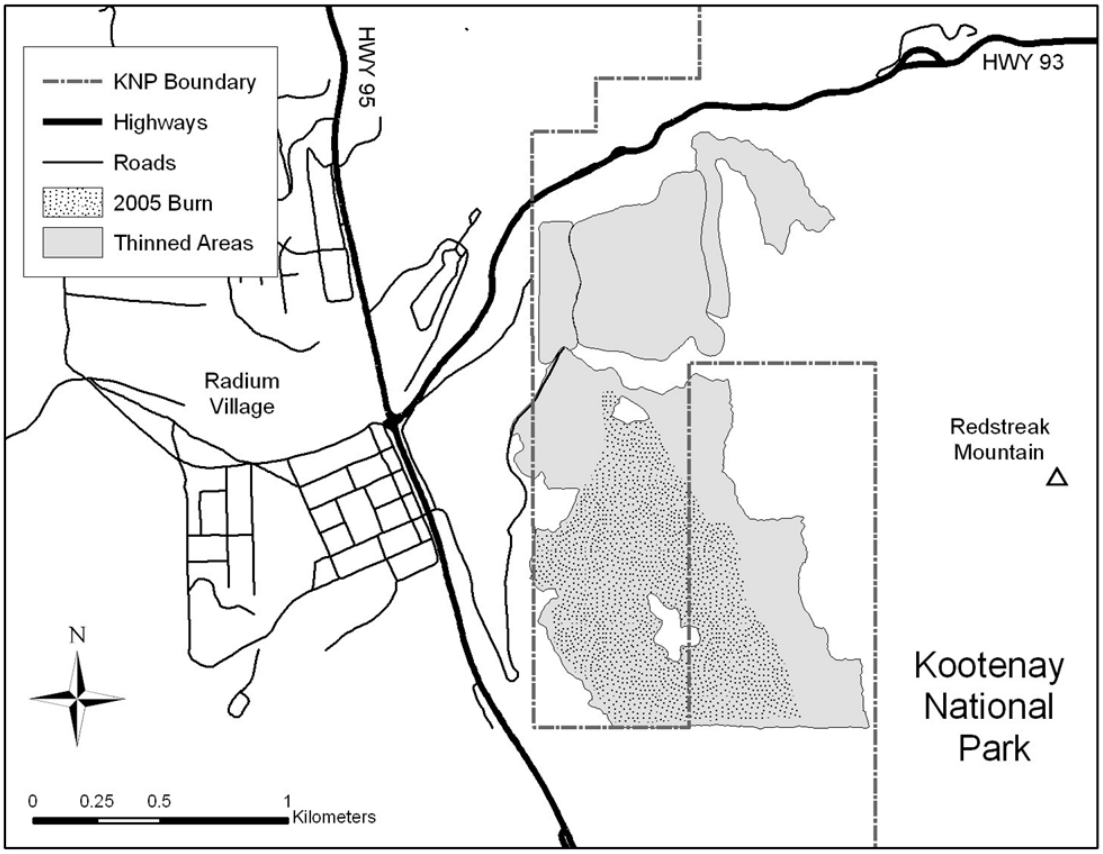

Figure 1. Layout of Redstreak restoration area in relation to the village of Radium Hot Springs and Kootenay National Park.

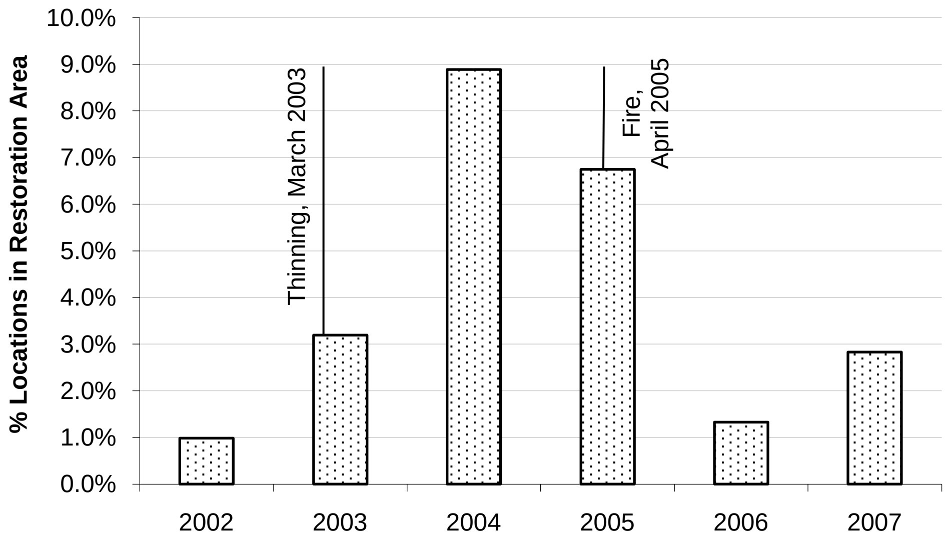

Figure 2. Percentage of bighorn sheep daily locations in restoration area by year, 2002 – 2007.

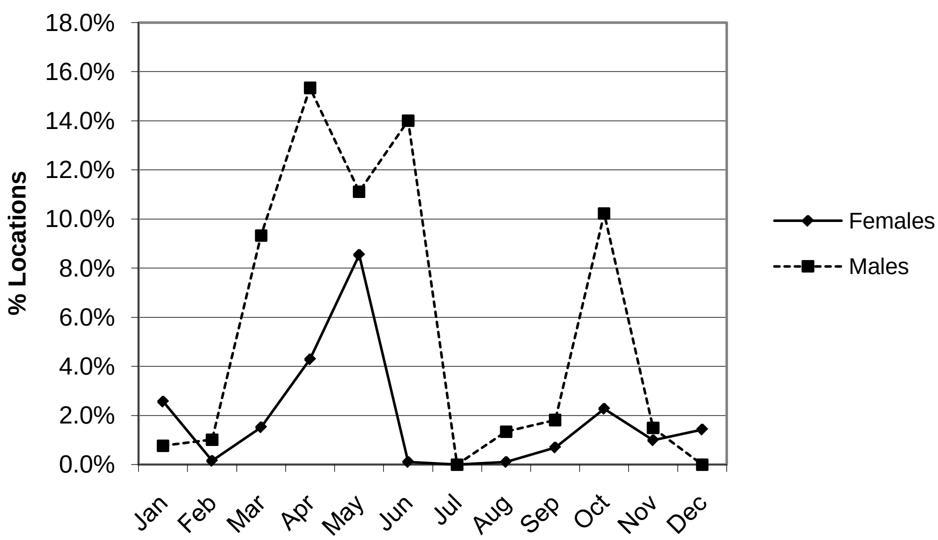

Figure 3. Percentage of bighorn sheep daily locations in restoration area by month, 2002 –2007.

Year	# Study Animals*	# Animals with ≥ 1 Location Inside	Average # Locations Inside Per Animal	Total # Locations (all animals)	% Total Locations Inside	□□□ Compared with 2002	P
2002	7	5	2.4	1830	1.0%	-	-
2003	9	9	7.9	2285	3.2%	22.97	< 0.001
2004	7	7	17.4	1721	8.9%	120.96	< 0.001
2005	8	8	17.9	2120	6.7%	83.39	< 0.001
2006	10	8	4.8	2865	1.3%	2.68	0.10
2007	9	9	8.0	2865	2.8%	18.39	< 0.001
2003-07	43	41	10.4	11473	10.4%	31.51	< 0.001

* Including only those study animals with at least 175 daily locations

Table 1. Bighorn sheep use of the restoration by year, 2002-2007, including average # daily locations in restoration area per animal, and % of locations of all animals in restoration area. Chi-square values and P values are shown for each post-treatment year (2003 – 2007) compared to the pre-treatment year (2002).

	Pre-Burn 2003-04	Post-Burn 2006-07	Chi-Square Value Pre-Burn vs. Post-Burn	P
# Locations Inside Burn Perimeter	47	8		
# Locations Outside Burn Perimeter	179	107	10.8	0.001
% Locations Inside Burn Perimeter	20.8%	7.0%		

Table 2. Comparison of pre-burn and post-burn use of the restoration area by bighorn sheep.

Factors Related to Poor Population Performance of California Bighorn Sheep on Hart Mountain National Antelope Refuge, Oregon

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Abstract: In 1995 the end of winter population of California bighorn sheep on Hart Mountain National antelope refuge was estimated at 600 individuals. By 2003 this population was estimated at 300 individuals and lamb recruitment during the period was adequate to maintain the population. For a 4 year period beginning in January, 2004 we radio marked and monitored 48 adult bighorn to determine cause of adult mortality, measure lamb production and recruitment, monitor herd health and measure sex and age specific survival. We will present results of this research and discuss management implications.

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Evaluating Survival and Demography of a Bighorn Sheep (*Ovis canadensis*) Population

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Abstract: Having an understanding of how animal populations interact with their natural community is fundamental to wildlife management. In 1982 and 1983, pneumonia in southwestern Alberta's Yarrow-Castle bighorn sheep population resulted in a dramatic die-off, in which the population declined from approximately 400 sheep to fewer than 150. The population recovered to approximately 200 individuals by 1995, but a decline was observed in the proportion of ewes throughout the mid-1990s. We assessed the survival and demography of this bighorn sheep population using data from 46 radio-collared ewes from 2003 to 2005. Annual adult ewe (≥ 2 years of age) survival estimates ranged from 0.83 ±0.07 to 0.90 ±0.06, and ewe survival did not differ significantly among years or core habitat areas, nor among seasons, or between probable causes of mortality. Annual lamb survival to ten months ranged from 0.41 ±0.01 to 0.54 ±0.02 over three years. The estimated reproductive rate among years (2003-2005) was 0.40 (95% CI: 0.29-0.55), with a recruitment (female lamb survival to 10 months) estimate that averaged 0.18 (95% CI: 0.12-0.27). Population growth rates fluctuate near 1.0, although recruitment appears low in comparison with other populations. We discuss possible factors influencing this bighorn sheep population and compare results to demographic patterns observed in other ungulate populations.

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A basic problem in population ecology is the identification and prediction of factors that affect population growth. However, without the collection of biological evidence, wildlife managers are left with a perplexing assortment of speculations. Predation, hunting, disease, weather, population density and natural food supply may all play roles in limiting wild game populations (Geist 1971, Murphy et al. 1990, Goodson et al. 1991, Jorgenson et al. 1997, Bergerud and Elliot 1998).

Long-term population trend data exists for many ungulate populations throughout North America, primarily attained through aerial census of unmarked individuals (Gonzalez-Voyer et al. 2001, Hamel et al. 2006). Wildlife managers rely on these surveys to mark trends in population dynamics (Festa-Bianchet 1992). However, when unexpected population changes are observed, distinguishing the causes through biannual trend surveys is almost impossible. Studies monitoring radio-collared individuals within a population are necessary for understanding which demographic variables are affecting population size (Gaillard et al. 1998). Identifying demographic markers in a population and managing on a herd-specific basis may be necessary.

Rocky Mountain bighorn sheep (*Ovis canadensis*) are specialized inhabitants of subalpine and alpine habitats. They tend to exist in small, sedentary, isolated populations with patchy distributions (Geist 1975, Risenhoover et al. 1988, Singer et al. 2000). They are habitat specialists preferring open grassy slopes for foraging in close proximity to steep rocky areas for escape terrain (Singer et al. 2000). Encroachment of conifers and shrubs as a result of fire suppression, have impacted sheep populations by limiting available habitat and restricting movement (Stelfox 1976, Risenhoover et al. 1988, Singer et al. 2000). Bighorn sheep are subject to fluctuations in population size due to a number of factors but the effects of disease on bighorn sheep populations are particularly dramatic, leading to significant die-offs (Singer et al. 2000, Cassirer and Sinclair 2007).

Bi-annual winter aerial census surveys in the Yarrow-Castle area of Alberta, Canada indicated an increase in the bighorn population during the 1970s to approximately 400 individuals (Clark and Bergman 2005). During 1982 and 1983, pneumonia caused this population to decline to less than 150 animals (Onderka and Wishart 1984). The trend from 1985 to 1993 reveals steady population growth, at an increasing rate of approximately 10% per year. However, it appears that population recovery ceased in the mid-1990s, leveling off to current numbers of 200 to 250 sheep. A general decline in the number of bighorn ewes after 1993 was observed from aerial census counts (Clark and Bergman 2005). Reasons for the decline in ewe numbers are unclear due to lack of data beyond the regular aerial census surveys.

The purpose of this study was to gain an improved understanding of factors that may limit ewe numbers in the Yarrow-Castle region. Specific objectives were to: 1) quantify survival of radio-collared ewes and their lambs, 2) assess causes of mortality of radio-collared ewes, 3) calculate radio-collared ewe reproductive rates, and 4) estimate population growth. We tested for effects of year, core area residency, season, and probable cause of mortality on adult ewe survival. If adult ewe survival was limiting, we wanted to determine if it was due to a single type of mortality effect. We estimated reproductive rates and lamb survival by monitoring the radio-collared ewe population. Population growth was estimated by combining the survival and reproductive rates. By comparing our results to other studies, we could begin to determine which factors may have the greatest influence on the Yarrow-Castle population.

Methods

Study area

The study was conducted in a 450 km^2 area, located along the front ranges of southwestern Alberta, Canada, approximately 30 km southwest of the town of Pincher Creek (49°29'N, 113°57'W). The most southerly portion of the study area borders the northern boundary of Waterton Lakes National Park, while river drainages and forest create the northern and western boundaries, and foothill and prairie habitat create the eastern boundary.

The Yarrow-Castle area is situated in the Rocky Mountain and Foothill natural regions of southern Alberta. Bighorn sheep predominantly use the subalpine and alpine sub-regions ranging in elevation from 1550 m to 2600 m. Vegetation patterns are largely influenced by elevation, topography, aspect and wind exposure. Krummholz subalpine fir (*Abies lasiocarpa*) and whitebark pine (*Pinus albicaulis*) dominate the treeline while open stands of Engelmann spruce (*Picea engelmannii*), subalpine fir, subalpine larch (*Larix lyallii*), limber pine (*Pinus flexilis*), lodgepole pine (*Pinus contorta*) and aspen (*Populus tremuloides*) are found at lower elevations. Rock faces, open scree slopes, and herb-rich grassy meadows are located throughout, while recurring Chinook winds produce snow-free phases during the winter. Winds of 100 km/hr are not uncommon. The area receives annual average precipitation of 1054 mm with annual temperature averaging -1.33 °C (source data: Alberta Environment, Spionkop Creek climate station daily air temperature and precipitation summary data, 1984-2004).

Potential predators of bighorn sheep in the Yarrow-Castle area include grizzly bear (*Ursus arctos*), black bear (*Ursus americanus*), cougar *(Puma concolor*), wolverine (*Gulo gulo*), wolf (*Canis lupus*), coyote (*Canis latrans*), bald eagle (*Haliaeetus leucocephalus*) and golden eagle (*Aquila chrysaetos*). The area also supports a diversity of other big game species including elk (*Cervus elaphus*), moose (*Alces alces*), mule deer (*Odocoileus hemionus*), white-tailed deer (*Odocoileus virginianus*), and mountain goat (*Oreamnos americanus*). Petroleum and natural gas developments, roadways, domestic grazing and controlled recreational activities occur in the study area. Motorized access in the area is controlled via locked gates and/or timing restrictions.

Capture and monitoring

We captured most ewes by net-gunning from the air using a helicopter during winter months, while a small number of individuals were captured during summer months using a clover trap (Clover 1954) baited with salt. Ewes were fitted with a very high frequency (VHF; 500 model, Telonics Inc., Mesa, Arizona) or global positioning system (GPS; 4000 model, Lotek Wireless Inc., Newmarket, Ontario) collar. Collars were affixed with a length of coloured rubber and engraved with a unique symbol allowing for individual identification in the field. Collars were fit on all captured ewes but biological data was only recorded if the animal did not appear to be overly stressed (breathing rate did not increase while processing). Horn measurements (total length, basal length and annuli lengths), age (determined by counting horn annuli), and body measurements (length and girth) were recorded.

From 2002 to 2005, 46 bighorn ewes were captured and radio-collared throughout the Yarrow-Castle study area. Thirty ewes were captured during December 2002, three in June 2003, twelve in January 2004, and one in January 2005. Ewe age at capture ranged between two and eight years, with an average of five (53% were <5 years of age).

Ground monitoring consisted of driving accessible roads and other access points and listening for radio collar signals using a hand-held telemetry receiver (R-1000 model, Communications Specialists Inc., Orange, California) and either a portable H-antenna or a truck-mounted omni antenna, both by Telonics. Ground monitoring was conducted weekly to ensure the best chances of finding fresh evidence for determining cause and approximate day of death for radio-collared ewe mortalities. We were not always able to conduct a weekly relocation for every individual for the entire year due to ewe location, collar complication or staff availability. Radio collars were equipped with 4- and 8-hour delay mortality sensors for GPS and VHF collars, respectively.

Lamb status

During the initial weeks of lambing, we visually determined the lambing status of radio-collared ewes on a daily basis, or as frequently as feasible to minimize chances of missing lambs. Since birthing events occurred over the entire range and staff availability was limited, our lambing observation attempts were sometimes spaced 2 to 5 days apart. For this study, lambing period was defined as starting at the latter part of May and progressing to mid-July (Festa-Bianchet 1988*c*). Ewes often moved into rugged, secluded terrain during lambing, which then required aerial observations to locate birthing events. After the lambing period, lamb survival was monitored by conducting bi-monthly observations until the lambs neared ten months of age. The final observations in March were typically re-evaluated, or required longer observation times, since the lambs tended to stray from their mothers for short periods but still associated with them by travelling, feeding (including occasional suckling attempts), or bedding down near them. The period in which weaning occurs is often indistinct (Festa-Bianchet 1988*d*) since young will still attempt suckling even once they are obtaining their nutritional needs from vegetation (Festa-Bianchet et al. 1994). However, October has been identified as the approximate time that bighorn wean (Festa-Bianchet et al. 1995). Since our lamb population was not collared or tagged, there is a possibility that lambs remained on their own once weaned from their mothers and their survival status mistakenly identified during final observations in March.

Survival rates

To ensure assumptions associated with calculating survivorship rates were met (Erickson et al. 2001), we addressed three that were relevant to our study. First, although radio-collared ewes were typically verified as alive or dead on a weekly basis, we consistently monitored individuals at least monthly, and therefore use a 30 day interval in the survival analysis. Lapses in our weekly observations were typically a result of logistical challenges with remote ewes, collar performance, or staff availability. We were able to determine the fates of all radio-collared ewes and all ewes were located at least once every month over the course of the entire study period. Second, during 2004 and 2005, 12 GPS collars were placed on ewes throughout the study area. The GPS collars were programmed to begin drop-off by September 2005. Due to drop-off timing, 10 of the 12 GPS-collared ewes were removed from any survival analysis since we were unable to determine their survival status to the end of the 2005 annual period or to the end of the field monitoring period which was April 2006. This eliminated effects of non-random censoring in the sample (Tsai et al. 1999, Garshelis et al. 2005). The remaining two GPS-collared individuals died prior to their collars' scheduled drop-off date and were included in the survival analysis. Third, aging ewes based on horn annuli is accurate only until about four years of age (Geist 1966). Therefore, we pooled data into one class of adult ewes to calculate survival (ewes ≥2 years of age).

One additional ewe was originally radio-collared within the study area but was clearly not a permanent resident of the Yarrow-Castle bighorn population. This ewe immediately returned to an area approximately 15 km southwest of the Yarrow-Castle and continued to inhabit that area for the remainder of the study and therefore was not included in our analysis. We estimated adult ewe survival rates from 33 VHF radio-collared ewes and two GPS-collared ewes. The 35 ewes were monitored for an average of 30 months each (min. 1.4, max. 40.7 months). Each study year consisted of a similar number of marked individuals (ewes at risk) within the survival samples.

Adult ewe survival rates were estimated using the Kaplan-Meier survival estimator, incorporating the staggered entry design (Pollock et al. 1989). The staggered entry design allowed for animals to enter the analysis at different times, assuming that new animals have the same chance of survival as previously tagged animals. We used the program Ecological Methodology Version 6.1.1. (Kenney and Krebs 2003) to perform the computations to estimate survival (Krebs 1999).

We examined survival rates based on four factors: 1) year, 2) core area residency, 3) season, and 4) mortality type. We assumed that 3 years of data would detect variance in survival rates but acknowledge this limited time span is minimal for long lived species. We calculated survival estimates separately for each year and tested for yearly differences using a log-rank test (Garshelis et al. 2005) within the Ecological Methodology program (Kenney and Krebs 2003).

We examined whether survival rates differed among Yarrow-Castle ewes that occupied different core areas. Ewe's could be more susceptible to mortality in some areas due to higher predator loads associated with an alternative prey base, specialized predators, forest encroachment or risks associated with moving among habitat patches to acquire their dietary needs. We identified core areas by creating 60% fixed kernel polygons using the GPS collar data. We assumed that the GPS-collared individuals represented range-use of all ewes within the study area. We used the program HRE: Home Range Extension for ArcView® (Rodgers and Carr 1998) to calculate 60% kernel polygons to represent ewe core range as opposed to a 50% value (Girard et al. 2002), because at 60% partial polygons within the identified core ranges were eliminated. Both VHF- and GPS-collared ewes were assigned to an identified core range within the study area. Survival estimates for core residency were conducted by pooling yearly survival for each core area, and comparing cumulative survival among core areas using log-rank tests.

We defined seasonal time periods using the elevation data collected by the GPS collars. Generally four seasonal divisions are recognized in temperate regions but since bighorn ewes utilize only two to three distinct seasonal ranges throughout the year, (Geist 1971:1975, Festa-Bianchet 1988*a*) we used seasonal migration to define season. Sheep will make altitudinal migrations throughout their range to exploit vegetation high in quality and availability (Geist 1971, Seip and Bunnell 1985). We calculated the mean daily elevation across all GPS-collared ewes for the entire study area over all years (2003-2005). We visually interpreted the graphic produced by plotting daily elevation averages to determine the dates for seasonal periods. Three seasonal periods were identified: winter (15 December-25 May), summer (26 May-23 August), and fall (24 August-14 December). We calculated survival rates for each seasonal time period among years and compared survival estimates among those time periods using log-rank tests.

Lastly, we wanted to determine if predator mortality affected ewe survival differently from non-predator mortality in the Yarrow-Castle area. As such, we compared predator mortality vs. non-predator mortality by estimating survival while factoring in one mortality type (e.g., predator mortality) and censoring deaths from the other type (e.g., non-predator mortality; Garshelis et al. 2005). We acknowledge that compensatory mortality could occur when a predator targets a weakened individual that would have otherwise been categorized as non-predator type mortality. Moreover, we may also misclassify mortality types if a dead carcass is scavenged by a predator but died from other causes. Nonetheless, we were interested in determining whether adult ewe mortality was primarily linked to predation. Predator mortalities were typically comprised of piled remains of sheared hair, broken bones and an opened skull. The non-predator mortalities consisted of whole or almost whole carcasses, but often fed upon by birds and insects. Carcass remains were occasionally examined by a qualified veterinarian to help determine cause of death. We used a log-rank test to assess if ewe survival was influenced by one type of mortality more than the other.

Lamb survival to ten months of age was estimated using the following formula: $1 - (\sum d_i / \sum b_i)$, where d is death of a lamb, and b is birth of a lamb from each ewe i. Only lambs of radio-collared adult ewes were considered in the survival estimates. A female that was never observed with a lamb by mid-July, was accepted as not lambing that year. We considered orphaned lambs (lambs of ewes that died during the months of June through early September) as mortalities, since they would not be fully weaned from their mothers and were likely still dependent on maternal care (Festa-Bianchet et al. 1994). Each female that was confirmed having a lamb was monitored bi-monthly to determine lamb survival until late winter. In March, a final lamb count for radio-collared ewes determined the total number of lambs surviving to approximately ten months of age. A log-rank test determined if lamb survival differed among years based on a summer (May-November) and winter (December-March) lamb season since high summer lamb mortality may indicate sporadic pneumonia (Cassirer and Sinclair 2007).

Reproductive rates

All radio-collared ewes were considered reproductively mature at capture. Ewes can reproduce at two years of age (Jorgenson et al. 1993*a*, Festa-Bianchet et al. 1994) and generally remain reproductive until about 14 years (Bérubé et al. 1999). Previous work has shown that ewes rarely twin (Geist 1971, Eccles and Shackleton 1979), and thus we assumed litter size to be 1. The lamb status of each ewe determined yearly reproductive success for each individual, although some ewes were not included in reproductive analysis if they did not survive to their first monitored lambing period, or if their GPS collars had dropped before their lamb was ten months of age.

We estimated the reproductive rate for the Yarrow-Castle ewe population from field data of 41 radio-collared ewes. In total, we observed 91 ewe-years of reproduction. Only two radio-collared ewes were two years of age during capture and neither ewe was lactating at the time. All radio-collared 3-year-olds were recorded as lambing. We calculated inter-birth intervals (the variability in lifetime reproductive success) in two ways, lamb produced and lamb surviving. We examined each ewe's reproductive record chronologically and tallied the number of years from the production of a lamb (or lamb surviving) to the production of the next lamb (or lamb surviving). We calculated the mean interval between lambs (or lamb surviving) across all ewes. In the producing column of the birth interval table (Appendix A), a one represented a ewe having a lamb every year during the study period, and a two meant that a ewe was producing a lamb every other year during the study period. A one in the surviving column represented a ewe whose lambs all survived to ten months, while a two meant the ewe had lost a lamb amid two successful observation years.

A reproductive rate was calculated for each ewe that produced a lamb whether it survived or not, and a recruitment rate was calculated for each ewe that produced a lamb that survived to ten months of age. We constructed two spreadsheets similar to those used by Garshelis et al. (2005). The spreadsheet for annual reproductive estimation incorporated columns that represented the reproductive history (production of a lamb) for each year (2003-

2005), and rows that represented individual ewe reproduction (Appendix B). Each ewe was assigned a number during each reproductive year she was observed. A cell with a 0, represented a year in which a ewe did not lamb, a cell with a one represented a ewe that produced a surviving lamb to ten months, while a grey cell with a one (or a grey cell with a 0 when referring to the recruitment table), represented a ewe that produced a lamb but the lamb did not survive to ten months. Annual reproductive rates were calculated by dividing the total number of female lambs born (produced) that year, by the total number of ewes observed that year. Individual reproductive rates were calculated by dividing the total number of female lambs born (produced) to each ewe (assumed that 50% of lambs born were female) by the number of years the ewe was observed. A recruitment rate was calculated by dividing the total number of female lambs born and surviving to ten months by the total number of observed ewe years over the study period (Appendix C). Confidence intervals for reproductive and recruitment rates were determined by calculating confidence limits for proportions based on a method equivalent to the ratio of *F* distributions (Zar 1984) and then calculating into an odds ratio, representing a lamb/ewe ratio.

Population growth rates

We estimated population growth rate (λ) for two scenarios using a female based, age structured, deterministic Leslie matrix (Leslie 1945, Caswell 2001). Our first approach incorporated two age classes based on our data (lamb and adult ewe $\geq$ 2 years of age), assuming yearling survival (1-2 years) was 100%. Bighorn yearlings have been found to occasionally experience 100% survival (Jorgenson et al. 1997). For our second approach, we used our data in association with three hypothetical estimates for yearling survival, based around yearling survival rates from other studies (Jorgenson et al. 1997, Loison et al. 1999, Gaillard et al. 2000). First, an average of the Yarrow-Castle adult survival estimate represented an upper limit for yearling survival. Second, an average of the Yarrow-Castle lamb survival estimate represented a lower limit for yearling survival while a midpoint of the upper and lower survival rates was used to represent a third yearling survival rate in the 3-stage matrices. We conducted both 2- and 3-stage (incorporating the yearling age class) matrix analyses for each study year (2003-2005) and compared the resulting λ estimates. Population growth estimates were calculated from the matrices using the excel software extension, PopTools (Hood 2006).

Results

Eleven radio-collared ewes died during the monitoring period with an average ewe lifespan of 6.87 years. Annual adult ewe (ewes $\geq$ 2 years of age) survival ranged from 0.83 to 0.90 over three years (Table 1). We did not find evidence that survival differed among years (2003 vs. 2004: χ^2 = 0.60, df = 1, P = 0.44; 2003 vs. 2005: χ^2 = 0.37, df = 1, P = 0.54; 2004 vs. 2005: χ^2 = 0.02, df = 1, P <0.995). Three core bighorn ewe territories were identified within the study area: a southern, a central, and a northern core. Ewes occupying the southern core experienced the lowest cumulative survival rate (Table 1). The southern core experienced several mortalities and had a lower survival estimate, but ewe survival among core areas was not significantly different (southern vs. central core area: χ^2 = 1.38, df = 1, P = 0.24; southern vs. northern core area: χ^2 = 1.05, df = 1, P = 0.31; and central vs. northern core area: χ^2 = 0.00, df = 1, P <0.995). Cumulative survival estimates were calculated for each seasonal period with the fall season having the greatest survival (Table 1), yet survival among seasons was not significantly different (winter vs. summer: χ^2 = 0.00, df = 1, P = <0.995; winter vs. fall: χ^2 = 2.28, df = 1, P = 0.13; summer vs. fall: χ^2 = 2.35, df = 1, P = 0.13).

Of 11 ewe mortalities, the evidence for seven suggested predators as the most likely cause, while four were non-predator related. Of the seven probable predator mortalities, four had evidence to suggest cougar kills, two from bear, and one from wolverine. Four non-predator mortalities consisted of one fall, one avalanche, one unknown, and one originating from a broken leg. Although cumulative ewe survival based on predator mortality type was lower than non-predator (Table 1), ewe survival did not differ significantly between mortality types (predator vs. non-predator: χ^2 = 0.82, df = 1, P = 0.37).

The majority of Yarrow-Castle lambs were born during the initial weeks of June and we did not observe any twinning during our study. Annual lamb survival ranged from 0.41 to 0.54 over three years (Table 2). The lambing rate was lower in 2004 (65%) when compared to 2003 and 2005, but lamb survival was greatest that year (54%). Although 2004 had the greatest lamb survival rate, it also had a higher occurrence of winter lamb mortality when compared to summer mortality. The lamb population suffered greater mortality during the winter seasons of 2004 (64% winter mortality) and 2005 (77% winter mortality); However, during 2003, the lamb population suffered equal mortality (50%) during the seasons. Lamb survival did not differ significantly between summer and winter season among years (2003 vs. 2004: χ^2 = 0.81, df = 1, P = 0.37; 2003 vs. 2005: χ^2 = 0.12, df = 1, P = 0.73; 2004 vs. 2005: χ^2 = 0.31, df = 1, P = 0.58).

Radio-collared ewes produced lambs on average every 1.3 years over the 3-year period. However, this interval increased to every 1.7 years for a radio-collared ewe that had to produce a lamb that survived to ten months of age (Appendix A). Based on these intervals, incorporating an average ewe lifespan of 6.87 years (average ewe age of the 11 radio-collared Yarrow-Castle ewe mortalities), a ewe will give birth to 2.93 lambs, of which 2.32 lambs will survive to ten months if primiparous at age three. All 3-year-olds in our study were recorded with lamb therefore the ewes have approximately 4 reproductive years on average. The overall reproductive rate (female lambs produced per ewe) was 0.40 (95% CI: 0.29-0.55). We observed reproductive rates of 0.47 (95% CI: 0.27-0.82), 0.32 (95% CI: 0.19-0.56), and 0.44 (95% CI: 0.24-0.81) female lambs/ewe for 2003, 2004, and 2005, respectively (Appendix B). An overall recruitment rate of 0.18 (95% CI: 0.12-0.27) was calculated for female lambs surviving into the population to ten months of age (Appendix C). Annual recruitment ranged from 0.18 to 0.19.

Annual estimates of λ based on the 2-age class matrix with yearling survival of 100% resulted in positive growth rates (1.018-1.064; Table 3). The λ estimates based on the 3-age class matrices (incorporating yearling survival of 87%, 66%, and 45%) were predictably lower. Population growth was negative for all 3-age class matrices during 2003 (0.930-0.997) and during all years when incorporating the low yearling survival rate of 45% (0.930-0.982; Table 3).

Discussion

Disease had played a prominent role in limiting the Yarrow-Castle bighorn sheep population in the early 1980s, and while disease no longer appears to be a factor, the population appears limited in some way.

Monitoring the radio-collared ewes allowed us to estimate survival and reproductive rates, as well as estimate population growth. It is difficult to detect sampling, yearly or environmental variance with only three years of data for a long-lived species but we assume that our estimates are representative for a longer period and compare our results with other bighorn populations within North America.

Adult female survival

Survival rates of adult female bighorn sheep vary across North America. Singer et al. (2000) found stable or increasing bighorn herds in the western United States having a combined-ewe age survival rate of 0.89, while populations suffering from active epizootics had a combined-age ewe survival rate of 0.67. In Alberta, Loison et al. (1999) found mean prime age (3-7 years) ewe annual survival rates ranged from 0.92 to 0.94 and Jorgenson et al. (1997) reported senescent (8+ years) ewe survival of 0.85. Our estimates of mean ewe survival rates are lower than those comparables, but our confidence intervals overlap with these rates from other areas. Our annual survival estimates include older ewes which typically experience lower survival than younger adult ewes (Jorgenson et al. 1997, Loison et al. 1999), which may account for these differences. We expect that our limited time span of data collection may affect the precision of our estimates.

Overall, adult ewe survival should be relatively stable with little variation among years (Gaillard et al. 1998, Loison et al. 1999). Changes in adult ewe survival may severely affect a population's growth rate, in particular prime-aged ewe survival (Gaillard et al. 2000). Our data did show yearly variation in the means from 0.83 to 0.90. The lower survival rate in 2003 (0.83) could be attributed to higher mortality in the southern core area that year due to predation but this appeared to be a 1-year event and if we consider the last two years only, ewe survival was more stable.

The Yarrow-Castle area supports at least three distinct core ewe groups. Ewe survival was low in the southern core during 2003, but because there was no significant difference in survival rates among the three core groups, we concluded that no one core group was driving overall survival. The southern core had a larger number of ewes at risk (radio-collared) when compared to the other two cores, therefore creating relatively equal survival among core areas.

Bighorn sheep generally occupy more than one range among seasons (MacCallum and Geist 1992, Alberta Environmental Protection 1993). Rams can experience lower survival in the fall due to the additional cost of participating in the rut (Festa-Bianchet 1987, Jorgenson et al. 1997), but reproduction does not appear to negatively affect female survival (Jorgenson et al. 1997). Seasonal difference in survival rates have been reported for other ungulate species, largely climate related (dall sheep *Ovis dalli*, Burles and Hoefs 1984; caribou *Rangifer tarandus caribou*, McLoughlin et al. 2003; and alpine ibex *Capra ibex*, Jacobson et al. 2004). Although the bulk of our ewe mortalities occurred between March and July, survival rates were not significantly different among seasons.

Predator-caused ewe mortality was slightly higher than non-predator related deaths in this study. It is possible that our predator related mortality is overestimated since many predators are also known to scavenge carcasses (Bauer et al. 2005, Green et al. 1997, Hornocker and Hash 1981, Landa et al. 1997, Mattson 1997, van Zyll de Jong 1975). During this study, cougar had caused the majority of predator related mortality. Cougars preying primarily on sheep can have a significant local impact on bighorn populations (Ross et al. 1997, Réale and Festa-Bianchet 2003). Bouts of cougar predation on bighorn sheep are known to last between three to five years and are associated with a noticeable decline in adult survival, in some cases dominating population dynamics (Festa-Bianchet et al. 2006). Initially, we were concerned that the southern core area bordering Waterton National Park could be a mainstay for cougar specializing in bighorn sheep, but according to the Cougar Management Guidelines Working Group (2005), a predator pit (Hayes et al. 2000) does not exist unless the prey species is in excellent physical condition and the population is experiencing high fecundity. Despite this, the study area bordering the park boundary supports several additional prey species such as mule deer, white-tailed deer, moose, elk, and mountain goat. Thus a predator pit could exist, but bighorn predation rates could also vary among years as the predators change between alternative prey species (Jorgenson et al. 1997).

Yarrow-Castle ewes suffered from non-predator caused mortalities. Some climbing deaths have been reported in bighorn sheep during the rutting season (Festa-Bianchet 1987) and also shortly after translocations (Kamler et al. 2003). Twenty-two percent of the Hells Canyon bighorn sheep metapopulation suffered from falls or injuries (Cassirer and Sinclair 2007), while sporadic disease was the primary source of adult mortality. Sporadic pneumonia-caused mortalities in both adults and lambs were the primary factor limiting population growth and yet, these were not catastrophic outbreaks (Cassirer and Sinclair 2007). Further investigation is required to determine if there is some underlying factor (e.g., disease) making Yarrow-Castle ewes susceptible to non-predator caused mortality, or if it is occurring by chance. Moreover, Yarrow-Castle ewes were not harvested, either legally or illegally, during the study period (2003-2005). However, during the winter of 2006/2007, three rams and two ewes were confirmed to be poached on two separate occasions within the Yarrow-Castle study area. The extent to which poaching is affecting the Yarrow-Castle bighorn population is unknown, but to the best of our knowledge, these were the first recorded sheep poaching incidents within the Yarrow-Castle area.

Lamb survival

Lamb survival in our area may be low in comparison to estimates in other areas (Festa-Bianchet 1988*b*, 1988*c*, Gaillard et al. 1998, Singer et al. 2000). In the western United States, stable or increasing bighorn populations experienced an average lamb (0-1 year) survival rate of 0.65, while declining herds reached only 0.21 (Singer et al. 2000). In a Alberta bighorn population, lamb survival to weaning (approximately 5 months of age) ranged from 0.53 to 0.87 (Festa-Bianchet 1988*c*) while juvenile survival (0-2 years of age) ranged from 0.39 to 0.48 (Gaillard et al. 1998). Our lamb survival (to 10 months of age) ranged from 0.41 to 0.54. Due to our limitations in detecting neonatal lamb mortalities and early mortalities that could have occurred before first visual confirmation, our lamb survival estimates could be overestimated. Furthermore, since lambs were not radio-collared or marked in any way, we can not be certain that a radio-collared ewe’s lamb was actually dead during our final lamb survival observations.

During 2004 the Yarrow-Castle lambing season was delayed. Fewer lambs were born during that year when compared to the other two years, yet lamb survival was highest that year. On the contrary, Festa-Bianchet (1988*a*) found lamb survival to decrease with prolonged birthdates. Lambs born in May experienced higher survival rates (survival to 1-year) that ranged from 0.19 to 0.68, while lambs born in June and July experienced survival rates that ranged between 0.11 and 0.33 (Festa-Bianchet 1988*b*). Portier et al. (1998) discovered neonatal survival to be higher in years with wet and warm springs, increasing maternal nutrition, as well as the quality and quantity of vegetation available to the lamb. According to Alberta Environment's climate data from Spionkop Canyon (within the southern core), the spring of 2004 was unusually wet and cool in the Yarrow-Castle area. Precipitation during April, May, and June 2004 were all higher than the 20-year averages for these months. The highest recorded monthly precipitation occurred during 2004 at 222 mm, when the monthly average was only 95 mm. Therefore, the wet spring may be associated with higher lamb survival that year. Cooler temperatures were also recorded for April, May, and June 2004 when compared to the 20-year monthly averages. May had the coldest recorded monthly average temperature at -7.16 °C while the 20-year average for May was +1.69 °C. Perhaps during 2004, being born late was more beneficial due to the cool temperatures that early born lambs would have had to contend with. The cooler temperatures and high precipitation levels would have also resulted in a later growing season that allowed these late born lambs to better survive. Alternatively, the 2004 lamb survival rate may reflect the fact that a number of lambs died shortly after birth, but were not detected.

Yarrow-Castle lamb survival was compared between the summer and winter seasons. Using 20 years of lamb mortality data, Portier et al. (1998) found summer mortality to be low, averaging 8% per year, compared to neonatal mortality rates of 17%, and winter mortality of 28%. Singer et al. (2000) established that summer lamb mortality was higher in declining or suspected diseased bighorn populations, than in populations that were increasing. Cassirer and Sinclair (2007) also found that summer lamb mortality was greater than 50% when sporadic pneumonia was the cause of death, with most mortalities occurring between six and ten weeks. Summer lamb mortality in the Yarrow-Castle area was 50%, 36% and 23% for 2003, 2004, and 2005, respectively. Our summer lamb mortality rates were higher than the 8% reported by Portier et al. (1998), but according to Singer et al. (2000) and Cassirer and Sinclair (2007), these higher summer lamb mortality rates could be indicative of a population limitation.

Reproduction

Our lifetime reproductive success is lower than that observed by Festa-Bianchet and Jorgenson (1996), where they found ewes producing an average of 7.09 and 5.23 lambs, of which 5.54 and 3.45 lambs were surviving to weaning. Our rates (2.93 lambs, 2.32 surviving to March) are derived from a small sample of ewes, involve lamb survival beyond weaning and incorporate a lower ewe lifespan than what Festa-Bianchet and Jorgenson (1996) report. The Yarrow-Castle reproductive rate during 2004 (0.32) was low since Singer et al. (2000) had comparable fecundity rates for declining bighorn populations (initial production of a lamb) of 0.36 for 4- to 8-year-olds and 0.29 for 9- to 14-year-olds. The numbers presented here representing the female lamb population are 50% of those reported by Singer et al. (2000). Singer et al. (2000) found increasing populations to have fecundity rates of 0.46 for 4- to 8-year-olds and 0.45 for 9- to 14-year-olds. These rates are similar to reproductive rates calculated to our area during 2003 (0.47) and 2005 (0.44). It is possible that the lower reproductive rate observed in 2004 (0.32) was a result of lambs dying before first visual confirmation, therefore any bias in reproduction would be toward a lower value. However, recruitment by radio-collared ewes in the Yarrow-Castle area (lamb surviving to 10 months) was low for all years, with an average of 0.18. Singer et al. (2000) found similar recruitment rates only in declining populations. Their declining populations exhibited recruitment rates of 0.12 for 4- to 8-year-olds and 0.17 for 9- to 14-year-olds, while their increasing populations had recruitment rates of 0.36 for 4- to 8-year-olds and 0.38 for 9- to 14-year-olds. Recruitment in the Yarrow-Castle population is consistent with rates observed in declining populations.

Population growth (λ)

Growth rate estimation for the Yarrow-Castle population incorporating a 2-age class (lamb and adult) matrix ranged from 1.018 to 1.064 with an average λ = 1.047, indicating the population is growing by approximately 5% per year. However, this level of growth was not observed in the aerial census trend data during the study period. It is possible that a 5% population increase may go undetected from one census to the next, depending on survey precision. Population growth may have been overestimated in the 2-age class matrix assuming 100% survival for yearlings. Since yearling survival in bovids is often lower and more variable than adult survival and higher and less variable than juvenile survival (in this case lamb survival; Gaillard et al. 2000), we estimated population growth using variations of yearling survival. Other studies have estimated yearling female bighorn survival ranging from 0.81 and 0.86 (Jorgenson et al. 1997, Loison et al. 1999), while some populations have experienced extreme yearling survival ranging from 0 to 100% (Jorgenson et al. 1997). Incorporating various yearling survival rates into a 3-age class matrix resulted in population growth that ranged from 0.930 to 1.041 among years with an average λ = 0.994. When utilizing an 87% yearling survival rate within the matrix, the average λ = 1.025 matched that of the increase observed during aerial census surveys between 2002 (n = 158) and 2005 (n = 162).

If we assume our estimates include the full range of variation, then the Yarrow-Castle bighorn population may occasionally be influenced by punctuated but sporadic predation events, and may be driven by density dependence and could be near their carrying capacity. Yarrow-Castle lamb survival and recruitment are low and population growth estimates are fluctuating around 1.0. Young are highly sensitive to limiting factors caused by population density or by stochastic environmental events (Gaillard et al. 1998). At high population densities, reproductive costs increase and lamb survival decreases (Festa-Bianchet and Jorgenson 1998, Festa-Bianchet et al. 1998, Portier et al. 1998, Bérubé et al. 1999, Coulson et al. 2000, Gallant et al. 2001).

One method to test if the Yarrow-Castle population is at carrying capacity would be to harvest a small number of bighorn ewes. If nursery herd densities were decreased at carrying capacity, lamb production and population growth should increase (Jorgenson et al. 1993*b*, Jorgenson et al. 1998, Wishart et al. 1996), increasing the overall health of the population. Nevertheless, if a rapid rate of increase was observed in the future, ewe harvests could be considered to reduce the risk of a pneumonia epizootic (Jorgenson et al. 1993*b*).

Bighorn ewe reproductive success decreases at increasing density because resources limit their fitness (Gallant et al. 2001). When resource conditions are optimal, bighorn sheep have the ability to double their population numbers in as little as three years (Wishart et al. 1996). Populations that exhibit slow growth rates, low productivity and low survival have likely exceeded their range capacity (Geist 1971). When habitat is limiting, lamb survival decreases, ewe survival decreases, and ram horn growth decreases (Demarchi et al. 2000, Festa-Bianchet 1988*b*, Festa-Bianchet and Jorgenson 1998, Portier et al. 1998, Festa-Bianchet et al. 2004). The habitat condition in the Yarrow-Castle area is largely unknown and requires further investigation. Increasing forage quantity and quality in the Yarrow-Castle area by using prescribed fire could improve overall population health. Fire suppression during the past century has dramatically changed the landscape and has likely altered the amount of range available to sheep. The last recorded wildfire (size unknown) in the Yarrow-Castle area was in 1936 (Alberta Sustainable Resource Development 2005). Prescribed burning increases herbaceous plants and removes obstructive shrubby plants; bighorn sheep select for these burned areas (Peek et al. 1979, McWhirter et al. 1992). Bighorn sheep populations benefit from newly formed food sources created by fire, avalanches, and mine reclamation (Wishart et al. 1996). There exists an opportunity to implement a habitat restoration strategy for the Yarrow-Castle bighorn sheep population. The restoration efforts could test whether fire suppression may have caused a long-term decline in suitable bighorn range, although this would require an adequate method of evaluating the effects of an applied burn and if it is in actuality improving forage quality for the Yarrow-Castle bighorn population.

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List of tables and appendices

Table 1. Kaplan-Meier 3-year cumulative survival estimates for bighorn ewes in the Yarrow-Castle study area, Alberta based on annual survival, core residence, seasonal period, and mortality type, 2003-2005.

Year	**Number of ewes**	**Number of mortalities**	**Annual survival rate (95% CI)**	**SE**
2003	29	5	0.83 (0.70 - 0.97)	0.07
2004	30	3	0.90 (0.79 - 1.00)	0.06
2005	27	3	0.89 (0.77 - 1.00)	0.06
Core area	**Number of ewes**	**Number of mortalities**	**Cumulative survival rate (95% CI)**	**SE**
Southern	15	7	0.48 (0.22 - 0.75)	0.13
Central	8	2	0.75 (0.45 - 1.00)	0.15
Northern	7	2	0.73 (0.42 - 1.00)	0.16
Seasonal period	**Number of ewes**	**Number of mortalities**	**Cumulative survival rate (95% CI)**	**SE**
Winter	31	5	0.84 (0.71 - 0.97)	0.07
Summer	29	5	0.82 (0.68 - 0.96)	0.07
Fall	25	1	0.96 (0.90 - 1.00)	0.04
Mortality type	**Number of ewes**	**Number of mortalities**	**Cumulative survival rate (95% CI)**	**SE**
Predator	35	7	0.77 (0.62 - 0.92)	0.08
Non-predator	35	4	0.86 (0.74 - 0.99)	0.06

Table 2. Survival (to approximately 10 months of age) of bighorn lambs born to radio-collared ewes in the Yarrow-Castle study area, Alberta, 2003-2005.

Year	**Marked Ewes**		**Lambs**			
	Total (*n*)	**Total lambed**	**Total (*n*)**	**Mortalities**	**Survival (95% CI)**	**SE**
2003	29	27 (93%)	27	16	0.41 (0.38-0.43)	0.01
2004	37	24 (65%)	24	11	0.54 (0.51-0.57)	0.02
2005	25	22 (88%)	22	13	0.41 (0.38-0.44)	0.01

Table 3. Variants of population growth (λ) for the Yarrow-Castle bighorn population, Alberta, 2003-2005.

Matrix stage	**2003**	**2004**	**2005**	**Average**
2-age class (100% yrlg. surv.)	1.018	1.064	1.060	1.047
3-age class (87% yrlg. surv.)	0.997	1.041	1.036	1.025
3-age class (66% yrlg. surv.)	0.965	1.013	1.007	0.995
3-age class (45% yrlg. surv.)	0.930	0.982	0.975	0.962

Appendix A. Bighorn ewe inter-birth intervals in the Yarrow-Castle study area, Alberta, 2003-2005.

Ewe I.D.	Year				Interbirth interval	
	2003	2004	2005		Lamb produced	Lamb surviving
0.003	1	1	1		1	1
0.009	1	0	0		2	
0.015	0	0	0		2	
0.021	0	0	1		1	
0.030	1	0	0		2	
0.040	1	0	1		1	2
0.058	0	1	0		1	
0.071	1	1	0			
0.090	0	0	0			
0.105	0					
0.145	1	0	0		2	
0.170	0	0	0		1	
0.201	0	0				
0.266	0	1	0			
0.308	0	0			1	
0.356	1	1	0		1	
0.508	0	1	0		1	
0.528	0					
0.534	1					
0.590	1	0	1		1	2
0.717	1	0	1		2	2
0.761	1	0	1		2	2
0.995	0	0	0		2	
1.183	0	0			1	
1.814	0	1	1		1	
1.830	0	0	0		2	
0.355	0					
0.080	0	0			1	
0.380	0	1			1	
0.328_04		0	0		1	
0.735_04		1	0		1	
0.650_04		1	1		1	1
0.105_04		0	1		1	
0.160		1				
0.340		0				
0.300		0				
0.420		1				
0.240		0	0			
0.100a		0				
0.500		1				
0.130		0				
Average interval					1.32	1.67

0	No reproduction observed
0 (shaded)	Produced lamb but lamb did not survive to 10 months of age
1	Produced lamb and lamb survived to 10 months of age

Appendix B. Bighorn ewe reproductive rates in the Yarrow-Castle study area, Alberta, 2003-2005.

Ewe I.D.	Year			Lambs	Female lambs	Years observed	Reproduction rate
	2003	2004	2005				
0.003	1	1	1	3	1.5	3	0.50
0.009	1	0	1	2	1.0	3	0.33
0.015	1	0	1	2	1.0	3	0.33
0.021	1	1	1	3	1.5	3	0.50
0.030	1	0	1	2	1.0	3	0.33
0.040	1	1	1	3	1.5	3	0.50
0.058	1	1	1	3	1.5	3	0.50
0.071	1	1	0	2	1.0	3	0.33
0.090	0	1	1	2	1.0	3	0.33
0.105	1			1	0.5	1	0.50
0.145	1	0	1	2	1.0	3	0.33
0.170	1	1	1	3	1.5	3	0.50
0.201	0	0		0	0.0	2	
0.266	1	1	0	2	1.0	3	0.33
0.308	1	1		2	1.0	2	0.50
0.356	1	1	1	3	1.5	3	0.50
0.508	1	1	1	3	1.5	3	0.50
0.528	1			1	0.5	1	0.50
0.534	1			1	0.5	1	0.50
0.590	1	1	1	3	1.5	3	0.50
0.717	1	0	1	2	1.0	3	0.33
0.761	1	0	1	2	1.0	3	0.33
0.995	1	0	1	2	1.0	3	0.33
1.183	1	1		2	1.0	2	0.50
1.814	1	1	1	3	1.5	3	0.50
1.830	1	0	1	2	1.0	3	0.33
0.355	1			1	0.5	1	0.50
0.080	1	1		2	1.0	2	0.50
0.380	1	1		2	1.0	2	0.50
0.328_04		1	1	2	1.0	2	0.50
0.735_04		1	1	2	1.0	2	0.50
0.650_04		1	1	2	1.0	2	0.50
0.105_04		1	1	2	1.0	2	0.50
0.160		1		1	0.5	1	0.50
0.340		1		1	0.5	1	0.50
0.300		0		0	0.0	1	
0.420		1		1	0.5	1	0.50
0.240		0	0	0	0.0	2	
0.100a		0		0	0.0	1	
0.500		1		1	0.5	1	0.50
0.130		0		0	0.0	1	
Female lambs	13.5	12.0	11.0		36.5		
Adult females	29	37	25		Sum	91	
Annual repro. rate	0.47	0.32	0.44			Sum	0.40
							Overall

0	No reproduction observed
1 (shaded)	Produced lamb but lamb did not survive to 10 months of age
1	Produced lamb and lamb survived to 10 months of age

Appendix C. Bighorn ewe recruitment rates in the Yarrow-Castle study area, Alberta, 2003-2005.

Ewe I.D.	**Year**			**Lambs**	**Female lambs**	**Years observed**	**Recruitment rate**
	2003	**2004**	**2005**				
0.003	1	1	1	3	1.5	3	0.50
0.009	1	0	0	1	0.5	3	0.17
0.015	0	0	0	0	0.0	3	0.00
0.021	0	0	1	1	0.5	3	0.17
0.030	1	0	0	1	0.5	3	0.17
0.040	1	0	1	2	1.0	3	0.33
0.058	0	1	0	1	0.5	3	0.17
0.071	1	1	0	2	1.0	3	0.33
0.090	0	0	0	0	0.0	3	0.00
0.105	0			0	0.0	1	0.00
0.145	1	0	0	1	0.5	3	0.17
0.170	0	0	0	0	0.0	3	0.00
0.201	0	0		0	0.0	2	
0.266	0	1	0	1	0.5	3	0.17
0.308	0	0		0	0.0	2	0.00
0.356	1	1	0	2	1.0	3	0.33
0.508	0	1	0	1	0.5	3	0.17
0.528	0			0	0.0	1	0.00
0.534	1			1	0.5	1	0.50
0.590	1	0	1	2	1.0	3	0.33
0.717	1	0	1	2	1.0	3	0.33
0.761	1	0	1	2	1.0	3	0.33
0.995	0	0	0	0	0.0	3	0.00
1.183	0	0		0	0.0	2	0.00
1.814	0	1	1	2	1.0	3	0.33
1.830	0	0	0	0	0.0	3	0.00
0.355	0			0	0.0	1	0.00
0.080	0	0		0	0.0	2	0.00
0.380	0	1		1	0.5	2	0.25
0.328_04		0	0	0	0.0	2	0.00
0.735_04		1	0	1	0.5	2	0.25
0.650_04		1	1	2	1.0	2	0.50
0.105_04		0	1	1	0.5	2	0.25
0.160		1		1	0.5	1	0.50
0.340		0		0	0.0	1	0.00
0.300		0		0	0.0	1	
0.420		1		1	0.5	1	0.50
0.240		0	0	0	0.0	2	
0.100a		0		0	0.0	1	
0.500		1		1	0.5	1	0.50
0.130		0		0	0.0	1	
Female lambs	5.5	6.5	4.5		16.5		
Adult females	29	37	25		Sum	91	
Annual recruit. rate	0.19	0.18	0.18			Sum	0.18
							Overall

0	No reproduction observed
0	Produced lamb but lamb did not survive to 10 months of age
1	Produced lamb and lamb survived to 10 months of age

Transmission of *Pasteurella haemolytica* between domestic sheep and a free-ranging bighorn ewe.

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(Presented by NWSGC Executive Director Kevin Hurley, 2008 NWSGC Business Meeting, April 30, 2008, Midway, Utah)

Abstract: A Nevada study involving transmission of *Pasteurella (Mannheimia) haemolytica* between a flock of domestic sheep (*Ovis aries*) and a free-ranging bighorn sheep (*Ovis canadensis*) is presented. An adult ewe (EarTag #135) was one of 20 bighorn sheep captured, sampled, and transplanted on January 10, 1994 from Hart Mountain, Oregon to the Trout Creek Mountains in Nevada. Five months later, this bighorn ewe (ET #135) was documented to have been in contact with 23 domestic rams for a period of less than 24 hours. Bighorn ewe (ET #135) was captured within 17 hours of documented contact with 23 domestic rams, sampled and removed from the wild on May 5, 1994. Five days later, on May 10, 1994, bighorn ewe (ET #135) died of pneumonia; post-mortem tissue and swab samples were obtained. On May 17, 1994, twelve days after bighorn ewe (ET #135) was removed from co-mingling with 23 domestic rams, nasal and pharyngeal swab samples were obtained from all 23 domestic rams. All *Pasteurella haemolytica* isolates cultured from Hart Mountain-transplanted bighorns, those collected from bighorn ewe (ET #135) at the time of re-capture and post-mortem examination, and those from 23 domestic rams, were serotyped and evaluated biochemically. *Pasteurella spp.* isolates collected from bighorn ewe (ET #135) during the initial transplant/sampling did not contain any of the same isolates found after contact with the domestic rams. After contact, identical isolates of *P. haemolytica* were recovered from post-mortem samples of both bighorn ewe (ET #135) and the domestic rams, indicating transmission of *Pasteurella* species occurred between domestic and bighorn sheep on the range. Similar incidences of documented transmission under free-ranging conditions have also been reported. (V. Coggins, Proceedings of the NWSGC 13th Biennial Symposium: 165-174.)

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History, Status, and Population Structure of California Bighorn Sheep in Utah

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Abstract: Bighorn sheep (*Ovis canadensis*) are native to Utah, and although nearly extirpated, they have been successfully restored to many of their former ranges. Since 1997, 3 populations of California bighorn sheep (*O. c. californiana*) have been established in Utah on Antelope Island, the Newfoundland Mountains, and the Stansbury Mountains. Our objectives were to examine factors contributing to the extirpation of bighorn sheep populations in the Great Basin of northern Utah, to document population growth and habitat use of reintroduced herds of California bighorns, and to discuss population structure and movements of these animals. We compiled information on the historical distribution of bighorns in our study area from published reports and historical accounts. Furthermore, for each reintroduced herd, we calculated growth rates and lamb survival from winter population estimates. To document habitat use, we observed bighorn sheep on 960 occasions and estimated home ranges using a 95% fixed-kernel estimator. We documented intermountain movements of bighorns by reviewing agency reports and contacting those individuals who reported bighorns outside of reintroduction areas. Population home ranges varied in size (18-130 km^2) and appeared to be determined by escape terrain and vegetation structure. Population growth was positive for all areas and varied between 0.110 and 0.190. Also, all populations had high lamb survival to first winter (0.67-0.92). In this area of the Great Basin, >11 groups of bighorn sheep (mean group size = 1.9, *SD* = 1.2) moved from reintroduction areas to 6 neighboring mountain ranges, an average distance of 29.3 km (range = 13-60 km). The primary limiting factor for the continued establishment and success of California bighorns in Utah is the presence of domestic sheep. We recommend that bighorns in our study areas be managed as a metapopulation and that domestic sheep be removed from areas adjacent to populations of established bighorns. Additionally, we recommended that future research focus on documenting movement corridors of bighorns, which will highlight areas where bighorn and domestic sheep movements may coincide, thus threatening the persistence of these new herds.

Key Words: bighorn sheep, California bighorn sheep, domestic sheep, Great Basin, metapopulation, *Ovis canadensis californiana*, population growth, translocation, Utah.

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Bighorn sheep (*Ovis canadensis*) are native to Utah and have inhabited the state for at least 12,000 to 15,000 years (Stokes and Condie 1961, Geist 1985). Historically, this species occurred throughout Utah and occupied the Rocky Mountains, the Great Basin, and the desert canyons portions of the state (Dalton and Spillett 1971, Smith et al. 1988). The ubiquity of bighorn sheep is indicated by abundant skeletal remains (Dalton and Spillett 1971), historical accounts (Wilson 1967), and depictions of these animals in Native American petroglyphs.

Although bighorn sheep were widely distributed historically, their distribution and numbers were greatly reduced by the influences of European settlement (Buechner 1960). By the 1930s, the combination of unrestricted grazing, disease, and over-hunting resulted in the extirpation of all bighorns in the Great Basin of Utah and the near extirpation of bighorn sheep in the state (Dalton and Spillett 1971, Smith et al. 1988, Bates 2003). Following the loss of native sheep in Utah, a concerted effort to reestablish bighorns did not begin for another 30 years.

Reintroduction has been an effective practice to restore bighorn populations (Krausman 2000), and this management technique has been used extensively in Utah (Smith et al. 1988). Early reintroduction efforts focused on restoring the Rocky Mountain subspecies (*O.c.canadensis*) to northern Utah and the desert subspecies (*O.c.nelsoni*) to the southern portions of the state. Additionally in the 1980s, two populations of Rocky Mountain bighorns were established in the Great Basin on the Utah/Nevada border. However, since 1997, only the California subspecies (*O.c.californiana*) has been used to populate this region of the state.

This paper focuses on populations founded with California bighorns. Recent evidence indicates, however, that the current taxonomy of bighorn sheep, particularly the California subspecies, is questionable and needs revision (Krausman and Shackleton 1999, Shackleton et al. 1999, Wehausen and Ramey 2000, Wehausen et al. 2005). We used the traditional taxonomy of California bighorns because these animals are designated and managed currently as such in Utah.

Populations of California bighorns have been in Utah > 10 years, and the number of animals has increased substantially. The Utah Division of Wildlife Resources (UDWR) has conducted 8 translocations, moved 194 animals, and established three populations of California bighorns in Utah. Our objectives were: (1) to examine factors that contributed to the collapse of historical populations of bighorns in the Great Basin of northern Utah, (2) to document habitat use and population growth of reintroduced herds of California bighorns, and (3) to quantify movements and discuss population structure of these bighorns in northern Utah.

Study Area

Our general study area is located in the eastern portion of the Great Basin within northern Utah (41°16´N, 113°38´W) (Fig. 1). The area encompassed a series of long, narrow mountain ranges that were separated by desert valleys, salt flats, and the Great Salt Lake. Elevation ranged from 1285 to 3362 m, but most mountain ranges were < 2200 m. Precipitation averaged < 310 mm annually, with spring and fall being the wettest seasons. Cover types of vegetation exhibited clinal variation with elevation. Valley elevations (~1,285 m) were characterized by salt-desert shrub communities and barren salt flats. Mid-elevations (1,300-2,200 m) contained grasses, brush, and pinyon (*Pinus edulis* and *Pinus monophylla*) /juniper (*Juniperus osteosperma*) cover. The highest elevations (> 2,300 m) were dominated by conifers and alpine habitat.

This portion of the Great Basin was and still is an important area for livestock grazing. Upon settlement in the 1840s, livestock owners steadily increased the number of domestic sheep and cattle in this region. Livestock grazing peaked between 1905 and 1925, and during this period > 250,000 sheep were trailed annually (Allred 1976). Today livestock grazing is regulated, but > 40 allotments for domestic sheep still exist on public land where thousands of animals graze. These allotments for domestic sheep are typically used between November and April each year.

Antelope Island

The first California bighorn population in Utah was established on Antelope Island (40°95´N, 112°21´W) in 1997. This study area (113 km^2) is a mid-elevation (2,134 m) island, mountain range that is located in the southeast portion of the Great Salt Lake (Fig. 1). Precipitation averaged 390 mm a year and perennial water was abundant. Vegetation on the island was dominated by grasses that included wheat grasses (*Elymus spp.*) and bromes (*Bromus spp.*), and low-growing brush, such as sagebrush (*Artemisia spp.*). Potential predators of bighorn sheep were coyotes (*Canis latrans*), bobcats (*Lynx rufus*), and golden eagles (*Aquila chrysaetos*). Wild ungulates that occupied the study area included bison (*Bison bison*), mule deer (*Odocoileus hemionus*), and pronghorn (*Antilocapra americana*).

Recently discovered skeletal remains indicate bighorn sheep were present on the Island $\geq$1,000 years ago (R. Rood, Utah Department of Natural Resources, personal communication), but a period of extensive livestock grazing likely caused the extirpation of native sheep. During the 1870s at least 10,000 domestic sheep were grazed on Antelope Island, and by the turn of the twentieth century, domestic sheep grazing was the primary land use (Holt 1994). Domestic livestock grazing on Antelope Island ended in 1981, when the state of Utah purchased the Island and designated it as a park. Antelope Island State Park received an average of 300,000 visitors annually, and most of these visitors come to view the wildlife (S. Bates, Utah State Parks and Recreation, personal communication).

Newfoundland Mountains

Five years after the reintroduction of bighorns on Antelope Island, a second population of California bighorns was established on the Newfoundland Mountains (41°16´N, 113°38´W) in 2001. The Newfoundland Mountains (190 km^2) are a long, narrow, mid-elevation (2,129 m) range located in the Great Salt Lake Desert. Vegetation varied from salt desert shrub communities in the valleys to a mixture of grasses and shrubs at mid-elevations that included bromes (*Bromus spp.*) three-awn (*Aristada purpurea*), and wheat grasses (*Elymus spp.*), cliff rose (*Conwania mexicana*) and rabbit brush (*Chrysothamnus spp*). Sparse juniper cover occurred at higher elevations. Perennial water was available but concentrated on the northern half of the range. Most of the land was managed by the Bureau of Land Management (BLM), although the United States Air Force had an operational bombing range which encompasses the southern portion of the study area. Public use was minimal on the Newfoundland Mountains due to limited access and the remoteness of the range. Potential predators of bighorns were coyotes, bobcats, and golden eagles. Mule deer were sympatric to bighorns in limited numbers, and no grazing permits were available for domestic livestock.

Bighorn sheep historically inhabited the Newfoundland Mountains (Dalton and Spillett 1971), but like many extirpated populations, little is known of their history. The mountain range was mined for various metals from 1870 to 1957 (BLM 1992) and livestock grazing was allowed until 2000. Presumably, the same factors that caused the extirpation of bighorns in Utah (e.g. livestock grazing, disease, and hunting) were responsible for the loss of this population. Today, most of these factors have been reduced or eliminated on the Newfoundland Mountains. For example, the Utah Chapter of Foundation for North American Wild Sheep (UFNAWS) spent $75,000 to close domestic sheep allotments on this range prior to reintroducing bighorn sheep (D. Peay, Utah Chapter of Foundation for North American Wild Sheep, personal communication). Domestic sheep grazing allotments still exist in several valleys and mountains ranges that are adjacent to the Newfoundland Mountains (Fig. 1).

Stansbury Mountains

A third population of California bighorns was established on the Stansbury Mountains (40°71´N, 112°63´W) in 2005. The Stansbury Mountains are located near the southwest shores of the Great Salt Lake (Fig. 1). They are a relatively large (650 km^2), high-elevation (3,362 m) range. Precipitation (350 mm) at low elevations was similar to Antelope Island, but higher elevations received considerably more moisture (> 1400 mm) (Taye 1981). Below 2200 m, vegetation was similar to Antelope Island, but with more extensive stands of trees. Above 2200 m, there was substantial tree cover that included aspen (*Populus tremuloides*), Douglas fir (*Pseudotsuga menziesii*), and Englemann spruce (*Picea englemannii*), as well as alpine habitat. The majority of the land is managed by the Forest Service and the BLM with small amounts of state, private, and tribal lands interspersed throughout the area. Potential predators of bighorn sheep were mountain lions (*Puma concolor*), bobcats, coyotes, and golden eagles. Sympatric wild ungulates included elk (*Cervus elaphus*) in limited numbers and mule deer. Domestic cattle were permitted to graze on public and private lands in the study area. Active mountain lion control was conducted in this study area from reintroduction in 2006 to the present by the Utah Division of Wildlife Resources and Wildlife Services. Individual mountain lions were removed if they killed 2 bighorn sheep within 90 days or 3 within a year.

It is unknown if bighorns historically inhabited the Stansbury Mountains, but it is possible. Bighorn sheep remains and petroglyphs have been found on several nearby mountains ranges: the Lake Side Mountains (12 km northwest), Stansbury Island (11 km north), and the Oquirrah Mountains (25 km west) (Dalton and Spillett 1971). Additionally, 4 rams from the Newfoundland Mountains wandered to the Stansbury Mountains prior to the 2005 reintroduction. Furthermore, precipitous terrain is abundant which indicates the range could have supported bighorns. Over the past 15 years, wild fires have burned much of the tree cover in the northern portion of the study area, which has increased the suitability of the habitat for bighorns. Additionally, UFNAWS spent $55,000 to close domestic sheep allotments on the Stansbury Mountains in 2005 (D. Peay, Utah Chapter of Foundation for North American Wild Sheep, personal communication), which was essential to prepare this area for a reintroduction of bighorn sheep.

Methods

Habitat

For each of the three study areas, we documented the amount of escape terrain and tree cover, and the number and distribution of water sources using ArcGIS 9.2 (ESRI, Redlands, CA). We defined escape terrain as habitat patches > 0.7 ha with slopes between 27 and 85 degrees (DeCesare and Pletscher 2006). We used a 10 m Digital Elevation Model obtained from the United States Geological Survey to create a slope layer using Spatial Analyst in ArcGIS. We then selected habitat patches in the slope layer that fit our definition of escape terrain and calculated their area. We totaled the area of all escape terrain patches within a study area to estimate available escape terrain.

To estimate the amount of tree cover in each study area, we used the Southwestern GAP layer obtained from the Utah GIS Portal (2008). This layer delineates 109 cover types and has a resolution of 0.4 ha. We selected all habitat types within this layer that contained tall vegetation (>1 m). These habitat types included the following: Great Basin pinyon-juniper woodland, Rocky Mountain Gambel Oak-mixed montane shrubland, Rocky Mountain montane mesic mixed conifer forest and woodland, Rocky Mountain aspen forest and woodland, and Rocky Mountain subalpine mesic spruce-fir forest and woodland. We totaled the areas of these polygons to estimate the amount of tree cover within each study area.

To document water availability, we used a GIS point layer that contained the locations of most springs within our study areas. This layer was obtained from the Utah GIS Portal (2008). We modified the layer by adding known water sources that were not accounted for within the layer.

To document habitat use, we observed bighorns on 960 occasions between 2004 and 2007 using radio telemetry, binoculars, and spotting scopes in all three study areas. Sightings were obtained year-round from both male and female groups. We estimated home ranges of each population using a 95% fixed kernel polygon created with the Home Range Tools extension for ArcGIS 9.2 (Rogers et al. 2005). We used an ad hoc approach to select the smoothing factor for home range calculations (Mills et al. 2006)

Population Dynamics

Bighorn population estimates, from 1997 to 2004, were obtained from aerial and ground counts conducted by UDWR and Utah State Parks employees. From 2005 to 2007, we conducted annual winter counts in all three study areas by observing bighorns from the ground. Additionally, we collected population data for only the Stansbury Mountains in 2008. For each population, we calculated growth rates (r) from population estimates using the instantaneous rate of growth equation ($N_t = N_0e^{rt}$); additionally, we estimated doubling times using ln 2/r (Johnson 1996). Growth rates for some populations were biased by the removal and addition of animals due to translocations, and we identified these biases in the results. We counted the number of lambs born during the parturition period (Apr-May) and estimated birth dates all lambs observed. We also counted the number of lambs that remained the following the winter. Lamb survival was estimated by dividing the number of lambs observed during winter counts by number of lambs counted during the parturition period.

Metapopulation

To describe the spatial structure of our study area, we used ArcGIS 9.2 to calculate the Euclidean distance between historical bighorn ranges and those ranges adjacent to them. Additionally, we gathered accounts of reintroduced bighorn moving between mountain ranges in our study area. This information was obtained from BLM reports and by interviewing those individuals who reported sighting bighorns outside of reintroduction areas.

Results

Antelope Island

Habitat.— Antelope Island had 8 km^2 of escape terrain, which represented 7% of the study area. The spatial distribution of escape terrain was concentrated in the center of the Island and was continuous. Tree cover (11 km^2) was dispersed throughout high elevations, and consisted of very sparse patches of junipers. Forty water sources existed on Antelope Island, and we observed bighorns using at least 7 of these springs throughout all seasons of the year. The home range for the Antelope Island population was 18 km^2 (Fig 2.). Habitat use by bighorns was restricted to high elevation areas in the center of the Island. During most years the island was completely surrounded by salt water, and no dispersal movements were documented.

Population dynamics.— The Antelope Island population was founded with 26 California bighorns from Kamloops, British Columbia, Canada in 1997. It was augmented 3 years later with 6 additional animals from Winnemucca, Nevada (Table 1). This population has grown from 26 animals to a high of 174 in 2005 (Fig. 3). From 1997 to 2007, the average growth rate (r) was 0.188, with a doubling time of 3.7 years. This, however, is a very conservative estimate of growth as 92 bighorns (51 ewes) were removed from this population during this period. From 2005 to 2007, we counted 105 young born (2005 = 38, 2006 = 32, 2007 = 35) on Antelope Island. In 2005, lamb survival to first winter was 0.71, and in 2006 it was 0.75. The mean and *SD* of lambing date for this population was April 17 ± 8.9 days.

Newfoundland Mountains

Habitat.— The Newfoundland Mountains had 33 km^2 of escape terrain which extended throughout 17% of the study area from mid to high elevations. Tree cover existed on 37 km^2 of the range and was comprised of sparse stands of junipers. Water sources were concentrated on the northern portion of the study area, and bighorns used at least 7 of 20 available springs. The population home range for bighorns on the Newfoundland Mountains was 130 km^2, which encompassed the entire length of the range (Fig. 2). Summer movements of bighorns were restricted to the northern portion of the range, near available water. Although few animals were radio collared, 10 dispersal movements from the Newfoundland Mountains have been documented since 2001 (Table 2).

Population dynamics.— Thirty-one California bighorn sheep from Nevada and Antelope Island were reintroduced to the Newfoundland Mountains during winter 2000-2001 (Table 1). The population was augmented in 2003 with 20 animals and again in 2008 with 18 additional rams, all of which were from Antelope Island. The Newfoundland Mountains population grew from 31 animals to almost 100 in 2007 (Fig. 3). The growth rate (r) from 2001 to 2007 was 0.190 with a doubling time of 3.6 years. The growth rate of this population is an over estimate as 20 animals (14 ewes and lambs) were added to the population during this period. From 2005 to 2007, we counted 86 lambs (2005 = 37, 2006 = 31, 2007 = 18) in this study area. Lamb survival was 0.65 in 2005 and 0.77 in 2006. The mean and *SD* lambing date for the Newfoundland

Mountains population was April 24 ± 4.8 days.

Stansbury Mountains

Habitat.— The Stansbury Mountains had 189 km^2 of escape terrain that comprised 29% of study area. Escape terrain was available throughout much of the mid to high elevations areas. Tree cover was extensive (349 km^2) and distributed throughout the entire range except the northern section. Water sources were scattered throughout the southern and central portion of the range, but there were few located in the northern portion of the study area. Bighorns, mostly rams, used 2 of 80 available water sources. The population home range for bighorns on the Stansbury Mountains was 24 km^2 (Fig. 2), which constituted only 4% of the study area. Bighorns used only the northern most extent of the range, in close proximity to the initial release site. Although > 90% of the animals were radio collared, we did not detect dispersal movements of bighorns from the Stansbury Mountains.

Population dynamics.— In the winter 2005-2006, 57 California bighorns were translocated from Antelope Island to the Stansbury Mountains (Table 1). The population was augmented in 2008 with 36 animals from Antelope Island (Table 1). From the 2006 to 2008, the growth rate (r) for Stansbury Mountains, excluding the 36 animals added in 2008, was 0.110. From 2006 to 2007, we counted 41 lambs born (2006 = 18, 2007 = 23). In 2006, lamb survival was 0.67 and in 2007 it was 0.91. The mean and *SD* lambing date for the Stansbury Mountains population was April 17 ± 7.8 days.

Metapopulation

Within the extent of our study area, 13 mountain ranges existed, and historically, bighorn sheep occupied at least 10 of these areas. The mean distance between mountain ranges was 22.3 km (*SD* = 4.8 km, range 8-45 km). Vegetation that occurred in the interspaces between ranges was low growing (< 1 m), which may have facilitated dispersal movements of bighorn sheep.

Today, 5 populations of bighorn sheep (3 California and 2 Rocky Mountain) exist within this region of Utah. With the exception of bighorns on the Stansbury Mountains, few of these animals were radio marked. Despite the lack of radio-marked animals, 11 dispersal movements have been documented since 2001 (Table 2). Bighorns have dispersed to at least 6 mountain ranges (Fig. 1), a mean distance of 29.3 km (*SD* = 13.9 km). Mean group size was 1.9 (*SD* = 1.2). Ten of 11 movements were animals dispersing from the Newfoundland Mountains. Eight of the dispersal groups consisted of only males. Male bighorns dispersed an averaged 31.7 km (*SD* = 14.3) and a maximum of 60 km. Additionally, one of these dispersing males reportedly contacted a herd of domestic sheep on the Grassy Mountains (21 km) in 2006, but we have no knowledge of the fate of that animal or where it moved after the encounter. The average distance that females dispersed was 16.7 km (*SD* = 4.0 km), and the maximum distance was 21 km.

Discussion

Habitat

Bighorn sheep are habitat specialists that require steep terrain, open habitats, and in many areas free water for survival (Risenhoover and Bailey 1985, Smith et al. 1990, Dolan 2006). These variables help explain the distribution of bighorns within a study area and may provide insight as to why a population of reintroduced animals succeeds or fails. The amount and configuration of escape terrain are positively correlated with the number of bighorns within a population; in Arizona, McKinney et al. (2003) recommended that bighorns be reintroduced in areas with at least 15 km^2 of escape terrain.

In Utah, California bighorns have been reintroduced into habitats with 8 to 189 km^2 of escape terrain. The study area with the least of amount of escape terrain, Antelope Island, also had the smallest population home range. In the Newfoundland Mountains study area, escape terrain was distributed throughout the entire length of the range, and the population home range of bighorns reflected this availability. Similarly, the Stansbury Mountains had abundant escape terrain, but bighorns only used a small portion of the habitat. Possibly, bighorns failed to disperse throughout the study area because of extensive tree cover. Indeed, bighorns prefer habitats with high visibility and avoid areas with tall vegetation (Risenhoover and Bailey 1985, Hayes 1994, Smith et al. 1999). In the absence of substantial tree cover, the amount and distribution of escape terrain appeared to influence the distribution of reintroduced bighorns within our study areas.

Water is also an important habitat component for the management and conservation of bighorn sheep, especially those occupying desert environments (Turner 1970, Leslie and Douglas 1979, Bleich et al. 2006, Marshal et al. 2006). The distribution of water sources can influence range use by bighorns (Leslie and Douglas 1979; 1980, Rubin et al. 2002, Oehler et al. 2003, Turner et al. 2004). For example, 97% of observations of the endangered Nelson's bighorn sheep *O. c. nelsoni* were within 3 km of perennial sources of water (Turner et al. 2004). Moreover, the lack of perennial water in some areas may increase the probability of population decline (Douglas 1988, Dolan 2006). Additionally, persistence of some populations of bighorn sheep in California is correlated with the presence of perennial sources of water (Epps et al. 2004).

In all of our study areas, bighorns used free water. On Antelope Island, perennial water was abundant, and bighorns used several water sources year round with peak use occurring in summer (Whiting et al. in review). On the Newfoundland Mountains, free water was only available in the northern portion of the study area, and bighorns concentrated in this area during summer. On the Stansbury Mountains, water sources were available throughout the central and southern portions of the study area, but few occurred within the home range of bighorns. Despite water being limited in the area used by bighorns, at least two water sources were used during summer. For this region of Utah, observational data suggests that bighorns have a physiological need for free water, especially during the summer months. If water developments are placed in areas that meet basic habitat requirements of bighorns (i.e. adequate escape terrain and visibility), then distribution of bighorns, at least during summer, may be increased.

Population Dynamics

When bighorn sheep are reestablished in areas with adequate habitat, they are capable of rapid growth rates (Singer et al. 2000, Hedrick and Gutierrez-Espeleta 2001). After an initial period of growth, however, some populations have declined (Smith et al. 1988). Population declines of bighorn sheep may be caused by a variety of factors, but disease (Gross et al. 2000, Monello et al. 2001) and predation (Rominger et al. 2004, McKinney et al. 2006) appear to be the most important causes. Our study shows that neither disease nor predation appear to be substantially influencing population growth of California bighorns in Utah. However, mountain lion control may have contributed to the high growth rates and survival observed on the Stansbury Mountains.

In the past ten years, California bighorn populations have experienced excellent growth in Utah. Populations on Antelope Island and the Newfoundland Mountains grew 19% annually. The most productive population was Antelope Island. Because it is an island and a State Park, this study area was isolated from many factors that limit population growth in bighorn sheep. Additionally, the animals on Antelope Island have facilitated the restoration of California bighorns in Utah. Nearly 150 bighorns from Antelope Island have been used to found two additional populations within the state. Antelope Island bighorns will continue to be used as a source for future reintroductions. In the near future, the Newfoundland Mountains and Stansbury Mountains populations may also provide bighorns for future translocations.

The excellent population growth that California bighorn populations have experienced in Utah is, in large part, due to high lamb survival and recruitment. In all years of the study, lamb survival was greater than 67% and as high as 92%. Also, limited observational data suggests that adult survival is high. If California bighorn populations continue growing at the present rate, the statewide population could possibly exceed 600 individuals by 2012.

Metapopulation

Management of bighorn sheep has traditionally focused on individual populations, but in many areas a metapopulation model may be more appropriate (Bleich et al. 1996). Historically, the individual population approach was used, because bighorn habitat is patchy with separation between populations; additionally bighorn movements between populations were thought to be limited (Geist 1971b;a). Schwartz et al. (1986), however, noted bighorns occasionally moved 20 to 45 km between populations and through habitats that would be considered unsuitable for bighorn sheep. Intermountain and inter-population movements of bighorns are now well documented and have been reported for both males and females (Chow et al. 1988, Bleich et al. 1996, DeCesare and Pletscher 2006). Dispersing bighorns provide connectivity between populations, and bighorn metapopulations have been reported in Arizona, California, Idaho, and Montana (Bailey 1992, Bleich et al. 1996, DeCesare and Pletscher 2006, Cassirer and Sinclair 2007).

For bighorn sheep, metapopulation structure has two vital implications: gene flow and disease transmission. Gene flow and the genetic health of bighorn populations has been a conservation concern (Whittaker et al. 2004). Indeed, some reintroduced populations have lost genetic variability due to the founder effect (Fitzsimmons et al. 1997), especially those occupying islands (Hedrick and Gutierrez-Espeleta 2001). Also, isolated populations may experience genetic drift due to inbreeding (Gilpin 1991). Schwartz et al. (1986) observed that only a limited movement between bighorn populations would be required to maintain genetic variability. In bighorn metapopulations, gene flow between populations is preserved largely through the movements of rams, because rams are more likely to disperse and move longer distances than ewes (Bleich et al. 1996).

Ram movements between populations, however, may also have a negative effect. Disease transmission is an inadvertent consequence of animals moving between populations (Gilpin 1991). This dynamic is particularly important in bighorn sheep, because they are highly susceptible to diseases carried by domestic sheep (Foreyt and Jessup 1982). Dispersing bighorns may leave traditional habitats and move through areas with domestic livestock. Additionally, during the breeding season bighorn rams may seek out domestic ewes (Gross et al. 2000). Animals that have contacted domestic sheep may then return to a bighorn population and precipitate a die-off. As a result, dispersal corridors and their juxtaposition to domestic sheep allotments should receive increased attention (Bleich et al. 1996).

Today, bighorns are being restored to the Great Basin of Utah, which may also result in the restoration of a historical metapopulation. Following reestablishment of bighorn sheep, there have been several reports of animals moving between mountain ranges. Dispersal movements are undoubtedly occurring at a higher rate than we documented. Bighorns moving between populations may preserve or increase genetic variation within this region. At least one dispersing ram, however, made contact with domestic sheep. Interactions, such as this, present a serious threat to established bighorn populations that are now healthy and growing. Although populations of California bighorns we studied have been disease free, it is conceivable that they may be severely reduced or eliminated by disease epizootics in the future. To reduce the probability of such an event, active measures should be taken to decrease the possibility that bighorn sheep will contact domestic sheep in this region.

Management Implications

In the Great Basin of Utah, managing bighorns on dispersed mountain ranges as a metapopulation will help ensure that reintroduced populations persist. As California bighorn populations in Utah increase in size and new populations are established, movements within this metapopulation will increase and more closely approximate historical movements. As a result, an increasing numbers of dispersing rams and possibly limited movements of females should be expected.

To date, UFNAWS has contributed >$1.4 million in northern Utah to close domestic sheep allotments and secure habitat for bighorn reintroductions. We recommend that the policy of removing domestic sheep prior to reintroduction be continued and expanded to include valleys and ranges adjacent to established bighorn populations. Additionally, an increased focus on the movements of rams within this metapopulation will elucidate movement corridors, while identifying domestic sheep allotments that pose the greatest threat to established populations.

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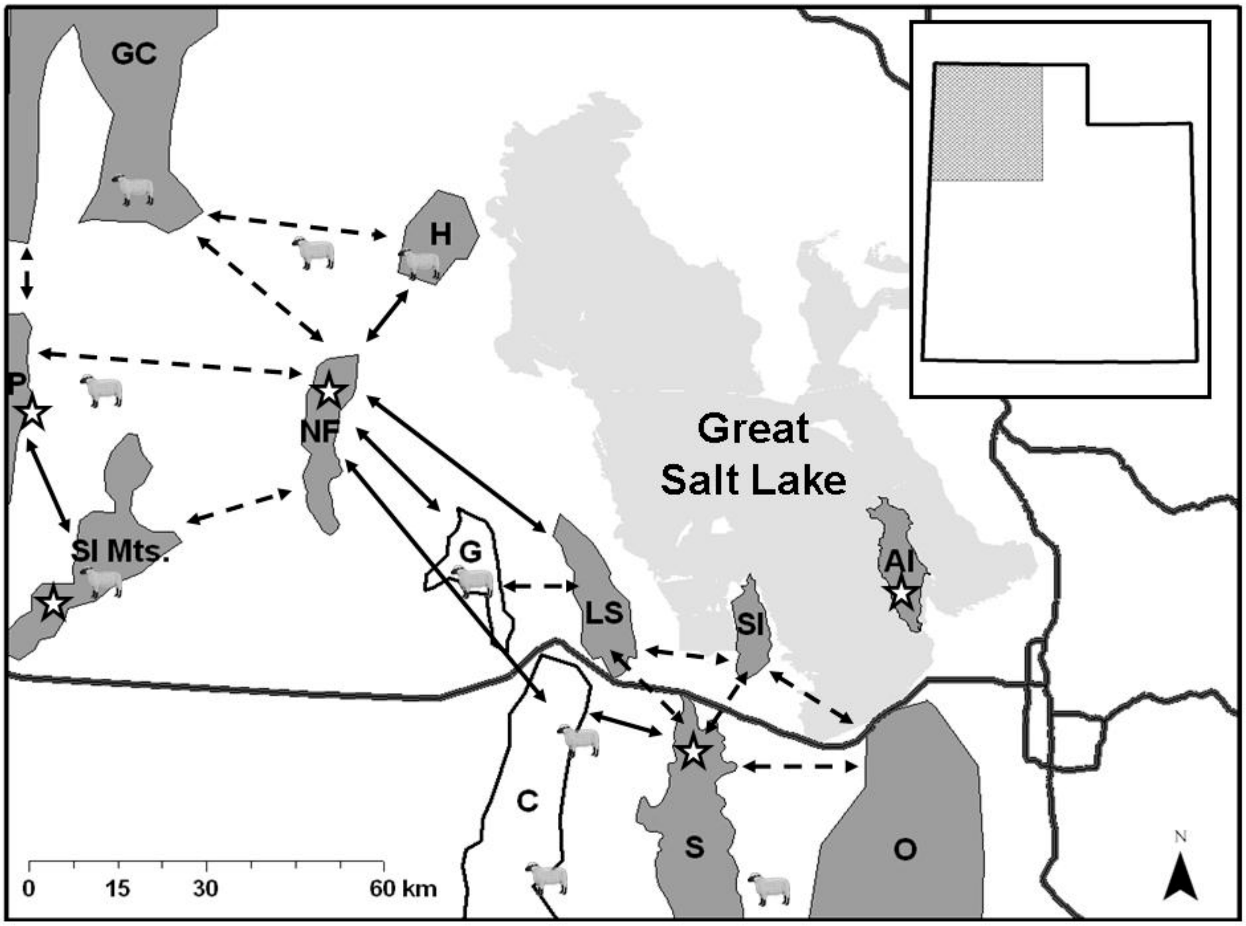

Figure 1. Probable historical distribution of a bighorn metapopulation in the Great Basin of Northern Utah. Mountain ranges that contained historical populations of bighorn sheep are indicated in gray; whereas those ranges where bighorns were not historically found are indicated in white. Broken arrows designate plausible movements of historical bighorns, and solid arrows designate movements of reintroduced bighorns. Sheep symbols indicate domestic sheep allotments, and stars represent extant bighorn populations. The names of the mountain ranges were abbreviated as follows: AI = Antelope Island, C = Cedar, GC = Grouse Creek, H = Hogup, LS = Lakeside, NF = Newfoundland, O = Oquirrah, P = Pilot, S = Stansbury, SI = Stansbury Island, and SI Mts. = Silver Island.

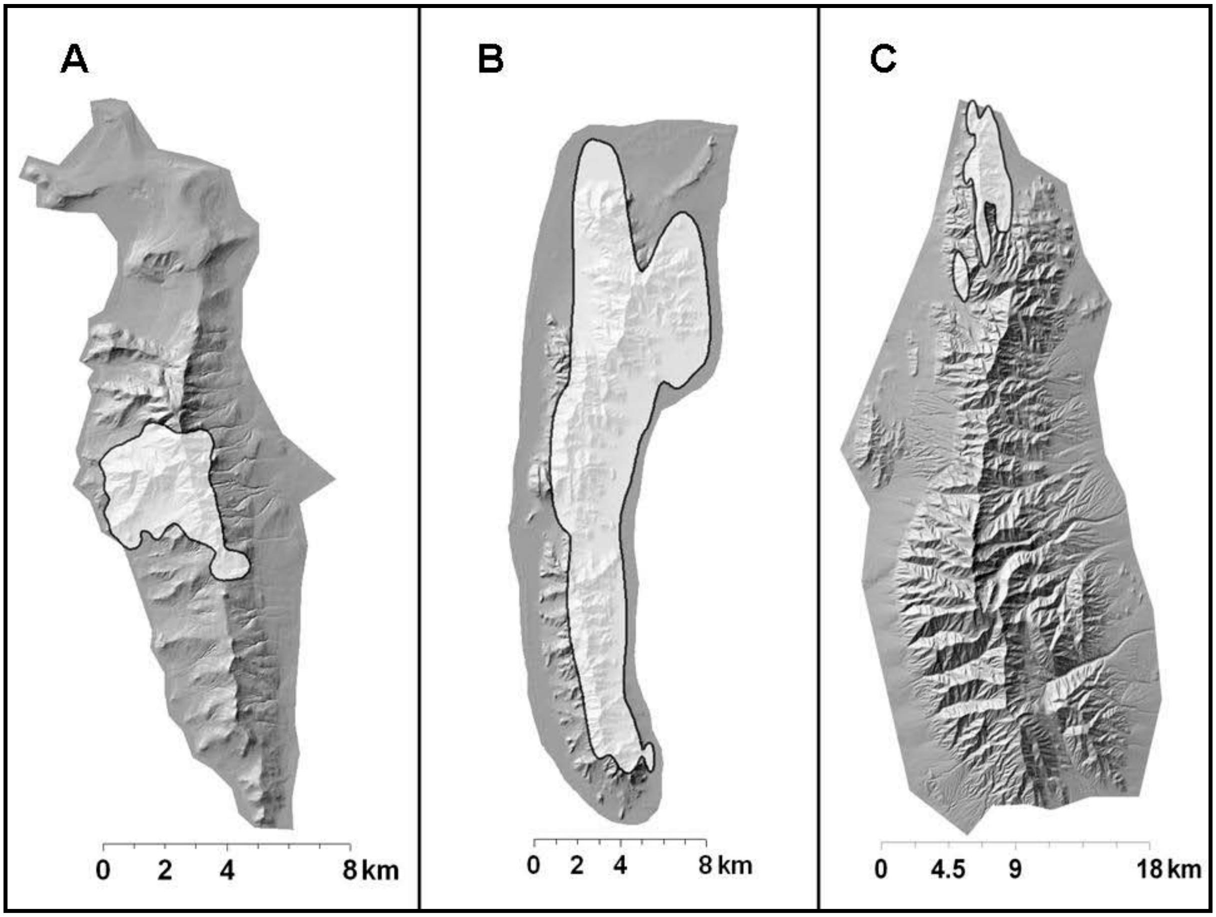

Figure 2. Shown here for comparison are 95% fixed-kernel home-range polygons for California bighorn populations in Utah from 2004 to 2007: (A) Antelope Island, (B) Newfoundland Mountains, and (C) Stansbury Mountains.

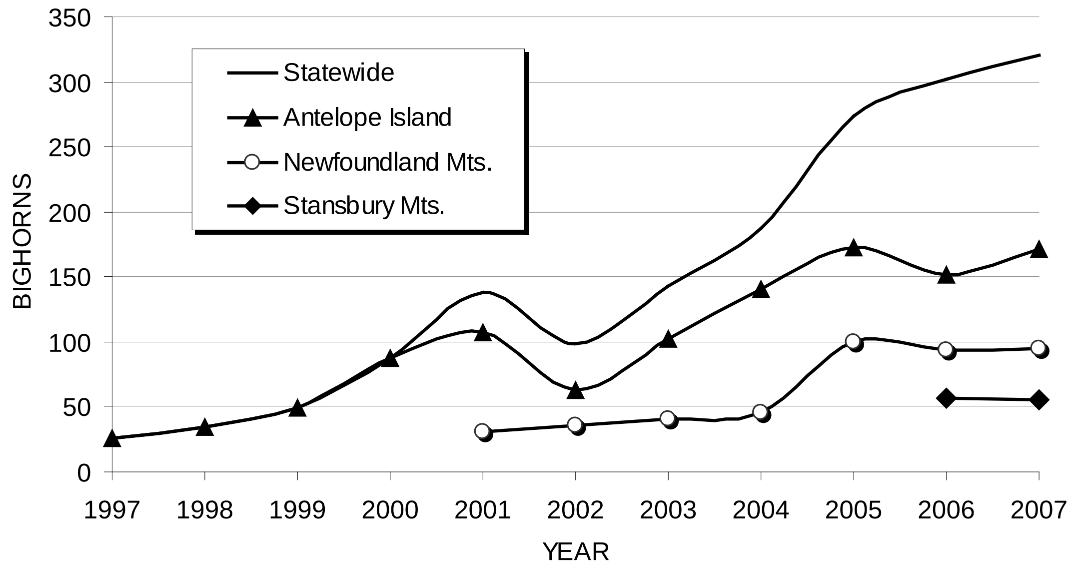

Figure 3. Population estimates plotted for California bighorn populations in Utah (1997-2007).

Table 1**.** Area of release, source herd, and demographics of California bighorn translocations in Utah from 1997 to 2008.

Year	Area	Type	Source	Ewes	Rams	Lambs
1997	Antelope Island	Reintro.	Kamloops, B.C.	18	4	4
2000	Antelope Island	Aug.	Winnemucca, NV	2	4	0
2001	Newfoundland Mts.	Reintro.	Antelope Island, UT	6	7	2
2001	Newfoundland Mts.	Reintro.	Hart Mt., NV	12	3	1
2003	Newfoundland Mts.	Aug.	Antelope Island, UT	13	6	1
2006	Stansbury Mts.	Reintro.	Antelope Island, UT	32	13	12
2008	Stansbury Mts.	Aug.	Antelope Island, UT	12	21	3
2008	Newfoundland Mts.	Aug.	Antelope Island, UT	0	18	0

Table 2. Location, demographics, and distance traveled during dispersal movements by bighorn sheep in the Great Basin of northern Utah (2001-2007).

Date	Location	Males	Females	Source population	Distance (km)
May 2001	Grassy	0	1	Newfoundland	21
Aug 2001	Hogup	0	1	Newfoundland	16
Jun 2002	Cedar	4	0	Newfoundland	41
Sep 2002	Stansbury	4	0	Newfoundland	60
Dec 2003	Lakeside	1	0	Newfoundland	36
Jul 2005	Grassy	2	0	Newfoundland	21
Aug 2005	Silver Island	3*	22*	Pilot	13
Sep 2005	Grassy	1	0	Newfoundland	21
Jul 2006	Lakeside	2	0	Newfoundland	36
Dec 2006	Grassy	1	0	Newfoundland	21
Jul 2007	Lakeside	2	0	Newfoundland	36

*Dispersal group was believed to have moved several years prior to the sighting, and the actual number of dispersing individuals was unknown.

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Status, Distribution, and History of Rocky Mountain Bighorn Sheep in Utah

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Abstract: Rocky Mountain bighorn sheep (*Ovis canadensis canadensis*) are native to Utah, and were abundant prior to European settlement. Bighorn populations began declining in the late 1800s, and by the 1930s, no self-sustaining populations existed in Utah. In 1966, the Utah Division of Wildlife Resources began reintroducing bighorns into their former ranges. In 1988, Smith et al. reported 242 Rocky Mountain bighorns had been reintroduced in or near Utah resulting in 8 populations. No current information exists, however, regarding the status and distribution of bighorns in Utah. Our objectives were to document reintroductions of Rocky Mountain bighorns since 1988, and provide population estimates, discuss challenges, and offer recommendations for the management of these herds. We interviewed wildlife biologists from state, federal, and tribal agencies to obtain information regarding each bighorn herd in Utah. Over the past 20 years, 607 additional bighorns were reintroduced in or near Utah, 9 new populations were established, and 200 harvest permits were issued. As of winter 2007-2008, approximately 1,909 bighorns resided in or near Utah. Of the 17 herds in Utah, 4 failed, 5 were declining, 1 was stagnant, 3 were growing, and 4 were successful. Disease is the most important limiting factor for bighorns in Utah. Our results chronicle the history of bighorn reintroductions in Utah, and this compilation of updated information will aid in the conservation and management of this unique ungulate.

Key Words: hunting, *Ovis canadensis*, reintroduction, Rocky Mountain bighorn, translocation, Utah.

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Introduction

Rocky Mountain bighorn sheep are native to Utah (Buechner 1960, Rawley 1985). They were historically abundant and extensively used by Native Americans, early explorers, and settlers (Dalton and Spillett 1971, Rawley 1985). Bighorn populations decreased throughout the state during the late 1800s, and by the 1930s, no stable populations existed (Smith et al. 1988, Smith et al. 1991). Domesticated livestock, particularly sheep, competed directly with bighorns for range resources. Moreover, domestic sheep were the primary vectors that transmitted diseases to bighorns, which led to catastrophic die-offs (Goodson 1982, Jessup 1985, Bunch et al. 1999, Singer et al. 2000b). Habitat change, human settlement, and indiscriminate hunting also contributed to the decline of bighorn populations in Utah (Irvine 1969, Dalton and Spillett 1971, Smith et al. 1988).

In 1966, the Utah Division of Wildlife Resources (UDWR) began reintroducing Rocky Mountain bighorns to historical ranges. These reintroductions were met with limited success (Smith et al. 1988, Smith et al. 1991). Smith et al. (1988) documented the status and distribution of Rocky Mountain bighorn sheep populations in Utah from 1966 to 1988. At that time, the UDWR, Colorado Division of Wildlife (CDOW), and Ute Tribe Fish and Wildlife Department (UTFWD) had conducted 15 translocations, released 242 bighorns, and established 8 populations in or on the boarder of Utah. Furthermore, those authors provided a conservative estimate of 239 bighorns in Utah and indicated that no harvest permits were available during that time (Smith et al. 1988).

Since 1988, bighorns in Utah have increased because of translocations, improved management, and high population growth rates in several herds. Our objectives were to update the status and distribution of Rocky Mountain bighorn populations in Utah, discuss challenges and limiting factors influencing each herd, and present the number of harvest permits sold and filled since 1991. This information will assist the UDWR in managing bighorns state wide and inform the interested public of the status and distribution of this unique mountain ungulate in Utah.

Methods

Desert bighorn (*O. c. nelsoni*), California bighorn (*O. c. californiana*), and Rocky Mountain bighorn sheep occupy areas in Utah. We recognize that recent morphometric evidence indicates that Rocky Mountain and California bighorns should not be considered separate subspecies (Wehausen and Ramey 2000); however, the UDWR retains this classification of two subspecies. Here, we refer to Rocky Mountain bighorns, unless otherwise specified.

We defined a reintroduction as moving bighorn sheep into an area without bighorns present and an augmentation as moving bighorn sheep into a location with bighorns already present. We used the term translocation to indicate moving bighorns from one location to a different location. Translocations often refer to reintroductions and augmentations collectively. Also, if multiple translocations occurred in an area within the first year, we considered all these releases as an initial reintroduction (Singer et al. 2000a).

We documented the histories and locations of each bighorn reintroduction by reviewing literature and contacting state, federal, and tribal biologists. We estimated the number of bighorns in each population by reviewing flight data from 2006 and 2007, conducting terrestrial counts by tracking collared animals, and interviewing local biologists. Desolation Canyon, Jack Creek, Bighorn Mountain, and Harper's Corner are rugged and inaccessible areas; therefore, the UDWR adjusted the minimum number of animals observed from aircraft using a 0.6 sighting probability factor to estimate population sizes in those areas (K. Hersey, UDWR, personal communication). Population counts for all other herds were minimum estimates, mostly obtained from terrestrial counts.

We contacted local biologists to identify potential limiting factors, habitat improvement projects, and the overall status of each bighorn herd. We determined causes of bighorn mortalities for the Mount Nebo, Mount Timpanogos, and Rock Canyon herds by retrieving and assessing carcasses of collared sheep. We sent carcasses that were not consumed by scavengers or bloated because of exposure to high temperatures to the Utah Veterinary Diagnostic Laboratory in Nephi, Utah, for necropsy.

Furthermore, we categorized each bighorn herd as successful, growing, stagnant, declining, or failed. Successful herds reached the minimum viable population number of 125 animals or the management objective number designated by wildlife managers. We considered growing herds to have more animals than released, stagnant herds to have the same number of animals as released, and declining herds to have fewer animals than released. Finally, we considered failed herds as having no bighorns present.

We quantified the number of bighorn harvest permits sold and filled, the amount of money generated from each permit, and the average number of days hunters spent in the field by reviewing harvest records from the UDWR and by conversing with a biologist from the UTFWD. We also contacted members of the Utah Chapter of the Foundation for North American Wild Sheep (UFNAWS) for Boone and Crockett scores of rams harvested in Utah.

Results

Since 1966, 46 bighorn translocations have occurred in or near Utah, 36 of which were conducted by the UDWR (Table 1). The other 10 translocations were conducted by the Nevada Department of Wildlife (NDOW), CDOW, and UTFWD. In all, 17 bighorn populations have been established in or near Utah. Of those herds, 4 failed, 5 were declining, 1 was stagnant, 3 were growing, and 4 were successful. A total of 849 bighorns were translocated in or near Utah (755 from out of state and 94 within state), and currently an estimated 1,909 bighorns reside in or on the borders of Utah.

Bighorn Herds

Brigham City (1966). – The UDWR selected Brigham City for the first bighorn reintroduction site in Utah (Fig. 1). From 1966-1970, 4 bighorn translocations occurred, resulting in the release of 60 animals (Table 1). Bighorns were held in a fenced enclosure on the mountain prior to being released and would occasionally escape, traveling south to nearby Willard Peak (8 km) and north to the Wellsville Mountain Range (10 km; Dalton and Spillett 1971). In 1973, a mature ram from Brigham City was observed in Weber Canyon, 64 km south of the release site (Stapley 1974). Unfortunately, this herd did not persist due to poaching and diseases contracted from domestic livestock including pneumonia and bronchitis (Smith et al. 1988). Close proximity to areas with domestic sheep and urban encroachment lessen the value of this site for reintroductions in the future. Further information regarding the Brigham City reintroduction is provided by Stapley (1974) and Smith et al. (1988).

Desolation Canyon (1970). – This herd is managed by the UDWR and UTFWD. Between 1970 and 1973, 21 bighorns from Wyoming and Alberta were released in Desolation Canyon (Fig. 1; Table 1). Smith et al. (1988) estimated this herd at 75-100 animals in 1988. Recently, UTFWD and UDWR biologists estimated 733 bighorns in Desolation Canyon (Table 2). Herd growth was partially due to 2 UTFWD augmentations in 1998 which added 64 sheep (Table 1). Furthermore, high lamb production and recruitment has perpetuated the rapid growth of this herd. Even during recent years of drought, this population recruits 30 lambs/100 ewes (B. Crompton, UDWR, personal communication).

Limiting factors for this herd included mountain lion (*Puma concolor*) predation and pinyon-juniper (*Pinus edulis and Juniperus spp.*) encroachment. Biologists have attempted to remove mountain lions that prey on bighorn sheep. Tracking and killing specific mountain lions, however, has been difficult because of the ruggedness of the terrain (B. Crompton, personal communication). Also, in 2008, the UTFWD is planning a prescribed burn on tribal lands in Florence Creek to improve bighorn habitat (K. Courts, UTFWD, personal communication). Additionally, lack of water sources may have limited range use and influenced population persistence in this area. To alleviate this problem, several guzzlers have been installed and five more will be constructed next year potentially allowing bighorns to expand range use (B. Crompton, personal communication).

To minimize interactions with domestic sheep in the area, the UFNAWS spent $400,000 to convert domestic sheep grazing permits to allotments for cattle (D. Peay, UFNAWS, personal communication). The Bureau of Land Management (BLM) also eliminated a number of domestic sheep allotments in order to reduce the probability of disease related die-offs in this area. In summary, the Desolation Canyon population is the largest herd of bighorn sheep in the state and has served as a source population for 2 bighorn herds in Utah: Mount Timpanogos and Carter Creek (Table 1).

Mount Nebo (1981 and 2004). – In winter 1981, 27 bighorns were captured at Whiskey Basin, Wyoming, and released on Mount Nebo. This herd was augmented with 21 additional sheep from Whiskey Basin the following year (Table 1). Bighorns were held in a fenced enclosure prior to reintroduction, similar to the Brigham City herd. In summer 1983, 55 bighorns were observed. Severe winters in 1983 and 1984, competition with deer (*Odocoileus hemionus*) and elk (*Cervus elaphus*), poaching, and interactions with domestic sheep decimated this herd (Smith et al. 1988). By 1987, only 5 bighorns remained.

In December 2004, the UDWR released 18 bighorns from Augusta, Montana, onto the slopes of Mount Nebo (Table 1). To decrease the probability of contact with domestic sheep, the UFNAWS spent $50,000 to convert domestic sheep allotments to cattle allotments in this area (D. Peay, personal communication). To reduce mountain lion predation, the UDWR increased mountain lion harvest permits to 20 per year on Mount Nebo. To date, 5 bighorn sheep have died due to mountain lion predation. Additionally, several wildfires have occurred in this area in recent years, thereby increasing the amount of available bighorn habitat by converting conifers and mountain brush to forb-grass habitat.

In December 2006, we observed 37 bighorns on Mount Nebo, and the herd had doubled in 2 years. In January 2007, 25 bighorns from Augusta, Montana were released onto the mountain, increasing the total number of bighorns to 62 (Table 1). Unfortunately in spring 2007, domestic sheep were observed interacting with bighorns and soon thereafter 7 collared ewes died from pneumonia. Of the 37 bighorns observed in 2006, only 11 survived to 2008. Interestingly, only 1 of the 25 bighorns released in 2007 died from disease, possibly because these animals had little interaction with bighorns from the 2004 reintroduction. Also, bighorns released in 2007 used different areas than bighorns released in 2004. As of winter 2008, we estimated 35 animals occupied Mount Nebo (Table 2).

Domestic sheep continue to threaten the persistence of bighorns on Mount Nebo. In 2007, there were 6 sightings of domestic sheep with bighorns, or in bighorn habitat. No domestic sheep allotments currently exist on Mount Nebo; yet, domestic sheep still frequent this area, raising serious management concerns. Usually, dispersing bighorn rams are the vector for transmitting diseases to bighorn herds (Gross et al. 2000), but in this population, domestic sheep have trespassed into bighorn habitat. It seems unlikely that this herd will succeed unless domestic sheep are eradicated from the area and prevented from returning.

Bear Mountain (1983). – During 1983 and 1984, 38 bighorns were captured at Whiskey Basin, Wyoming, and released on Bear Mountain (also referred to as Bare Top Mountain). From 2000 to 2001, 10 additional bighorns were released to potentially increase genetic diversity (Table 1). This population has been studied extensively and has benefited from many habitat improvement projects over the last 20 years (Greenwood et al. 1999, Smith et al. 1999). In the 1990s, this area was treated with prescribed burns and clear-cut logging. Afterward, Greenwood et al. (1999) found bighorn group size significantly increased in treated areas, and these authors postulated that burned areas would be a key habitat component for bighorns to expand range use in this area. Smith et al. (1999) suggested that bighorns moved into treatment areas possibly because of improved visibility for predator detection. In 1995, UDWR biologists collared 36 bighorns, and mountain lion predation was responsible for 45% of recovered carcasses (C. Greenwood, UDWR, personal communication).

In the 1970s, domestic sheep allotments were purchased or closed in anticipation of restoring bighorns to this area. During 1993 and 1994, however, a slight die-off occurred and decreased the herd to about 50 animals (C. Greenwood, personal communication). Although unconfirmed, disease possibly played a role in the die-off. This population has since recovered, and biologists currently estimate 100 bighorns in the Bear Mountain herd. Additionally, bighorn sheep from Bear Mountain have been captured and translocated to other areas in the state to augment existing herds and to establish new populations. In 1993, 2 bighorns were translocated to the Pilot Mountains, and in 2000, 15 bighorns were released in Jack Creek (Table 1).

Beaver Creek (1983). – In 1983, the CDOW released 21 bighorns from Basalt Ranch, Colorado, into the Beaver Creek Drainage on the border of Utah and Colorado in northeastern Utah (Table 1). Four months later, 3 rams from Beaver Creek were observed with the Bear Mountain herd, 43 km to the west (Smith et al. 1988; Fig. 1). In the early 1990s, a collared ram was observed with a herd of domestic sheep 15 km away near Cold Springs Mountain, Colorado (C. Greenwood, personal communication). Shortly after, a major die-off occurred, reducing the estimated 80-90 bighorn sheep to 10 individuals (C. Heyd, National Park Service, personal communication). Later that year, CDOW and UDWR biologists located and killed all remaining bighorns in an attempt to clear the area of diseased animals, because additional reintroductions were scheduled to occur west of the Beaver Creek Drainage (C. Greenwood, personal communication). This reintroduction was considered a failure because of fatal interactions with domestic sheep.

Harper's Corner (1984). – This herd is located in Dinosaur National Monument on the border of Utah and Colorado and is managed by the National Parks Service (NPS). In 1952, the CDOW released 32 bighorn sheep near Ladore Canyon, Colorado, just outside Utah (Smith et al. 1988). In 1984, the CDOW released 19 additional bighorns at Harper's Corner, Utah, across the Green River from Ladore Canyon (Smith et al. 1988; Fig. 1). This herd was augmented twice by the CDOW from 1997 to 2000, adding 48 bighorns to this population (C. Heyd, personal communication; Table 1).

In 1999, biologists estimated 150 bighorns resided in the Harper's Corner herd; however, this population has since decreased to 93 animals (Table 2). Biologists attribute the decline of bighorn sheep in this area to disease (C. Heyd, personal communication). The possibility of disease transmission from domestic sheep is high, as grazing allotments for these animals border the Monument. In spring 2006, bighorn lamb production was 45 lambs/100 ewes. Yet, winter lamb-to-ewe ratios were 11 lambs/100 ewes later that year (C. Heyd, personal communication). Another limiting factor is mountain lion predation which occurs in this area, but its impact on the herd is unknown. Additionally, poaching was reportedly a problem in the 1980s and 1990s, although it likely had a minimal impact on the number of bighorns in this area (C. Heyd, personal communication).

Estimating how many bighorns reside in Utah is difficult, as bighorns often swim the Green River and spend time in both states. The NPS initiated a study in 2006 to determine the movements of bighorns within the Monument. Biologists observed 56 sheep during their study and equipped 20 animals with GPS collars, 7 of which were captured in Utah (C. Heyd, personal communication). Also, the NPS has improved and enhanced bighorn habitat throughout the area by conducting prescribed burns of pinyon-juniper forests.

Deep Creek Mountains (1984). – The Deep Creek Mountains are located in the Great Basin of Utah, and were inhabited by bighorns historically (Dalton and Spillett 1971). In 1984, 16 bighorns were released on the Deep Creek Mountain Range south of Wendover, Utah (Fig. 1). In 1989, this population was augmented with 14 additional bighorns (Table 1). Initially, habitat in this area appeared promising due to the presence of high elevation summer range, extensive winter range, low competition with deer herds, and abundant water sources (UDWR, 1990). However, this herd failed likely because of interactions with wintering domestic sheep near the Trough Springs-Lime Springs area and cougar predation (UDWR, 1990). Indeed, 3 of the 4 confirmed mortalities from 1987 to 1989 were from predation by cougars (UDWR, 1990).

A viable population of bighorns can possibly inhabit the Deep Creek Mountains; however, extensive juniper cover, potential interactions with domestic sheep, and mountain lion predation are problematic. If these potential limiting factors are resolved, the UDWR may transplant 50 California bighorn sheep from Antelope Island State Park, Utah, to the Deep Creek Mountain Range in 2010 (K. Hersey, personal communication).

Pilot Mountain (1987). – Similar to the Deep Creek Mountains, Pilot Mountain is located in the Great Basin and was inhabited by bighorns historically (Dalton and Spillett 1971). This herd is located north of Wendover on the border of Utah and Nevada (Fig. 1), and is managed by the

UDWR and the NDOW. Both states have released animals in the area. The Pilot Mountain herd originated in 1987, with 24 sheep translocated from Basalt Ranch, Colorado. From 1987 to 1998, a total of 58 animals were released on Pilot Mountain (Table 1). These animals have moved extensively and have been observed 13 km south on the Leppy Hills in Nevada and the Silver Island Mountains in Utah. In 1999, the UDWR estimated 100 bighorns occupied the Pilot Mountain Range (UDWR 1999; Table 2); although, this may have been an overestimation (K. Enright, UDWR, personal communication). In July 2006, we observed 25 bighorns on the Silver Island Mountains. The current population estimate for this herd is 40 animals (K. Huebner, NDOW, personal communication; Table 2).

Pilot Mountain receives a mean of 12 cm of precipitation annually. To alleviate water related stress, the NDOW plans to replace an old guzzler in Miners Canyon, which has recently been frequented by bighorns. The NDOW also plans to convert an upland game guzzler to a big game guzzler on Leppy Hills (K. Huebner, personal communication). The major concern for this herd is the close proximity of domestic sheep that seasonally occupy Leppy Hills. At present, there are no plans to augment this herd until the domestic sheep issues are resolved.

Sheep Creek (1989). – This herd originated in 1989 with the release of 21 sheep captured near Whiskey Basin, Wyoming. Between 2000 and 2001, 7 additional sheep were released in the area (Table 1). This herd is monitored by tracking several animals equipped with radio-collars, and this area is aerial surveyed yearly to obtain population estimates (C. Greenwood, personal communication). In the mid 1990s, this herd experienced a lamb die-off. Assuming that lungworm (*protostrongyluss spp.*) infestations were the source of lamb mortality, local biologists responded by medicating bighorns with fenbendazole. This treatment has purportedly increased recruitment (C. Geenwood, personal communication). The management goal is to have 75 bighorns in this area and as of 2007, 55 bighorns were present (Table 2).

Pinyon-juniper encroachment due to fire suppression has occurred in Sheep Creek, resulting in decreased visibility for bighorns which may potentially increase mountain lion predation. Concerned with predation on bighorns, the UDWR increased the number of harvest permits for mountain lions in the Sheep Creek area. At its highest point, 10 mountain lion permits were issued (C. Greenwood, personal communication). The UDWR and United States Forest Service (USFS) have plans to conduct prescribed burns in Sheep Creek and neighboring areas, specifically to increase visibility for bighorns and enhance bighorn habitat.

Hoop Lake (1989). – In 1989, 23 bighorns were released near Hoop Lake on the North Slope of the Uintah Mountains (Table 1). Due to low recruitment and ongoing contact with domestic sheep, the UDWR has been reluctant to augment the Hoop Lake herd. Bighorn sheep and domestic sheep shared a summer range near Burrow Peak, and the range use of these 2 species also overlapped on private land near Gregory Basin (R. Wood, UDWR, personal communication). Biologists were also concerned with high lungworm infestations in this herd and medicated bighorns each winter with fenbendazole.

Contrary to most areas that bighorn populations occupy in Utah, cougar predation has not been observed in the Hoop Lake herd. Few mule deer winter near Hoop Lake, resulting in less overlap of cougars and bighorns on winter range. Coyote predation, however, has purportedly been a limiting factor, particularly impacting lamb survival (R. Wood, personal communication). Indeed, in other areas, these canids have been efficient predators of young bighorns (Hebert and Harrison 1988, Hass 1989).

Bighorns from the Hoop Lake population have been observed interacting with the nearby Sheep Creek herd in northeastern Utah (Fig. 1). UDWR biologists plan to radio-collar several sheep in winter 2008 to better understand herd movements (R. Wood, personal communication). In 2000, the population estimate was 7 animals. Recently, this population has increased to 26 animals (Table 2).

Bighorn Mountain (1993). – Bighorn sheep on Bighorn Mountain have high growth rates and exceptional survival (B. Crompton, personal communication). From 1993 to 1995, 54 bighorns were released into this area (Table 1). In 2007, there were an estimated 505 sheep on Bighorn Mountain (Table 2). This area has abundant bighorn habitat. It is similar to nearby Desolation Canyon and Jack Creek in that it receives little snowfall in winter and has new-growth forage nearly year round (Fig. 1). Mountain lion predation has been documented, but reportedly has had little effect on the growth of this herd.

Wildlife managers are concerned about water availability and pinyon-juniper encroachment in this area. The UDWR placed several big-game guzzlers on Bighorn Mountain, with plans to install 5 more in 2008. UDWR biologists are also interested in habitat improvement projects that will reduce tree cover in this area (B. Crompton, personal communication). Disease has had little influence on this herd, partially because several domestic sheep allotments were purchased in the early 1990s, and the BLM closed several others during this time. Two years ago, however, a domestic goat was observed interacting with a band of bighorns (B. Crompton, personal communication). Overall, this herd is considered a success.

Jack Creek (2000). – This herd is located 64 km north of Bighorn Mountain along the Green River corridor. In 2000, 15 bighorns from Bear Mountain, Utah, were reintroduced into the area. The following year, 15 more bighorns were augmented to this herd from Montana (Table 1). This herd has experienced substantial growth over the past 8 years. In 2008, biologists estimated 72 bighorns in the area (Table 2). Bighorns from Jack Creek occur as a metapopulation with animals in Desolation Canyon and Bighorn Mountain (B. Bates, UDWR, personal communication; Fig. 1).

When sheep were initially placed in Jack Creek, many were radio-collared, and UDWR biologists documented several bighorn mortalities due to mountain lion predation (B. Crompton, personal communication). Although mountain lion predation has occurred, it has purportedly not inhibited population growth. In 2006, the Trail Canyon Fire improved habitat for bighorns, and possibly encouraged range expansion. The biggest concern for bighorns in Jack Creek is disease. Nine Mile Canyon is north of Jack Creek and has abundant bighorn habitat, but domestic sheep also occur in this area.

Carter Creek (2000). – From 2000 to 2003, 3 bighorn translocations occurred in Carter Creek totaling 24 animals (Table 1). Bighorns in Carter Creek intermixed frequently with animals from Sheep Creek, establishing a metapopulation. The Flaming Gorge Reservoir separates these 2 herds from the Bear Mountain and Goslin Mountain herds (Fig. 1). Regardless, sheep swim the reservoir and some mixing occurs (Smith 1992). Similar to other herds in northeastern Utah, bighorns in Carter Creek experience persistent mountain lion predation. Pinyon-juniper encroachment has also been a problem in this area. In nearby areas, prescribed burning and logging have proven successful in increasing bighorn habitat and promoting range expansion (Greenwood et al. 1999, Smith et al. 1999). Wildlife managers are planning to implement these habitat improvement projects in Carter Creek in the near future (C. Greenwood, personal communication). Dense tree cover also makes it difficult to get accurate population counts. Therefore, biologists collared several animals and conducted population counts from the ground with greater success. This herd has an estimated 45 animals and is growing (Table 2).

Mount Timpanogos (2000). – Eighty-two bighorn sheep have been released on Mount Timpanogos over the past 8 years (Table 1). The first release occurred in Grove Creek Canyon near Pleasant Grove, which was where one of the last sightings of a bighorn ewe occurred before Rocky Mountain bighorn sheep were extirpated from Utah (Dalton and Spillett 1971). Bighorns on Mount Timpanogos have been monitored continuously since release. In 2007 and 2008, we documented cause-specific mortalities for 10 bighorns: 2 died from disease, 3 were killed by mountain lions, 2 were hit by automobiles, 2 were stranded at high elevations during winter, and 1 cause of death was unknown. Moreover, lambs were seldom recruited into this herd. In spring 2007, we counted 28 lambs born, but only 4 survived to winter. This low survivorship was likely the result of disease. Recently, we estimated 51 bighorns on Mount Timpanogos (Table 2).

In 2007, 20 bighorns from Sula, Montana, and 18 bighorns from Alamosa, Colorado, were released on Mount Timpanogos (Table 1). These newly augmented sheep interacted infrequently with resident sheep (sheep released from 2000 to 2002). Furthermore, newly augmented bighorns resided at higher elevations and used areas outside the home range of resident bighorns. For instance, from 2000 to 2006, only 5 resident bighorns were observed at elevations > 3,000 m. In 2007, however, we observed 30 bighorns at elevations > 3,000 m. These newly augmented bighorns may have used habitats similar to bighorns in their source herd. For example, bighorns from Alamosa, Colorado used winter ranges at 3,000 m and summer ranges up to 4,200 m in their source herd. Overall, this use of dissimilar habitats by these animals is promising for the future of this herd because it may reduce competition among conspecifics for resources thereby increasing carrying capacity.

Rock Canyon (2001). – Twenty two bighorn sheep from Hinton, Alberta, were reintroduced into Rock Canyon in 2001. This herd was recently augmented in January 2007, with 5 ewes from Sula, Montana and 5 ewes from Augusta, Montana (Table 1). Similar to the Mount Timpanogos herd, bighorns released in Rock Canyon in 2007 seldom interacted with resident bighorns released in 2001. Additionally, these augmented bighorns have occupied areas outside the home range of resident bighorns. For instance, we never observed a resident bighorn give birth outside of Rock Canyon; however, 5 of the 10 augmented bighorns gave birth in areas other than Rock Canyon in spring 2007. Again, this range expansion may be beneficial for this herd.

This population has experienced stagnant growth over the past 7 years, mainly because lamb survival to first winter has been extremely low. In 2007-2008, we documented cause-specific mortalities for 19 bighorns: 14 died from disease, 2 were hit by automobiles, 1 was killed by a mountain lion, and 2 were unknown. Although there are no domestic sheep allotments near Rock Canyon, we often encounter stray domestic animals interacting with bighorns, or in bighorn habitat. In fall 2007, UDWR biologists removed 5 domestic sheep and 6 domestic goats near Rock Canyon. One of these domestic sheep was mingling with a group of 4 bighorns at the time it was removed. Recently, this herd experienced a partial die-off. In January 2008, we counted 41 animals. Since then, at least 12 bighorns have died from pneumonia. We estimated fewer than 29 bighorns now occupy Rock Canyon.

Rock Canyon has exceptional lambing habitat; however, summer and winter ranges are in close proximity to the urban interface, and bighorn were often seen in yards, on roads, and in parks especially during drought years. Only one perennial source of water exists in Rock Canyon, and bighorns have been observed drinking from fountains and swimming pools in residential neighborhoods. Bighorns in Rock Canyon and Mount Timpanogos are considered a metapopulation (Fig. 1), as ewes and rams often cross State highway 189 and interact with neighboring herds.

Goslin Mountain (2005). – The Goslin Mountain herd is the most recent reintroduced population of bighorns in Utah. Over the past 3 years, 76 bighorns from Montana have been released on Goslin Mountain (Table 1). Recruitment has been high for this young herd (C. Greenwood, personal communication). In winter 2007, UDWR biologists estimated 125 bighorn in this population (Table 2). Similar to other herds in northeastern Utah, mountain lion predation on bighorns occurs on Goslin Mountain, but its impact on population growth appears to be minimal. Pinyon-juniper encroachment was not a limiting factor in this area. In 2002, the Mustang Ridge Fire burned nearly 8,094 hectares (20,000 acres), subsequently expanding and improving available bighorn habitat. The USFS and UDWR combined efforts to reseed much of the area including steep slopes near rock outcroppings and cliffs. This herd has benefited from these habitat improvements and as a result, has possibly the highest potential to succeed of all the bighorn herds in northeastern Utah (C. Greenwood, personal communication).

Hunting Permits

In 1988, no hunting permits were available in Utah for Rocky Mountain bighorn sheep (Smith et al. 1988). In 1991, the first 3 rams were harvested near Rattlesnake Canyon, which is part of the Desolation Canyon herd. Since then, the UDWR has issued 153 Rocky Mountain bighorn ram tags in 5 hunting units, with a success rate of 98% (Fig. 2). The UTFWD sold 12 Rocky Mountain bighorn ram tags to the public, with a harvest rate of 100%. They also issued 35 tags to Ute Indian tribe members with a success rate of roughly 50%. Overall, 200 hunting permits have been issued in Utah since 1991.

Bighorn Sheep hunters spent an average of 8.8 days per hunt. The largest ram harvested in Utah was shot in 2006 on Ute tribal lands and scored 195 4/8 Boone and Crockett (R. Foutz, UFNAWS, personal communication). The most expensive tag purchased in Utah was sold for $85,000 on the Ute tribal lands (K. Courts, personal communication). Other tags in Utah have sold for as much as $82,500 (R. Foutz, personal communication). To date, over $1,155,000 has been raised from bighorn sheep conservation tags (K. Hersey, personal communication). Similar to other states, conservation tags generate a significant amount of money each year for bighorn research, habitat improvement projects, and translocations (Krausman 2000).

Discussion

Bighorn sheep inhabited nearly every mountain range in Utah prior to European settlement (Dalton and Spillett 1971), but by the 1930s they were virtually extirpated from the state. Since 1966, bighorns have been restored to many of their historical ranges in Utah thanks to the efforts of several state, provincial, tribal, and federal agencies, as well as many conservation groups (Fig. 2). Although the number of bighorns in Utah has grown from 239 animals to over 1,900 animals over the past 2 decades, most populations face an uncertain future. Of the 17 herds reintroduced in Utah, 4 failed, 5 are declining, 1 is experiencing stagnant growth, 3 are growing, and 4 are considered successful. Furthermore, the 4 successful herds contain over 76 % of the bighorns in Utah. Six of the 14 extant herds, however, have been established for less than 8 years, and more time is needed to assess their long-term levels of success (Table 2).

The UDWR has identified several areas they would like to reintroduce Rocky Mountain bighorns, including Lower Desolation Canyon and Nine Mile Canyon in eastern Utah, and Indian Canyon, Diamond Mountain, and Ashley Creek in northeastern Utah. Additionally, Avintaquin Canyon in the Wasatch Mountains is scheduled to receive bighorns in the winter of 2008-2009. To increase the probability of successful reintroductions, the UDWR is identifying potential limiting factors in these areas, with plans to address them prior to reintroducing bighorns.

Management Implications

The number of bighorns initially released into an area can influence the success of a reintroduction. In the western United States, from 1923 to 1997, bighorn reintroductions were deemed unsuccessful if the average (± *SD*) number of animals released was 30 ± 3.5; whereas, successful translocations averaged 41 ± 4.3 bighorns released (Singer et al. 2000a). In Utah, from 1966 to 2008, the mean number of bighorns initially reintroduced was 22 ± 7.4 (range = 9-48; Table 1). To enhance the success of future reintroductions in Utah, we recommend that wildlife managers increase the number of bighorns initially released to a minimum of 41 animals.

Diseases contracted from domestic sheep are by far the most serious limiting factors for bighorn populations in Utah. Recent recommendations for reintroducing bighorns indicate that a 23 km buffer is needed to reduce the probability of bighorns and domestic sheep from co-mingling (Singer et al. 2001). In Utah, the 4 reintroductions that failed were partially or entirely due to diseases transmitted by domestic sheep. Furthermore, all 6 bighorn herds experiencing declining or stagnant growth either had direct contact, or share seasonal ranges, with domestic sheep. Conversely, the 3 growing and 4 successful herds in Utah have had little to no contact with domestic sheep, in part because the UFNAWS spent nearly $1,000,000 purchasing or converting domestic sheep allotments to cattle allotments (D. Peay, personal communication). We recommend that wildlife biologists assess bighorn habitat and its proximity to domestic sheep prior to future reintroductions to ensure that these areas are separated by at least 23 km (Singer et al. 2000a).

Finally, bighorn sheep are one of the rarest ungulates in North America (Valdez and Krausman 1999), and small populations of these animals are more susceptible to extinction (Berger 1990). Rocky Mountain bighorn sheep are an integral part of the biodiversity in Utah and are an important game species. The UDWR Statewide Management Plan for Bighorn Sheep (2008) indicates that it is important to establish viable bighorn populations for consumptive and non-consumptive uses. Since the UDWR has plans for several additional reintroductions and translocations of Rocky Mountain bighorns in Utah, we recommend continual monitoring of these herds to identify, mitigate, and remove potential limiting factors, and to determine if populations have been established successfully. Successes and failures of reintroductions are often poorly documented (Short et al. 1992), and much can be learned to enhance the success of translocations (Krausman 2000). Hopefully, this review of the last 4 decades of bighorn management in Utah will help to identify areas of improvement and facilitate the establishment, perpetuation, and conservation of this unique mountain ungulate in Utah.

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Table 1. Area, year, number of animals released, and source herds for all reintroduced populations of Rocky Mountain bighorns in or bordering Utah.

Population	Year Released	# Released	Source Herd
Brigham City	1966	14	Whiskey Basin, WY, USA
Brigham City	1966	20	Waterton, AB, Canada
Brigham City	1969	12	Banf, AB, Canada
Brigham City	1970	14	Banf, AB, Canada
Desolation Canyon	1970	9	Ute Tribe, Whiskey Basin, WY, USA
Desolation Canyon	1973	12	Ute Tribe, AB, Canada
Desolation Canyon	1998	44	Ute Tribe, Kaleden, BC, Canada
Desolation Canyon	1998	20	Ute Tribe, Fowler, CO, USA
Mount Nebo	1981	27	Whiskey Basin, WY, USA
Mount Nebo	1982	21	Whiskey Basin, WY, USA
Mount Nebo	2004	18	Augusta, MT, USA
Mount Nebo	2007	25	Augusta, MT, USA
Bear Mountain	1983	19	Whiskey Basin, WY, USA
Bear Mountain	1984	17	Whiskey Basin, WY, USA
Bear Mountain	2000	7	Almont Triangle, CO, USA
Bear Mountain	2001	3	Basalt Ranch, CO, USA
Beaver Creek	1983	21	CDOW, Basalt Ranch, CO, USA
Harper's Corner	1952	32	CDOW, unknown
Harper's Corner	1984	19	CDOW, Rocky Mtn. Nat. Park, CO, USA
Harper's Corner	1997	21	CDOW, Dome Rock State W. A., CO, USA
Harper's Corner	2000	27	CDOW, Georgetown, CO, USA
Deep Creek Mountains	1984	16	Whiskey Basin, WY, USA
Deep Creek Mountains	1989	14	Whiskey Basin, WY, USA
Pilot Mountain	1987	24	Basalt Ranch, CO, USA
Pilot Mountain	1993	2	Bear Mountain, UT, USA
Pilot Mountain	1998	32	NDOW, unknown
Sheep Creek	1989	21	Whiskey Basin, WY, USA
Sheep Creek	2000	6	Almont Triangle, CO, USA
Sheep Creek	2001	1	Basalt Ranch, CO, USA
Hoop Lake	1989	23	Whiskey Basin, WY, USA
Bighorn Mountain	1993	26	Estes Park, CO, USA
Bighorn Mountain	1995	28	Georgetown, CO, USA
Jack Creek	2000	15	Bear Mountain, UT, USA
Jack Creek	2001	15	Sula, MT, USA
Carter Creek	2000	10	Almont Triangle, CO, USA
Carter Creek	2001	18	Basalt Ranch, CO, USA
Carter Creek	2003	6	Desolation Canyon, UT, USA
Mount Timpanogos	2000	25	Desolation Canyon, UT, USA
Mount Timpanogos	2001	10	Hinton, AB, Canada
Mount Timpanogos	2002	9	Sula, MT, USA
Mount Timpanogos	2007	20	Sula, MT, USA
Mount Timpanogos	2007	18	Alamosa, CO, USA
Rock Canyon	2001	22	Hinton, AB, Canada
Rock Canyon	2007	10	Sula, MT / Augusta, MT, USA
Goslin Mountain	2005	34	Thompson Falls, MT, USA
Goslin Mountain	2007	42	Sula MT / Rock Creek , MT, USA

Table 2. Area, year founded, number of translocations and animals released, past and present population estimates, and status of each bighorn herd in Utah. Four herds failed, 5 populations experienced a decline in bighorns, 1 population is stagnant, 3 populations have experienced growth, and in 4 herds the number of bighorns increased.

Population	**Year Founded**	**Trans-locations**	**Animals Released**	**1988 Estimate**	**1999 Estimate**	**2007 Estimate**	**Status**
Brigham City	1966	4	60	0	0	0	Failed
Desolation Canyon	1970	4	85	75 - 100	300	733	Success
Mount Nebo	1981	2	48	10 - 15	0	0	Failed
Mount Nebo	2004	2	43	10 - 15	0	35	Declining
Bear Mountain	1983	4	46	70	100	100	Success
Beaver Creek	1983	1	21	30	0	0	Failed
Harpers Corner	1952	4	99	30 - 35	150	93	Declining
Deep Creek Mtns.	1984	2	30	35	?	0	Failed
Pilot Mountain	1987	3	58	24	100	40	Declining
Sheep Creek	1989	3	28	0	50	55	Growing
Hoop Lake	1989	1	23	0	50	26	Stagnate
Bighorn Mountain	1993	2	54	0	140	505	Success
Jack Creek	2000	2	30	0	0	72	Growing
Carter Creek	2000	3	34	0	0	45	Growing
Mount Timpanogos	2000	5	82	0	0	51	Declining
Rock Canyon	2001	2	32	0	0	29	Declining
Goslin Mountain	2005	2	76	0	0	125	Success
Total		**46**	**849**	**239-309**	**890**	**1909**	

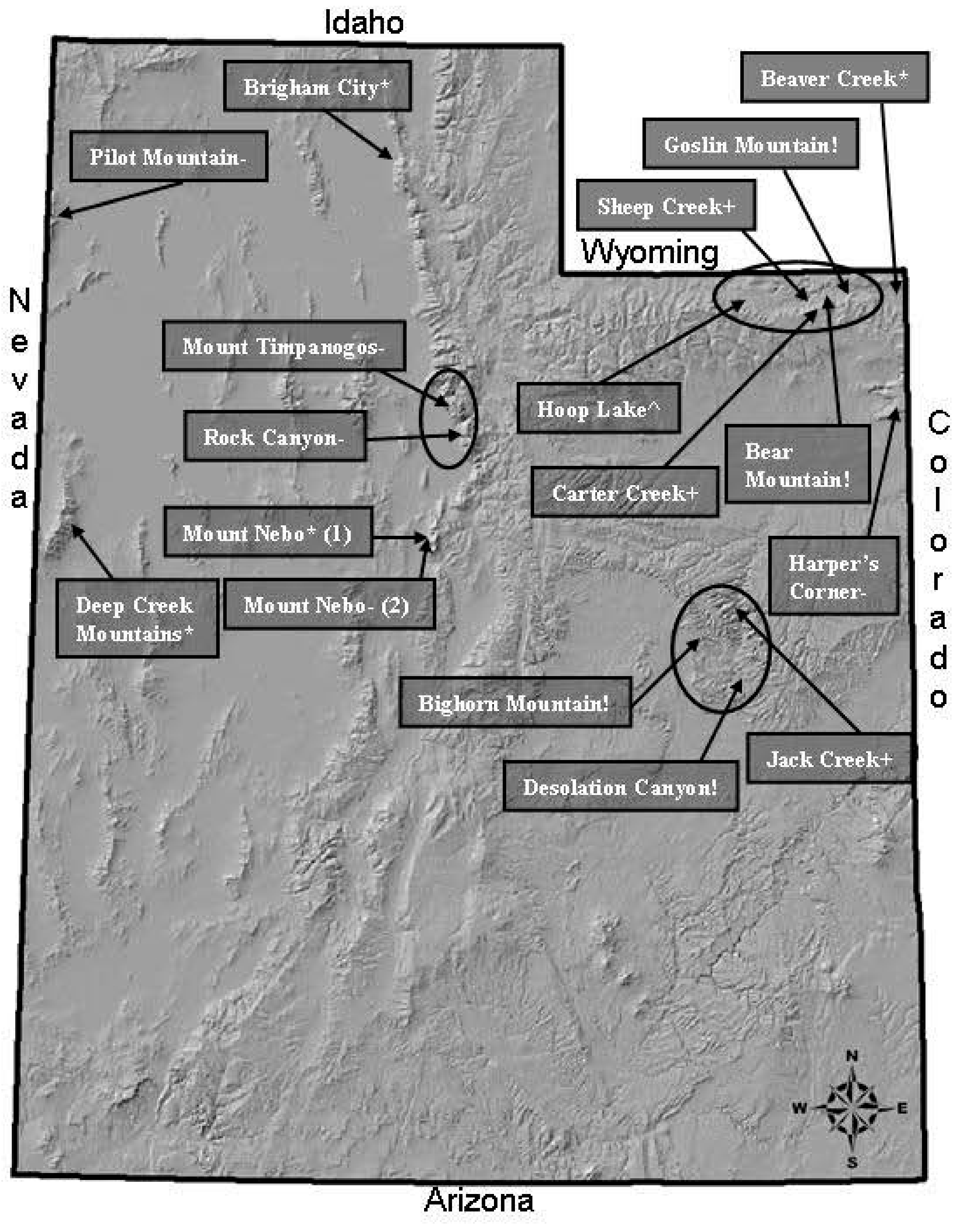

Figure 1. Distribution of 17 reintroduced populations of Rocky Mountain bighorn sheep in Utah. Symbols represent (*) failed herds, (-) declining herds, (^) stagnant herds, (+) growing herds, (!) successful herds. Ovals represent metapopulation structures.

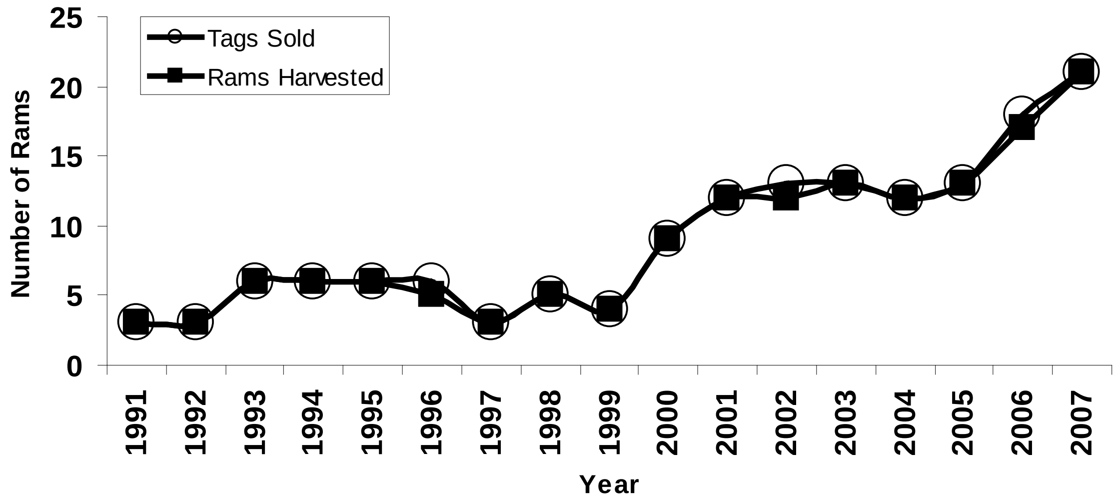

Figure 2. Number of harvest permits sold and filled for reintroduced Rocky Mountain bighorn sheep in Utah. From 1991-2007, the Utah Division of Wildlife sold 153 harvest permits, 150 of which have been filled.

Reintroducing Bighorn Sheep to Grand Staircase-Escalante National Monument

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Abstract: In 1999 the grand Staircase-Escalante National Monument (GSENM) in partnership with Utah Division of Wildlife Resources (UDWR), the Foundation for North American Wild Sheep (FNAWS), and Brigham Young University (BYU) began an aggressive effort to reintroduce desert bighorn sheep (*Ovis Canadensis nelson*) into GSENM. Sheep were captured and released into GSENM in 1999, 2000, and 2006. Transplant animals came from 3 locations in Nevada. To better understand the movements of these animals, 20 were fitted with radio transmitters. Graduate students from BYU under the guidance of Dr. Jerran Flinders studied the movements of these animals in 1999 and 2000. Through their efforts and later the efforts of GSENM and UDWR biologists, important distribution data were collected and act as the basis of the GSENM sheep program. Today GSENM biologists have a much better understanding of appropriate sheep habitat and continue to locate areas that may act as future release sites while at the same time maintaining key areas as acceptable sheep habitat.

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Evaluation of an Augmentation of Bighorn Sheep at Badlands National Park, South Dakota

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Abstract: Rocky Mountain bighorn sheep (*O. canadensis canadensis*) were reintroduced to Badlands National Park (BNP) in 1964, representing the eastern most extent of the species' current and historic range. In September 2004, 23 bighorn sheep were captured at Wheeler Peak, New Mexico and released at BNP to augment the existing population of approximately 68 individuals. Because it has been recommended that introduced populations are regularly monitored to evaluate the success or failure of transplants, the objectives of this study were to: 1) document survivorship, natality, dispersal, and recruitment of introduced bighorn sheep females and their offspring, 2) estimate 95% and 50% adaptive kernel planimetric and surface area home ranges of introduced bighorn sheep females, 3) determine habitat selection of introduced bighorn sheep females, 4) compare home range size and habitat selection of introduced to resident bighorn sheep females. Eighteen of 23 introduced bighorn sheep survived/remained with the sub-population. In 2005 and 2006, the 3 month-old lamb to adult ewe ratios were 90:100 and 62:100, respectively. In June 2006, 9 of 9 surviving yearling lambs dispersed from BNP with dispersal distances ranging from 43 to 524 km. In May 2007, 3 of 8 surviving yearling lambs dispersed from BNP with a dispersal distance of 25 km. The 95 % adaptive kernel and surface area estimates of the introduced bighorns increased between years, but core home range size did not differ between years. The 95% and 50% adaptive kernel planimetric and surface area home range estimates were greater in resident that introduced sheep. Introduced and resident bighorn sheep differed in their use of habitat with introduced sheep selecting areas closer to roads, human use areas, and water. We propose that differences observed between introduced and resident bighorns may be due in part to the acclimation of the introduced sheep to the presence of humans in their former range.

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The Effects of Disease, Stress, and Distribution on Bighorn Sheep Restoration in Nebraska

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Abstract: Twenty-two Rocky Mountain bighorn sheep (*Ovis canadensis*) were released in the southern Panhandle of Nebraska in 2001. Since the reintroduction, population size has fluctuated between approximately 30 to 60 animals, peaking at just above 60 in 2005. Due to the significant population fluctuations, research that investigates potential population limiting factors is crucial to long-term survivability of bighorn sheep in this area. The objectives of this study were to assess occupied and available habitat and investigate physiological stress response. Furthermore, all results were to be considered as they may have related to a respiratory disease epizootic that reduced the population by approximately 50% in early 2006. Observational data that was collected since the reintroduction was analyzed to identify primary occupied areas and illustrate changes in occupied habitat that may have been related to the respiratory epizootic. Fecal glucocorticoid metabolite assays were conducted to assess physiological stress response, and comparisons were drawn to evaluate differences in stress between occupied private properties and the Wildlife Management Area that served as the site of the reintroduction. On average, fecal glucocorticoid levels were significantly higher (t_{236} =2.92, P=0.004) in samples collected from sheep inhabiting private properties (33.60 ng/g) in comparison to sheep inhabiting the Wildlife Management Area (28.22 ng/g). These findings suggest that sheep occupying private properties may be exposed to a stressor that is not present within the Wildlife Management Area, such as livestock. When examined in the context of the affects of respiratory disease, these findings indicate that stress may have played a significant role in the outcome of the 2006 epizootic. Ultimately, this study suggests that careful management of occupied private properties may alleviate potential stressors that could contribute to disease.

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In March of 2001, the Nebraska Game and Parks Commission released 22 Rocky Mountain bighorn sheep into the Wildcat Hills of western Nebraska. The 22 sheep, consisting of twelve ewes, six lambs, and four rams, were captured and transported from the Pike's Peak area in Colorado and released in Cedar Canyon Wildlife Management Area (CCWMA). This release marked the first reintroduction of bighorn sheep in the southern panhandle of Nebraska. Prior to the reintroduction, the last documented sighting of bighorn sheep in Nebraska was in the early 1900s.

The first five years following the reintroduction were marked by successful growth of the population. By the end of 2005, the population had climbed to about 65 animals. Lamb production and survival rates were high and overall mortality rates were low. The population was on the rise, and a self-sustaining population was expected to be established in the Wildcat Hills within the next few years. However, the first few months of 2006 proved to be catastrophic for the population.

Initial concerns regarding the health of the population arose from observations of coughing sheep within CCWMA in the spring of 2005. At this time, the population was spilt into two sub-herds; one that remained primarily with the boundaries of CCWMA and one that spent the majority of the time on neighboring private properties. The coughing appeared to escalate and spread amongst the sub-herd inhabiting CCWMA. Despite known interactions between the two sub-herds, the sheep occupying the private properties did not develop the cough until considerably later. Captures of two sheep on CCWMA property revealed infection of *Mannheimia haemolytica* as well as *Pasteurella trehalosi*.

Eventually, the coughing seemed to subside in the group of bighorn sheep within CCWMA. However, by early 2006, the sub-herd occupying the private properties was observed coughing, and by early February, pneumonia began to result in numerous mortalities within this group. In the end, the respiratory complex reduced the bighorn sheep population in the Wildcat Hills by about 50%. It was noted that all carcasses were found on private land, and no known mortalities occurred within CCWMA. The sheep that stayed primarily within CCWMA appeared to fend off early symptoms of respiratory irritation, while the majority of sheep inhabiting the neighboring private lands died of pneumonia.

Although it is widely known that *Pasteurella* causes respiratory distress in bighorn sheep and generally results in eventual death by pneumonia, the process of bacterial colonization of the lung is not well understood. It has been hypothesized that *Pasteurella* increases in number in the nose until an excess of organisms in the nose results in entry into the lungs (Grey and Thomson 1971). A healthy animal should be successful in clearance of the bacteria from the lungs, but the process may be inhibited by incidents of stress, concurrent viral infections, or environmental or climatic change (Boyce et al. 2004). These predisposing factors may compromise immunity of bighorn sheep, allowing for a shift from benign to lethal *Pasteurella* spp. infection or facilitating the establishment of highly pathogenic forms that would otherwise be controlled by immune system function (Monello et al. 2001). Factors that may result in suppression of the immune system and predisposition to pneumonia may include parasites such as lungworms (*Protostrongylus* spp.) or mites (*Psoroptes ovis*), nutritional deficiencies, periods of low forage quality and quantitiy, high predation or harassment, harsh weather conditions, inbreeding, or density dependent stress resulting from overcrowding (Risenhoover et al. 1988, Bailey 1990, Belden et al. 1992, Jones and Worley 1994, Frank et al. 2006).

The respiratory disease complex in bighorn sheep is complicated by the fact that infected individuals do not always die and sometimes no harmful effects of the bacteria are observed. Because bighorn sheep infected with apparently pathogenic strains of *Pasteurella* sometimes show no clinical signs of respiratory disease, it is believed that certain ecological or environmental conditions play a role in the all-age die-offs (Festa-Bianchet 1988, Ryder et al. 1992). The stressors that may have played a role in the pneumonia epizootic in the Wildcat Hills are not well understood. Inclement weather, interactions with livestock, predators, human disturbances, movement patterns, and environmental factors are all variables that are worthy of investigation in light of potential stress as it relates to the respiratory disease complex. Of particular interest is the possibility that a stressor existing in the occupied private lands but absent within CCWMA may have played a role in the outcome of the all-age die-off.

Study Area

The primary research sites for this project included three properties: Cedar

Canyon Wildlife Management Area (CCWMA) located at N 41 45.930’ W 103 45.927’, the Hampton property located at N 41 42.374’ W 103 50.190’, and the Montz property located at N 41 46.716’ W 103 55.207’. These three properties are situated in the southern panhandle of Nebraska in an area known as the Wildcat Hills. CCWMA is an 890 hectare state-owned property open to the public for hunting and recreation. The Hampton and Montz properties are privately owned ranches that are periodically grazed by cattle and encompass 3,520 hectares and 1,942 hectares respectively.

All three properties are located approximately 11 – 19 kilometers southwest of Gering, Nebraska. Although these areas are primarily within the boundaries of Scotts Bluff County, the southernmost portion of the Hampton property extends into Banner County. CCWMA was chosen for the release site of the reintroduction in 2001 based on a bighorn sheep habitat suitability assessment of the Wildcat Hills (Forbes 1999). The Hampton and Montz properties were colonized naturally by bighorn sheep following the reintroduction. These three properties were selected as primary research sites for this project based on previously collected observational bighorn sheep occupancy data.

Methods

Observational data was collected by field technicians since the reintroduction took place in 2001. Data included location, habitat, behavior, and distance from escape terrain, people, water, and livestock. The location data was used to determine occupied habitat and assess changes over the past years, and the additional variables were considered in relation to stress response as measured by fecal glucocorticoid assays and disease as it has affected the population.

Fecal samples were collected opportunistically beginning in November of 2006 and ending in December of 2007. Samples were collected from sheep inhabiting CCWMA, the Hampton property, and the Montz property for a total of 285 samples. To prevent disturbing of the bighorn sheep during collection, defecation was observed from a distance that did not alarm the animals, and pellets were picked up only after the sheep had moved a reasonable distance from the area on their own. Because the hormones may not be distributed evenly throughout the samples, pellets were collected from various segments of the entire sample.

The pellets were homogenized in freezer bags by thorough mixing and mashing. The freezer bags were marked with the date, time, location, and individual, and then stored in the freezer within two hours following collection. Fecal pellets were collected from ewes, rams, and lambs, and efforts were made to collect from several of the same radio-collared ewes as often as possible in order to establish baseline glucocorticoid levels for several individuals. Field notes were recorded during sample collection documenting weather and observations of any existing potential stressors (i.e. livestock in the immediate vicinity, presence of predators, human disturbances, observable changes in social structure or distribution of individuals, etc.).

Immediately prior to extraction, the frozen fecal samples were thawed and homogenized by thorough mixing. Plastic containers were labeled for each sample, and approximately 1 gram of each sample was placed in the appropriate separate container. The containers were then placed in an oven at 37° C for 18 – 24 hours to complete the desiccation process. Following desiccation, a mortar and pestle was used to grind each sample to a fine dust. Detritus including sticks, hay, and other sizeable debris were removed from the sample and discarded.

From each of the finely ground samples, 0.2 grams of dried fecal material were placed in the bottom of appropriately labeled 15 ml extraction tubes. A solution of 90% ethanol (90:10 EtOH:distilled water) was added to the tubes in the amount of 2 ml. Tubes were placed on a shaker and shaken for 30 minutes and then centrifuged at 2000 x g, and 1 ml of ethanol was removed from each tube. The extracts were then capped and stored at -20° C until the assay procedure.

A commercially available kit was used for the assay procedure. Specifically, the I^{125} corticosterone radioimmunoassay (RIA) kit (ICN #07-120103, ICN Biomedicals, Costa Mesa, California) was used to quantify the fecal glucocorticoid metabolite concentrations. This procedure has been determined to be effective for quantifying fecal glucocorticoid metabolite extracts in a wide array of wildlife species (Wasser et al. 2000). All samples were diluted 1:4 in a phosphate-buffered saline (PBS) and assayed in duplicate following the ICN protocol for the I^{125} corticosterone RIA.

A standard assay validation was performed to ensure that the assay could accurately and precisely measure fecal glucocorticoid metabolites in bighorn sheep. Parallelism was demonstrated through preparations of serial dilutions of a pooled sample that produced a displacement curve parallel to the standard curve. The pooled sample was measured in each assay performed to assess between-assay reliability. Based on the duplicate sample agreement (n=374 assay determinations), the intra-assay coefficient of variability was 4.7%. The interassay coefficient of variation (n=6 assays) was 14.4 %. The range of standards was 12.5 – 500 picograms per tube.

Fecal glucocorticoid metabolite concentrations were analyzed by calculating the mean and range for several different groups of samples. An Analysis of Variance (ANOVA) was conducted to evaluate differences in glucocorticoid metabolite levels between the groups. These groups included ewes, rams, and lambs, as well as samples divided by location of collection. The glucocorticoid concentrations of the samples collected within CCWMA and surrounding areas were compared with those collected on the Hampton and Montz properties. Because there were no sheep inhabiting the Hampton or Montz properties during December through February, samples collected during these months were removed from the CCWMA group to form an adjusted group that was representative of samples collected over corresponding time periods. Additionally, differences across seasons were analyzed and samples collected from five adult ewes were compared. The individual ewe data included samples collected from three ewes primarily inhabiting CCWMA as well as two ewes primarily inhabiting the Montz property. The Hampton property was rarely occupied throughout the duration of this study.

Results and Discussion

Results of the glucocorticoid metabolite assays suggest that while sex and age class do not significantly affect stress as measured by corticosterone concentration, there are significant differences across seasons and the areas occupied by the sheep of this particular population. Additionally, an analysis of fecal glucocorticoid metabolite concentrations from samples collected from five adult ewes revealed no significant differences between individuals. Overall, the average concentration of corticosterone for the 285 samples collected was 27.58 ng/g of feces. Results ranged from a minimum of 7.13 ng/g to a maximum of 77.85 ng/g with a standard deviation of 13.41 (Table 1).

Table 1. Overall corticosterone concentration data.

	AVERAGE	MAX	MIN	MEDIAN	STDEV	TOTAL SAMPLES COLLECTED
OVERALL	27.58	77.85	7.13	25.23	13.41	285
RAMS	27.02	35.01	13.97	26.08	6.22	155
EWES	28.31	70.69	7.13	24.15	18.01	75
LAMBS	28.17	77.85	12.47	24.46	14.18	55

The observational data collected since the release in 2001 emphasized the failure of the bighorn sheep to re-colonize the Hampton property following the respiratory epizootic that decimated the sub-herd which had previously occupied that area. The additional variables that were recorded revealed that bighorn sheep in the Wildcat Hills typically occupy areas greater than 100 meters from water, livestock, and people, and they are generally found within 25 meters of escape terrain.

Perhaps the most interesting findings of the study were the glucocorticoid assay results which revealed that bighorn sheep occupying the Montz and Hampton properties experience significantly increased levels of corticosterone in comparison to sheep occupying CCWMA and areas in the immediate vicinity (Table 2). A two-sample *t* test assuming equal variances was performed and the Montz and Hampton group yielded significantly ($t_{236} = 2.93$, $P = 0.004$) higher corticosterone concentrations than the adjusted CCWMA and nearby areas group.

Table 2. Corticosterone concentrations by location.

	Average	Max	Min	STDEV	Median	Total Samples Collected
CCWMA and Nearby Areas	25.46	77.85	7.13	12.56	22.89	211
Montz and Hampton	33.60	76.74	15.58	13.99	29.4	74
Adjusted CCWMA	28.22	77.85	7.13	12.68	25.84	165

The difference could be attributed to numerous variables, and should be discussed with careful consideration of the respiratory disease epizootic of 2006. One of the variables that could have contributed to the increased corticosterone levels is livestock. The Montz and Hampton property are both periodically grazed by cattle, while CCWMA is generally not grazed, and was never grazed throughout the duration of the study. Although numerous variables may have contributed to the increased corticosterone levels, the grazing is the most obvious difference between CCWMA and the Montz and Hampton properties.

The existence of competition between cattle and bighorn sheep is debatable. Because bighorn sheep prefer steeper slopes in comparison to the gentle slopes typically used by cattle, ranges generally do not overlap spatially. It has been suggested that bighorn sheep prefer slopes > 30% in contrast to the ≤ 30% slopes favored by cattle during the winter (Lauer and Peek 1976). Although earlier studies did not reveal competition between cattle and bighorn sheep (Halloran and Blanchard 1950, Couey 1959, and Arellano 1961), it has been argued that bighorn sheep have not used certain gentle slopes due to the grazing of cattle on these areas (Barmore 1962).

The analysis of data collected since the reintroduction in 2001 revealed that bighorn sheep were documented at distances greater than 100 meters from livestock 99.51% of the time. From these results, it could be inferred that bighorn sheep generally avoid close contact with cattle. However, this data may not be adequate to accurately reflect the complex relationship between bighorn sheep and cattle in the Wildcat Hills. The data does not exemplify occurrences of cattle in areas generally used by bighorn sheep or the observed utilization of resources that have been determined to be important to the sheep. Detailed observations about cattle and sheep including recorded occurrences of cattle in primary areas of sheep habitat, even in instances when the sheep are not in the area, would improve knowledge about the dynamics between bighorn sheep and cattle in the Wildcat Hills.

Although very few direct interactions between cattle and bighorn sheep have been documented within the Montz or Hampton properties, it is plausible that the Hampton property is no longer used by sheep due to an avoidance of cattle. It has been suggested that although bighorn sheep may not compete directly with cattle for space or resources, they often exhibit a level of social intolerance for cattle (King and Workmann 1984), and numerous studies support the argument that bighorn sheep avoid areas grazed by cattle (Barmore 1962, Albrechtsen and Reese 1970, Ferrier and Bradley 1970, Dean 1975, and Gallizioli 1977). In certain instances, this avoidance could also be attributed to overgrazing and a resulting lack of adequate bighorn sheep forage in grazed areas.

Based on this available information about the relationship between cattle and bighorn sheep, it could be speculated that the increased corticosterone levels found in fecal samples collected on the Montz property were at least partially influenced by the presence of cattle in the area. It was suggested that an outbreak of respiratory disease in Aravaipa Canyon, Arizona, that reduced the desert bighorn population by 52% was a result of livestock related viral disease compounded by stress related to nutrition (Mouton et al. 1991). Although the culprit of the all-age die-off in the Wildcat Hills was a bacterial infection that was more likely to have originated from domestic sheep, the pneumonia epizootic may have been related to stress and nutrition associated with cattle in ways similar to such an instance.

However, there are numerous other variables to consider in the investigation of potential causes of elevated corticosterone levels in samples collected on the Montz property. One important consideration is the number of sheep occupying the Montz property in comparison to the number occupying CCWMA throughout the study. Throughout the duration of the study, only a small group of sheep inhabited the Montz property. For the majority of the time, this group included two adult ewes, a yearling ewe, two lambs, and several young rams that tended to come and go on a regular basis. This group was significantly smaller than the group or groups inhabiting CCWMA. Typically there were over a dozen adult ewes comprising a group at CCWMA in addition to the majority of yearlings and lambs of the population and rams that were frequently observed with the herd.

The small size of the group inhabiting the Montz property during much of the study period could be directly related to the increased corticosterone levels due to variables such as alertness and foraging efficiency. A relationship between increased foraging efficiency and increased group size at least up to five sheep has been demonstrated, and it has been determined that sheep in small groups were more likely to momentarily cease foraging activity to scan their surroundings in alertness than were sheep in larger group (Risenhoover and Bailey 1985). Similar studies revealed that sheep foraging efficiency increased with group size up to 20 animals, and solitary sheep were three times more alert than individuals in groups of 20 animals (Berger 1978 and Simmons 1982). Despite the individual increased alertness in small groups, the combined alertness of sheep foraging in groups of 20 animals afforded nearly seven times the number of alert postures per minute, and therefore it could be said that the ability to detect predators or other threats increases with group size. Considering this correlation between group size and increased foraging efficiency and predator detection ability, it could be inferred that sheep in smaller groups naturally experience higher levels of stress in comparison to individuals comprising large groups. This could contribute to an explanation for the higher levels of corticosterone in the samples collected from the Montz property compared with the CCWMA samples.

Ultimately, further research is necessary to determine the cause of the increased fecal glucocorticoid metabolite concentrations in samples collected from the Montz property. Cattle and small group size are two variables that could serve as focal points for future research projects aiming to assess stress in this bighorn sheep population.

In addition to comparisons of samples collected across different areas, fecal glucocorticoid metabolite results were grouped and compared by season (Table 3). An Analysis of Variance (ANOVA) revealed significant differences in corticosterone concentration across seasons ($F = 61.22$, F *crit* $= 2.64$). Measurements were highest in the summer with an average of 35.64 ng of corticosterone/g of feces and lowest in the winter with an average of 15.23 ng/g. Samples collected in the spring averaged 34.12 ng/g, while samples collected in the fall averaged 24.91 ng/g.

Table 3. Average corticosterone concentrations by season.

	Winter	**Spring**	**Summer**	**Fall**
Ewes	17.06	35.37	31.3	22.04
Rams	16.4	34.05	44.26	19.37
Lambs	14.01	30.18	38.4	24.03
Overall	15.23	34.12	35.64	24.91
Total Samples Collected	76	69	80	60

The results of this project largely support another study (Goldstein et al. 2005) which demonstrated that bighorn sheep glucocorticoid levels appear to reflect a cyclical pattern based on the seasons, with the highest levels measured in the summer and the lowest levels measured in the winter. One important consideration however, is that according to the results of this project, corticosterone levels of ewes are actually slightly higher in the spring than in the summer months. It can be inferred that this is due to the lambing season. Ram corticosterone levels, on the other hand, were higher in summer than spring. Overall, it does appear that there is a natural fluctuation of fecal glucocorticoid metabolites based on the seasons. It is plausible that these fluctuations are more a result of normal seasonal metabolic rhythms than a result of actual seasonal changes in the degree of physiological stress experienced by the animals. Therefore caution is urged in the interpretation of the seasonal comparisons of fecal glucocorticoid metabolite measurements used in this study.

This project did not reveal significant differences in corticosterone levels of rams compared to ewes, nor did it reveal significant differences in the comparison of adults and yearling with lambs. Therefore age class and sex of bighorn sheep may have little effect on the concentration of corticosterone found in fecal samples, suggesting that males and females, as well as adults and lambs, all face similar stressors and respond to them in similar physiological ways. The project also revealed no significant difference between average corticosterone levels of five adult ewes from which samples were collected throughout the duration of the study. Further research that involves very consistent sampling from individuals over extended periods of time would be necessary to draw solid conclusions about differences in individual corticosterone levels. For purposes of this study, the individual ewe results provide preliminary baseline data illustrating corticosterone measurements for several adult ewes in this bighorn population.

A final aspect of this project worthy of consideration is the necessary caution in interpretation of the glucocorticoid metabolite results. While fecal glucocorticoid metabolite assays provide a noninvasive alternative to traditional stress assessment methods that involve capture of wildlife for collection of blood samples, careful consideration of all of the existing variables is essential to drawing accurate conclusions from the results. Specifically, caution is urged in consideration of what the results might mean for the animal in terms of acute versus chronic stress.

The release of glucocorticoid hormones in response to a stressful event initiates numerous physiological reactions that are critical to survival in the presence of a stressor (Von der Ohe and Servheen 2002). In the case of acute stress, this release of hormones is healthy and advantageous to the animal. However, in the instance of prolonged stress and extended periods of high glucocorticoid levels in the bloodstream, these hormones can also have a deleterious effect on the health of the animal. In instances of elevated circulating glucocorticoids over prolonged periods of time, the immune system of the animal may be compromised, resulting in increased susceptibility to disease. Direct results of prolonged elevation of glucocorticoids may include inhibition of enzyme production, delayed processing of antigens, and quantitative reduction of immune system responses (Kiecolt-Glaser et al. 1984, Golub and Gershwin 1985).

Ultimately, the findings of this project raise questions about the differences in corticosterone levels experienced by the reintroduced sheep inhabiting private properties in Nebraska in comparison with sheep inhabiting Cedar Canyon Wildlife Management Area, as well as the reason behind the changes in primary areas occupied, specifically the failure to re-colonize the Hampton property, that followed the epizootic. Further research aimed at identifying differences between the Montz and Hampton properties and CCWMA would be of value. Understanding these differences could have implications for disease prevention and bighorn sheep management in the Wildcat Hills of western Nebraska.

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Correcting the Type Locality of Ovis canadensis canadensis Shaw

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Abstract: The type locality of the Rocky Mountain bighorn (*Ovis canadensis canadensis*) has been variously recorded as near Calgary; near Banff; and more recently as on the Bow River in the mountains near Exshaw AB. These locales are a result of a coordinate error made in 1802 by the collector, a fur trader named Duncan McGillivray. His coordinates placed the collection site in southeastern British Columbia even though he was on the Bow River in Alberta. His fur trader/surveyor companion at the time of the collection was David Thompson who made a detailed description of the collection site in his journals which were published several years later. The actual type locality carefully described by Thompson is on the shale banks of the Bow River seven miles downstream from Exshaw and five miles from the foot of the nearest mountain.

Key words*:* Bow river, David Thompson, Duncan McGillivray, *Ovis canadensis canadensis,* Seebe, type locality

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The type locality of *Ovis canadensis canadensis* is generally indicated as the mountains on the Bow River near Exshaw Alberta (Wilson and Reeder 1993). The Bow River location is correct; the mountains near Exshaw are incorrect. The error developed as a result of an inaccurate date and location provided by Duncan McGillivray in a memorandum written 2 years after he had collected the type bighorn ram (McGillivray 1802). In his memorandum McGillivray writes that on November 30, 1800 he shot the ram at "longitude 115.30 West, and latitude 50. North". These coordinates placed the type locality in southeastern British Columbia. While the latitude is clearly wrong, his longitude where it intercepts the Bow River is in Banff National Park approximately 45 km west of Exshaw is also incorrect. McGillivray's recollections were obviously approximations of when and where he killed his bighorn ram. The latitude error was noted by Allen (1912) and in a footnote he attempted to show where the Bow River emerged from the first range of mountains as 51 20' N which is where the Ghost River emerges from the mountains about 21 km north of Exshaw.

At the time of McGillivray's collection he was accompanied by David Thompson, a fur trader, surveyor and map maker for the North West Company of Montreal. Thompson's narrative of their travels along the Bow River was edited over 100 years later by J. B. Tyrrell (1916). Tyrrell states that Thompson and McGillivray followed the north bank of the Bow River, (without any reference to the collection of mountain sheep), "to the steep cliffs of the mountains where the town of Exshaw is now situated". Tyrrell's quote has a footnote by E. A. Preble from the Biological Survey, Washington D.C. that states, "Near this point, McGillivray killed and preserved a mountain sheep….the locality from which the type came". This incorrect conclusion of the type locality of *Ovis canadensis canadensis* has prevailed to this day. The mountains near Exshaw were actually the approximate location of the survey party on 30 November which was the date that McGillivray had incorrectly recalled when he had collected his ram.

In a more recent and more thorough edition of Thompson's narrative by Barbara Belyea (1998) the date of McGillivray's collection was on 29 November 1800. On that date Thompson clearly describes the steep shale banks along the Bow River where McGillivray killed his bighorn. He refers to a 3 mile stretch of the Bow River as having many strong rapids with several falls: "the most considerable of these falls were 3 which all lay in the same bend of the river" namely what is now known as Kananaskis Falls. This stretch of river included the Moberly Rapids and Horseshoe Falls west to Kananaskis Falls at Seebe Alberta which is approximately 5 km east of the front range of the Rocky Mountains, (both sets of falls were dammed and redirected for electric power in the early 1900s). On the same day that McGillivray killed the ram the survey party "put up at 4 PM, having amused ourselves the whole after noon with running after the Goats {sheep}" (Belyea 1998). The pursuit of the sheep would have taken place on horseback on the meadows above the shale river breaks below Horseshoe Falls (Dam). The meadows and shale banks comprised of the Blackstone formation below Horseshoe Dam still persist, however, bighorns no longer occur on this site. The coordinates for the portion of the Bow River that represents the river breaks and the type locality of where McGillivray collected *Ovis canadensis canadensis* are 51 07' 14" N, 115 01' 45"W. Ironically, this historic site which is the type locality of our provincial mammal, the Rocky Mountain Bighorn, is now threatened by the approval of the M.D. of Bighorn in September 2007 for a housing development for 5000 people.

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Western Association of Fish and Wildlife Agencies Wild Sheep Working Group(s)

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Abstract: In January 2007, the Directors of 23 fish and wildlife management agencies in the western U.S. and Canada, acting as the Western Association of Fish and Wildlife Agencies (WAFWA), unanimously voted to establish a Wild Sheep Working Group (WSWG). This WSWG was charged with completing a comprehensive, west-wide assessment of all facets of wild sheep management, with initial emphasis on addressing recommendations for the management of domestic sheep and goats in wild sheep habitat. To address both the immediate and the long-term facets of this WSWG, this WSWG effort was partitioned into two segments. The first step was establishment of WSWG #1, which produced and delivered a report to the WAFWA Directors by June 21, 2007; this report was presented to, and unanimously endorsed by, the WAFWA Director's Business Meeting in Flagstaff, AZ in July 2007. The WAFWA WSWG #2 was initiated in August 2007, and included representatives of all 19 jurisdictions (i.e., states, provinces, territories) in WAFWA that manage wild sheep. This presentation will inform NWSGC Symposium attendees as to progress and outputs of both WSWG #1 and #2.

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Wandering Wild Sheep Policy: A Theoretical Review

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Abstract: Removing wandering bighorn sheep (*Ovis canadensis*) to manage transmission and spread of disease is a common and widespread management policy in the western U.S. Wandering bighorn sheep are removed when found in close proximity to domestic sheep or goats to prevent disease transmission from domestic livestock to bighorn sheep herds. The policy is most appropriately applied as an interim emergency measure when management has failed to maintain effective separation between domestic sheep or goats and bighorn sheep. In practice, however, this policy has been applied in a broad range of circumstances where its effectiveness is questionable. The policy is often viewed as a stand-alone management tool for providing long-term separation rather than an interim emergency measure. In some cases it has been implemented without consideration of its appropriateness, effectiveness, or impacts on bighorn sheep management goals and long-term conservation. The purpose of this review is to evaluate the effectiveness and appropriateness of this policy relative to the distribution of bighorn sheep, their habitat, and public-land domestic sheep allotments across the landscape. Effectiveness was measured in terms of providing separation, preventing disease transmission, and maintaining or enhancing bighorn sheep population viability. Management recommendations for appropriate application are advanced. Federal and state resource management agencies are encouraged to clarify appropriate implementation of the policy to foster the restoration and long-term conservation of bighorn sheep across the western U.S.

Key words: bighorn–domestic sheep interaction, bighorn sheep, disease transmission, domestic sheep, management, risk of contact, separation, wandering bighorn sheep

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It is widely accepted among wildlife researchers and managers that bighorn sheep (*Ovis canadensis*) and domestic sheep are incompatible on sympatric range and must be spatially or temporally separated to prevent disease transmission and catastrophic population-wide bighorn sheep die-offs (Foreyt and Jessup 1982; Goodson 1982; Coggins 1988, 2002; Martin et al. 1996; Schommer and Woolever 2001, 2008; Singer et al. 2001; USDA Forest Service 2006a, b; Western Association of Fish and Wildlife Agencies 2007;George et al. 2008). Effective spatial or temporal separation between these species is now commonly recommended as the most prudent management approach (USDA Forest Service 2006a, b; Western Association of Fish and Wildlife Agencies 2007; Miller et al. 2008; Schommer and Woolever 2008).

Removing (placing in captivity or killing) bighorn sheep known or suspected to have contacted domestic sheep or goats is a common management practice among western U.S. states, and is commonly referred to as the "wandering wild sheep policy" (Policy). This Policy is endorsed by the Western Association of Fish and Wildlife Agencies, an association comprised of 23 state and provincial wildlife agencies from western U.S. and western Canada (Western Association of Fish and Wildlife Agencies 2007). Toweill and Geist (1999) identified 15 U.S. western states managing bighorn sheep. In 14 of those states, interaction between domestic and bighorn sheep is a management concern and all of these states have endorsed (either formally or informally) and/or practiced removing wild sheep interacting with domestic sheep or goats (Table 1).

The primary purpose of this Policy is to manage transmission and spread of disease within and between bighorn sheep herds. Individual bighorn sheep found in close proximity to domestic sheep or goats are removed because of the potential for disease transmission from these domestic livestock to bighorn sheep. By removing potentially infected bighorn sheep, the Policy aims to prevent the spread of disease to other bighorn sheep herds and avoid potentially catastrophic population-wide die-offs. The Policy is most commonly and appropriately applied to “wandering wild sheep” defined for this review as bighorn sheep exhibiting infrequent but often long-distance movements outside their normal population range and habitat, and coming in close proximity to domestic sheep or goats. Wandering wild sheep are commonly young dispersing rams. The Policy is most often implemented in a passive and reactive way with managers responding as reports of wandering wild sheep are received. However, the probability of detecting and reporting bighorn and domestic sheep or goat interactions is inherently low because many bighorn sheep populations are not actively monitored; terrain can be rugged and inaccessible; bighorn sheep can move extensively over a short time period, passing through domestic sheep areas quickly; and domestic sheep bands can be scattered, with interactions occurring far from herders’ control.

The Policy is typically envisioned as a tool to address situations where the risk of contact between bighorn sheep and domestic sheep or goats is low (i.e., expected infrequent interaction events) and occurs outside of normal bighorn sheep range. In these typical applications, the Policy is thought of as a stand-alone management tool providing effective long-term separation and prevention of disease transmission. In practice, however, the Policy has been implemented in a broad range of circumstances beyond its original intent without consideration of its appropriateness, effectiveness, or impacts on bighorn sheep management goals and long-term conservation. Although the application of this Policy has merit in certain circumstances when applied to wandering bighorn sheep outside their normal range, in some cases, the Policy has been relied upon for maintaining long-term separation, or used as rationale for precluding the need for separation within occupied bighorn sheep range.

The institutionalized acceptance of and unquestioned reliance on this Policy may, in some cases, (1) encourage inappropriate and ineffective application, (2) provide rationale for complacent status quo management when more effective separation measures are needed, (3) perpetuate continued risk of contact and disease transmission, and (4) hinder long-term conservation of bighorn sheep. A critical review of this Policy is needed to better understand the appropriate applications of this management tool in the context of long-term bighorn sheep conservation throughout the western U. S.

Landscape Considerations

Appropriate application of the Policy depends on the relative juxtaposition and characteristics of 3 primary landscape-level parameters: (1) bighorn sheep distribution and connectivity (isolated vs. interconnected populations), (2) bighorn sheep habitat distribution and connectivity (fragmented vs. continuous), and (3) distribution of active domestic sheep allotments (allotment). Variation in relative juxtaposition and characteristics of these 3 landscape parameters results in a continuum of landscape configurations across the west, requiring critical case-by-case analysis to determine the appropriate application and effectiveness of the Policy. The extremes of the continuum can be classified as the Discrete Parameter Model (DPM) on one end and the Continuous Parameter Model (CPM) on the other. As discussed below, application of the Policy is most appropriate under the DPM but becomes problematic as landscape configurations tend towards the CPM.

Discrete Parameter Model

The DPM describes landscapes where bighorn sheep populations and habitats are isolated and fragmented, and neither overlap allotments. The origin of the Policy is rooted in such a stereotypic model of bighorn sheep distribution across western landscapes. Bighorn sheep populations are typically envisioned as small isolated herds scattered across fragmented habitat patches associated with isolated mountain ranges throughout the west (Van Dyke et al. 1983; Risenhoover et al. 1988; Bleich et al. 1990; Singer et al. 2000a, b). This stereotypic landscape view reflects a common pattern across the west of dramatic historic bighorn sheep population reductions followed by subsequent restoration of small isolated populations. Under the DPM, allotments are disjunct from occupied bighorn sheep range and habitats, often located in lower elevations within valley bottoms or along foothills between mountain ranges occupied by bighorn sheep (Figure 1).

Isolated bighorn sheep populations may have historically functioned as metapopulations connected by intermountain dispersal of ewes and rams (Schwartz et al. 1986, Bleich et al. 1996; Singer et al. 2000b). Today however, isolated bighorn sheep populations are typically managed independently according to population-specific management goals, with each population having its own unique history and management concerns.

Continuous Parameter Model

The CPM describes landscapes on the other end of the continuum where bighorn sheep populations and habitats are interconnected and continuous, and allotments overlap occupied bighorn sheep range and their habitats. This situation is commonly found where bighorn sheep occupy low-elevation grasslands along river canyons where suitable habitat is continuous and bighorn sheep populations are interconnected throughout linear river corridors. Under the CPM, bighorn sheep populations tend to function in large metapopulations (Hells Canyon Bighorn Sheep Restoration Committee 1997, USDA Forest Service 2006a, Hells Canyon Bighorn Sheep Restoration Committee 2004; Figure 2).

Management Application

Critical underlying management assumptions of the Policy are (1) the Policy is applied to wandering sheep moving outside of their normal population boundaries and habitats (movements most often associated with young dispersing rams), (2) wandering sheep movements are infrequent and aberrant, (3) the Policy is applied outside of occupied bighorn sheep range, (4) removal of wandering sheep does not substantially impact population viability or hinder attainment of management goals, and (5) removal of wandering sheep will provide long-term effective separation and prevention of disease transmission. Application of the Policy must be questioned when 1 or more of these management assumptions are not met. The degree to which application of the Policy will meet these management assumptions depends on the particular landscape configuration relative to the 3 primary landscape parameters identified above.

Discrete Parameter Model

Application of the Policy is most appropriate as a stand-alone management tool on western landscapes approaching the DPM, particularly when isolated bighorn sheep populations are meeting identified management goals and are not reliant on inter-population movements (natural dispersal) for maintaining viability and/or genetic diversity. Critical management assumptions of the Policy have the highest probability of being met under the DPM. Because allotments are disjunct from occupied bighorn sheep range and suitable habitats, interaction events are more likely to involve wandering bighorn sheep. As young dispersing animals do not contribute significantly to the reproductive success of the source population, removal of these wandering sheep would have fewer impacts on population viability or attainment of management goals.

Under the DPM, less frequent interaction events would be expected and, depending on the distance between allotments and suitable habitat, application of the Policy as a stand-alone management tool may provide long-term separation and prevention of disease transmission. In addition, consequences of undetected interaction events are lower under the DPM. As bighorn sheep are managed as isolated populations within fragmented habitats, a disease outbreak can usually be contained to a single isolated population.

Continuous Parameter Model

Application of the Policy is less appropriate as landscape configurations approach the CPM. Under this model, critical management assumptions will likely be violated. With allotments located within occupied bighorn sheep range, interaction events are more likely to involve adult resident, rather than wandering, wild sheep. Removing this reproductively important population segment could have negative impacts on population viability and attainment of management goals. Furthermore, impacts to population viability may be exacerbated for at-risk populations that are at low population levels, experiencing declining population trends, impacted by disease, and/or in need of enhancement.

A substantially increased frequency of interaction events would be expected under the CPM. With resident bighorn and domestic sheep concurrently occupying the same range, the risk of contact and disease transmission would be elevated (due to increased proximity) and prolonged (due to increased duration of co-mingling opportunities throughout the grazing season). A greater number of expected interaction events coupled with the inherent low probability of detection would result in a continual high risk of disease transmission. Under the CPM, application of this policy would not provide short- or long-term separation or prevention of disease transmission. In addition, consequences of undetected interactions are far greater under the CPM. As bighorn sheep populations are interconnected across continuous habitats, a single disease transmission event in one population has a high probability of being transmitted to adjacent connected populations, precipitating a chain reaction, affecting metapopulation viability across a wide geographic area.

Intermediate Landscape Configurations

As landscape configurations diverge from the DPM, the effectiveness of this Policy will wane. In general, the risk of contact and disease transmission (frequency of interactions) will increase and the effectiveness of the Policy will decrease as (1) distance between areas grazed by domestic sheep or goats and bighorn sheep decreases and (2) bighorn sheep habitat connectivity increases between occupied bighorn sheep range and allotments. Also, consequences of undetected interaction events (impacts to bighorn sheep viability) increase as wild sheep populations become more connected and their habitats more continuous.

For example, application of the Policy may be problematic when domestic sheep grazing occurs outside of occupied bighorn sheep range, but within adjacent and continuous suitable wild sheep habitat. Under this situation, if bighorn sheep management goals include expanding bighorn sheep populations into unoccupied suitable habitats, implementation of the Policy, by removing pioneering bighorn sheep as they attempt to colonize new habitat, may preclude attainment of management goals. At the same time, if interactions between these pioneering individuals and domestic sheep go undetected, the source population's continued viability could be threatened.

Management Recommendations

The need to remove wild sheep that have come into contact with or are in close proximity to domestic sheep or goats is well understood. However, this review indicated the effectiveness (providing separation and preventing disease transmission) of the Policy is limited to landscape configurations approaching the DPM. Under most other landscape configurations, application of the Policy would fail to meet critical management assumptions, be ineffective in providing separation or preventing disease transmission, and have a high likelihood of negatively impacting bighorn sheep viability.

Managers should rely on the Policy as a stand-alone management tool to provide separation and prevent disease transmission only when applied to wandering wild sheep and only when applied outside of occupied bighorn sheep range (domestic sheep and goat grazing is spatially separated from occupied bighorn sheep range across non-bighorn sheep habitats). For all other cases, the need to remove bighorn sheep because of interactions with domestic sheep or goats should be viewed as a management failure triggering implementation of more effective separation strategies to prevent contact and preclude the need for further removal of wild sheep.

The post hoc nature and retroactive implementation of the Policy (bighorn sheep are removed after separation has failed and disease transmission has potentially occurred) and resulting potential impacts to bighorn sheep viability through direct removal of resident wild sheep or disease outbreaks, precludes this strategy as an effective management tool where domestic sheep or goats are grazed within or adjacent to occupied bighorn sheep range. This review indicated the Policy should not be used, even in conjunction with other management practices, as a rationale for precluding the need for spatial separation. Management strategies should focus on preventing the need for implementation of the Policy by providing effective temporal or spatial separation between bighorn sheep and domestic sheep and goats.

Under all landscape configurations, the Policy should not be relied on as a stand-alone management approach if reoccurring or frequent bighorn sheep-domestic sheep or goat interactions persist. Continued need to remove wild sheep within a management area should trigger management review for developing and implementing more effective separation measures.

Prior to Policy implementation, managers should consider conducting case-specific assessments for the appropriate application of the Policy based on the 5 critical management assumptions and 3 landscape parameters identified above. To promote bighorn sheep conservation, state and federal agencies should re-evaluate the proper context for application of this common management tool based on these guidelines. Effective spatial and/or temporal separation of bighorn and domestic sheep should be the primary management goal to foster abundant self-sustaining bighorn sheep populations across the western U.S.

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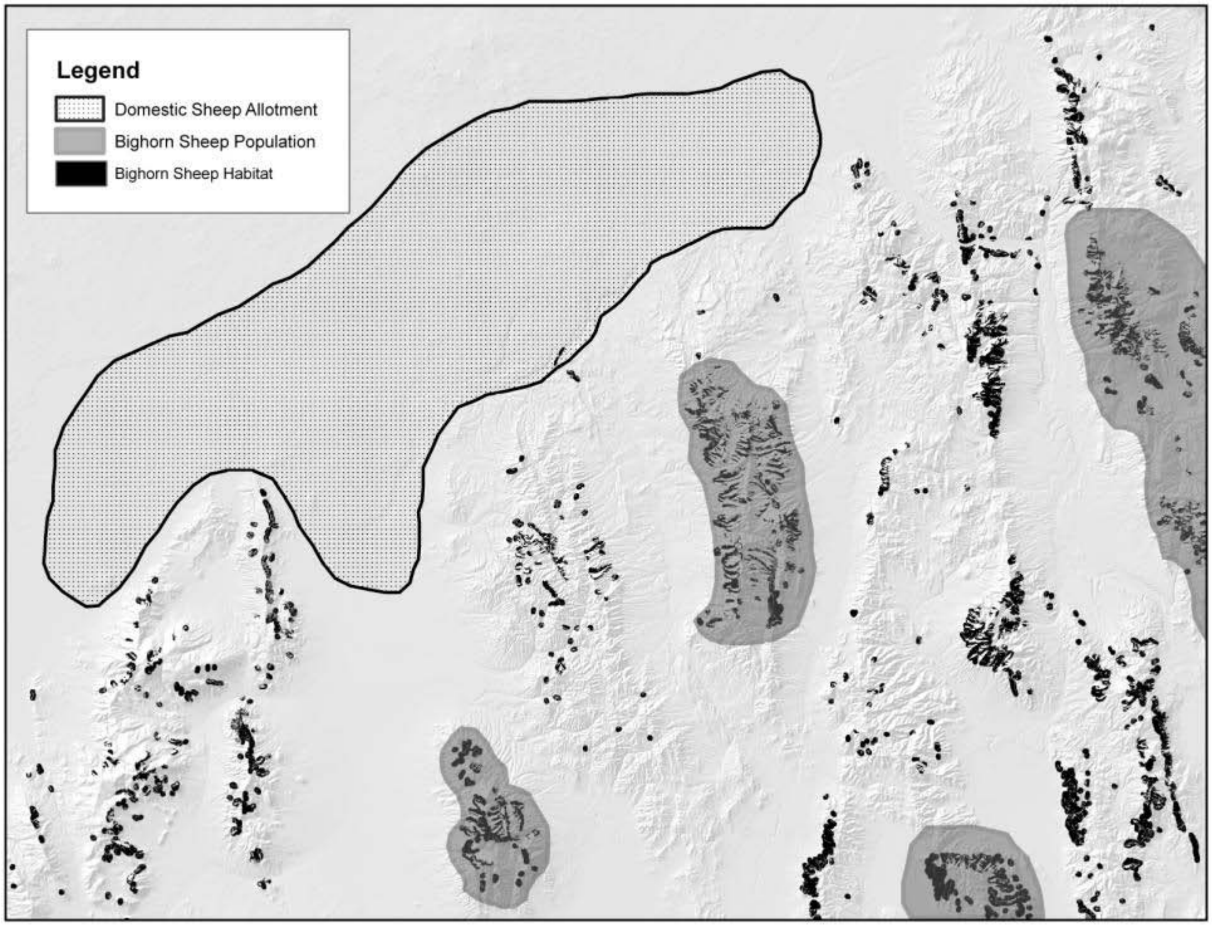

Figure 1. Conceptual Discrete Parameter Model showing isolated bighorn sheep populations, fragmented bighorn sheep habitats, and disjunct domestic sheep allotments.

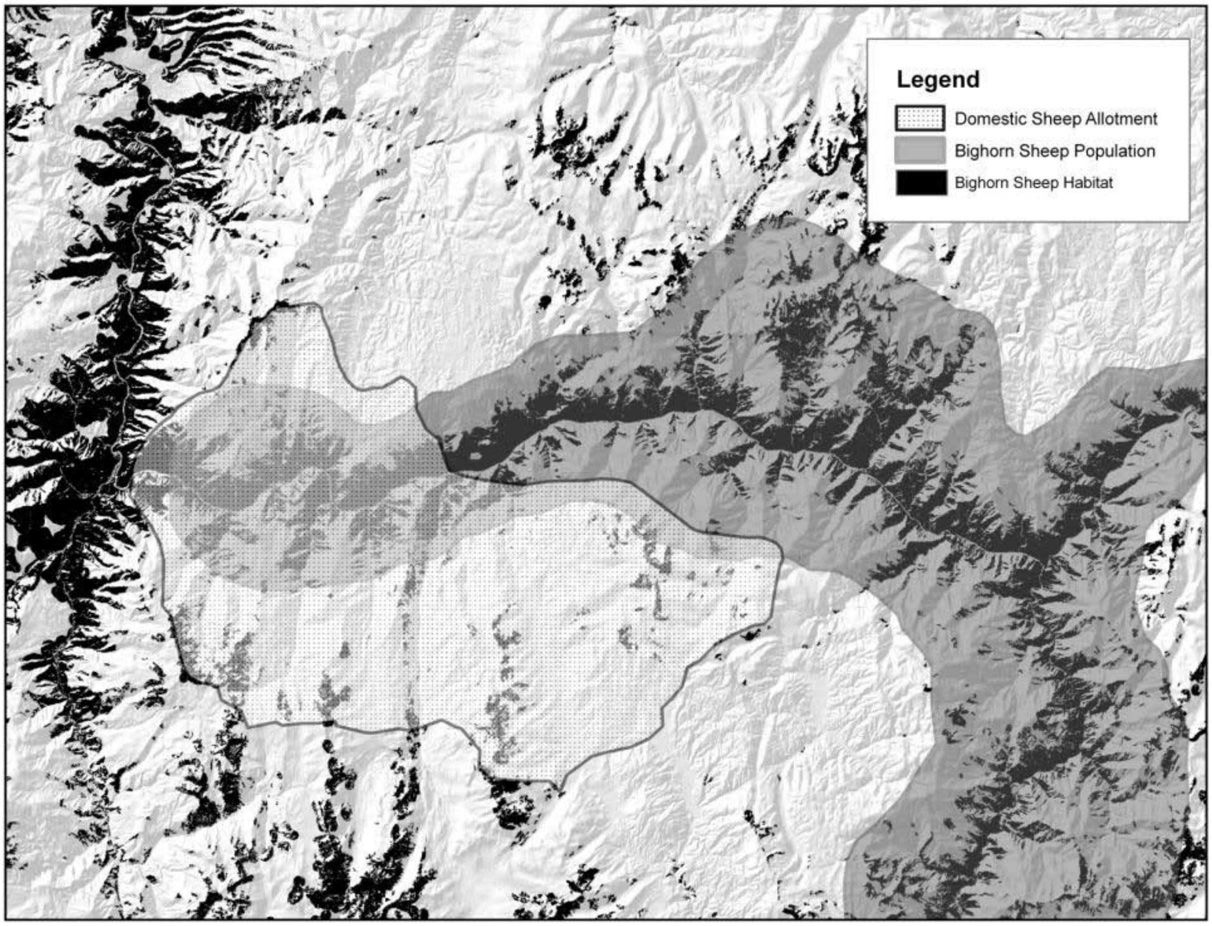

Figure 2. Conceptual Continuous Parameter Model showing interconnected bighorn sheep populations, continuous bighorn sheep habitat, and overlapping domestic sheep allotments.

Table 1. Informal survey of 15 western U.S. states regarding bighorn sheep management, bighorn-domestic sheep interaction concerns, and application of a wandering wild sheep policy.

State	Managing bighorn sheep[1]	Bighorn-domestic sheep concerns[2]	Endorse wandering wild sheep policy[2]	Source
Arizona	RM[3], DS[4]	YES	YES[6]	Bob Henry, Arizona Game and Fish Department
California	CA[5], DS	YES	YES	Tom Stephenson, California Department of Fish and Game
Colorado	RM, DS	YES	YES	Janet George, Colorado Division of Wildlife
Idaho	RM, CA	YES	YES	Dale Toweill, Idaho Department of Fish and Game
Montana	RM	YES	YES	Tom Carlson, Montana Fish Wildlife and Parks
Nebraska	RM	YES	YES	Kit Hams, Nebraska Game and Parks
Nevada	RM, CA, DS	YES	YES	Mike Cox, Nevada Department of Wildlife
New Mexico	RM, DS	YES	YES	New Mexico Department of Game and Fish 2004
North Dakota	CA	YES	YES	Brett Wiedmann, North Dakota Game and Fish
Oregon	RM, CA	YES	YES	Victor Coggins, Oregon Department of Fish and Wildlife
South Dakota	RM	YES	YES	John Kanta, South Dakota Game, Fish and Parks
Texas	DS	NO	N/A	Calvin Richardson, Texas Parks and Wildlife
Utah	RM, CA, DS	YES	YES	Anis Aoude, Utah Department of Natural Resources, Division of Wildlife Resources
Washington	RM, CA	YES	YES	Paul Wik, Washington Department of Fish and Wildlife
Wyoming	RM	YES	YES	Kevin Hurley, Wyoming Game and Fish Department

[1] From Toweill and Geist 1999
[2] Data sources identified in the "Source" column
[3] Rocky Mountain bighorn sheep
[4] Desert bighorn sheep
[5] California bighorn sheep
[6] Includes informal, draft and pending, and formal policy

Modelling and Management of Bighorn Sheep Movement Corridors

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Abstract: Open forest and grassland habitats in the mountains of south-eastern British Columbia are being lost to forest encroachment and urban development. These habitats provide critical winter and transitional ranges for bighorn sheep (*Ovis canadensis*) and play a crucial role in maintaining migratory behaviour. We used GPS telemetry data collected from a sample of bighorn sheep at Kootenay National Park and Radium Hot Springs, British Columbia to test a previously developed theoretical model of potential linkages between seasonal habitats for bighorn sheep. The theoretical linkage model was a poor predictor of bighorn sheep movement routes because migration events were rapid movements through poor quality habitat. We used the map of observed migration routes to prioritize mid-elevation transitional habitats for re-introduction of fire, and to identify a low elevation corridor connecting patches of historic winter range as a priority area for forest thinning, prescribed fire, and other treatments. We plan to continue to use GPS telemetry to monitor bighorn sheep response to management actions.

Key Words: bighorn sheep, British Columbia, GPS, Kootenay National Park, *Ovis canadensis*, prescribed fire, radiotelemetry, restoration, seasonal migration, wildlife corridor.

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In south-eastern British Columbia, forest encroachment into grasslands and other open habitats is a serious issue for biodiversity conservation and, more specifically, for the integrity of bighorn sheep (*Ovis canadensis*) habitat and movement corridors (Davidson 1991; Demarchi et al. 2000; Gray 2001; Gayton 2004). Conifer in-growth due to fire suppression on sheep winter ranges has reduced forage availability (Davidson 1991) and increased the risk of spread of disease by concentrating sheep in small areas (Schwantje 1988). Mid-elevation "transitional" habitats also usually include open forest habitats (British Columbia Forest Service 1997) and may be susceptible to degradation through conifer encroachment.

In the Radium Hot Springs area, sheep movements through valley bottoms (characterized by extensive human development) expose sheep to several risks, including the need to cross high-volume highways and exposure to lethal disease through contact with domestic animals. In spite of these threats, sheep must undertake regular movements across the landscape to optimize seasonal nutritional and habitat requirements (Hebert 1973; Festa-Bianchet 1988; Risenhoover et al. 1988). Examples of critical habitat elements include lambing ranges and mineral licks, both of which may be long distances away from core seasonal habitats. Sheep also need to undertake occasional long-distance movements to promote the interchange of animals and genes between populations (Geist 1971; Epps et al. 2005). Given the highly mobile manner in which sheep use the landscape, the identification and restoration of movement corridors of bighorn sheep is an important conservation measure for this species (Risenhoover et al. 1988; Demarchi et al. 2000; Tremblay 2001; Dibb 2004; Tremblay and Dibb 2004).

Our first formal attempt at understanding bighorn sheep movements in the Radium Hot Springs area consisted of a theoretical geographic information system (GIS)-based modelling exercise aimed at identifying potential movement corridors for sheep (hereafter referred to as the "linkage model"). This modelling work and accompanying management recommendations served as a basis for a multi-year ecosystem management project initiated by Parks Canada for the south end of KNP and that included ecosystem restoration measures (Dibb and Quinn 2006).

In 2002 we began a global positioning system (GPS) telemetry study on the Radium Hot Springs bighorn sheep with the aim of adding an empirical basis to our growing understanding of sheep movements in the area (Dibb 2006). More specifically, we wanted to identify seasonal ranges and critical habitats as well as movement corridors linking them. We also sought to use empirical data to test the theoretical linkage model and its underlying assumptions.

In this paper, we report on selected components of this telemetry study, which included the following objectives for the Radium Hot Springs bighorn sheep herd: (1) determine seasonal home ranges and use of unique habitats (e.g., lambing areas, mineral licks), (2) locate seasonal movement corridors, (3) test the linkage model, (4) compare corridor maps generated by the linkage model and the telemetry data, and (5) identify priorities for future habitat restoration work.

Study Area

The study area encompassed 543 km^2 in the Stanford and Brisco Ranges of the Rocky Mountains near Radium Hot Springs in south-eastern British Columbia, and was centred on 50^o 38' N, 116^o 0' W. This area extended from the community of Windermere in the south to the community of Spillimacheen in the north, and was bounded to the west by the Columbia River and to the east by the Kootenay River valley (Figure 1). We defined the study area as the minimum convex polygon (MCP) enclosing all telemetry points collected from all study animals from 2002 through 2004. Elevations ranged from just below 800 m at the Columbia River to nearly 2,800 m at the highest summits. Approximately one-third of the study area was within Kootenay National Park, with most of the rest occurring on British Columbia provincial crown lands. Important areas of winter range also occurred on private, municipal, and First Nations lands in the Columbia Valley.

Climate was characterized by a transition from low precipitation and relatively warm conditions in valley bottoms to higher precipitation and cool temperatures at higher elevations (Achuff et al. 1984). Low elevation forests were dominated by Douglas fir (*Pseudotsuga menziesii*), white spruce (*Picea glauca*), and aspen (*Populus tremuloides*) and were interspersed with patches of grassland (Achuff et al. 1984). Upper elevation forests were dominated by white spruce, Engelmann spruce (*Picea engelmannii*) and hybrids of these two species, and by subalpine fir (*Abies lasiocarpa*). Seral forests of lodgepole pine

(*Pinus contorta*) were present after fire, except near tree-line. Tree-line occurred at approximately 2,300 m.

Approximately 10,000 permanent human residents occupied the Columbia Valley along the western edge of the study area, including 805 permanent residents of the village of Radium Hot Springs (British Columbia Stats 2008). However, the Columbia Valley also had a "shadow" population of second home owners and seasonal residents, estimated at 20,000 to 30,000 persons (District of Invermere 2008), and a growing tourism industry. Provincial Highways 93 and 95 crossed the study area east-west and north-south respectively. While human settlement was centred on the Columbia Valley, recreational activities occurred throughout the study area.

Methods

Development of the Linkage Model

We used the ARC/INFO GIS software (ESRI 1999) to develop a raster-based (25 x 25 m cell size), spatially explicit model aimed at delineating probable movement corridors for bighorn sheep within the study area. This theoretical model was based on information from a variety of sources including the literature, key informant interviews, personal observations in the field, and existing digital biophysical data sets. The model contained three submodels or routines (habitat, human disturbance, and movement), each containing variables believed to influence sheep movements (Figure 2). Detailed descriptions of the model can be found in Tremblay (2001) and Tremblay and Dibb (2004).

The habitat routine was designed to account for the quality of the habitat, without consideration of human disturbance. Habitat suitability ratings from existing biophysical data sets (Poll et al. 1984; Delta Environmental Management Group 1992; Marcoux et al. 1997) were standardized and reclassified into "habitat coefficients" ranging from 0 to 1, representing minimal and optimal habitat, respectively. Separate habitat layers were created for the growing and winter seasons.

The purpose of the disturbance routine was to account for the alienation effect that human disturbance has on bighorn sheep habitat use. We first conducted a comprehensive inventory of all sources of human disturbance including linear developments such as roads, railways and trails, as well as point sources such as settlements, campgrounds and picnic areas. We then determined human use levels for each of these features, on a seasonal basis, using a combination of existing traffic data for major roads, a series of automatic counters installed at strategic locations on selected secondary roads and trails throughout the study area, and key informant interviews. Zones of influence (ZOIs) and disturbance coefficients (DCs) were then determined for each feature based on empirical studies of the effects of humans on sheep (MacArthur et al 1979,1983; Stemp 1983) in addition to area-specific information gleaned from personal observations and key informant interviews pertaining to the sensitivity of bighorn sheep to human disturbance. Both the nature and predictability of disturbance were important considerations in determining ZOIs and DCs. For example, roads were given less extensive ZOIs than trails because sheep are generally less sensitive to vehicles than they are to humans on foot due to the greater predictability of disturbances along roads. We rated disturbance coefficients on a scale of 0 to 1, representing maximum and minimum disturbance, respectively, and produced separate disturbance layers for summer and winter.

The primary consideration in building the movement routine was security.

From previous empirical studies of bighorn sheep ecology (Wishart 1958; Geist 1971; Becker et al. 1978; Martin and Stewart 1980; Lawson and Johnson 1982; Boyd et al. 1986; MacCallum 1991), we determined that the two most important security factors affecting sheep movements were the presence of escape terrain and visibility. We defined escape terrain as slopes >80%. Escape terrain coefficients were applied to bands surrounding these areas reflecting the fact that bighorn sheep use generally decreases with increasing distance from escape terrain (Tilton and Willard 1982; Stemp 1983; MacCallum 1991). Consistent with the overall modelling scheme, these coefficients were rated from 0 to 1, representing minimal and optimal security, respectively. Areas of high visibility were defined as those areas corresponding to “open” habitats, such as grasslands, rocky ridges and open forests. We assigned an optimal rating of 1.0 to areas of high visibility while areas of lesser visibility were given a rating of 0.5. This rating scheme reflected the belief that visibility enhances corridor suitability but the lack thereof does not act as an absolute constraint on sheep movements. Overall coefficients for the movement routine were obtained by multiplying the visibility and escape terrain coefficients.

The final output of the model consisted of maps representing, on a seasonal basis, the spatial distribution of "corridor value" across the study area for bighorn sheep. Corridor value was defined as the suitability of an area to support the movement of bighorn sheep. Seasonal corridor value was determined by combining the outputs of the habitat, disturbance and movement routines, according to the following equation:

final corridor value = habitat value x disturbance coef. x movement coef.

Seasonal corridor value maps were generated and served as the primary basis for delineating potential movement corridors for sheep across the study area. The final corridor maps included site-specific knowledge of sheep movements and habitat use acquired through key informant interviews and personal observations.

Collection of Telemetry Data

We captured bighorn sheep by free-range darting while the sheep occupied their winter ranges, between January and March inclusive in each year from 2002 through 2005. We selected 10 adult animals annually, including both males and females, out of a total population size of 150 to 200, and selected different animals each year. Among rams, we selected one-half to three-quarter curl rams, but avoided selecting full-curl rams since those animals could experience increased mortality risk during the fall hunting season. All study animals were fitted with GPS radio collars programmed to log two or more GPS locations per day for up to 12 months, covering at least the period from just prior to study animals leaving their winter range in spring to just after the animals return to their winter range in the fall. Collars were removed in November or December and were unavailable for approximately 8 – 10 weeks during annual refurbishment. Refurbished collars then were re-deployed on a new sample of sheep for the subsequent year.

The Parks Canada Agency Animal Care Committee approved animal capture and handling methods under Research and Collection Permits LLYK02-01, LLYK02-35, LLYK03-15, LLYK04-02, and KOONP-2005-3518. More details on sheep capture and GPS data acquisition methods are provided in Dibb (2006, 2007).

Telemetry-based Corridor Delineation

We constructed an approximate, visual representation of movement routes by considering sequences of telemetry points of individual animals within a GIS. This product was intended to be directly comparable with the final corridor map derived from the linkage model. We converted point sequences into linear representations of movement for each study animal in years 2002 to 2004. We used visual interpretation of these data to derive a network of 27 location nodes at which many polylines intersected, mainly at mountain peaks, intersections of ridge crests, mineral licks, and valley bottom sites frequently used by sheep, with an average of approximately 5 km separating consecutive nodes. We constructed separate networks for males and females.

We estimated the extent to which a route (edge) between nodes functioned for sheep movement by tallying the number of telemetry point sequences that traversed more than half the edge at an average straight-line speed of at least 1 km per hour. This categorization into "high-speed" and "low-speed" movement (corresponding to "directed" and "foraging" movements reported by Woolf et al. [1970]) was necessary because movements in core habitat areas typically were very small, irregular in direction, and, in some habitat patches, numbered literally thousands of individual movement segments that were impractical to count. Instead, these core habitat areas were identified using 95% fixed kernel density functions for each sex independently. The tallying of "high-speed" movements, on the other hand, was intended to capture movement outside of core habitat patches represented by the kernel density functions. We chose the threshold of 1 km per hour because this appeared to be the approximate limit separating movements typical within core habitats from movements between core habitats.

We depicted the relative use of each route on a movement route diagram by constructing edges with line thickness proportional to the number of movement events. Movement routes were simply depicted as the shortest line segment between 2 nodes, even though sheep sometimes followed markedly non-linear paths. We categorized movement events as "summer", extending from mid-May through October, and "winter", extending from November through mid-May. Return trips between 2 nodes were counted as 2 trips.

Testing the Linkage Model

Our general approach to testing the linkage model was to use GPS telemetry data from study animals to determine sheep preference or avoidance of the corridor value classes generated by the linkage model. We accomplished this by first determining, for each study animal, the number of telemetry points in each of the linkage model's corridor value classes. We then determined the relative proportions of these classes within each animal's individual home range and within the overall study area. Finally, we calculated utilization:availability ratios, and then applied compositional analysis (Aebischer et al. 1993; Mladenoff et al. 1999) to compare use to availability for each of the linkage model's 5 summer (May through October) corridor value classes (very low, low, moderate, high and very high). Since the linkage model did not differentiate corridor use by sex, we pooled the telemetry data for both sexes. We did not test Tremblay's winter corridor value model based on findings reported in Dibb (2006) that the Radium bighorn sheep in winter (November through April) rarely moved outside the village of Radium Hot Springs and its immediate surroundings.

We performed compositional analyses by using the BYCOMP program (Ott and Hovey 1997) within SAS statistical software. BYCOMP first employed a multivariate analysis of variance (MANOVA) and calculated the Wilks' Lambda (λ) statistic to determine whether sheep use of corridor classes differed from random. Next, for use determined to be non-random, BYCOMP ranked corridor classes in order of sheep preference, and calculated levels of significance for preference differences between ranks using a t-test. When comparing preference of pairs of classes we considered $p < 0.05$ to represent significant differences.

We assessed corridor value class selection at 2 spatial scales in order to investigate the possible effects of an arbitrary definition of study area (Aebischer et al. 1993). First, we considered selection at the home range scale in which availability was determined within the minimum convex polygon (MCP) home range of each animal. Then, we considered selection at the scale of the entire study area.

We conducted the analyses using: 1) all GPS location points meeting certain criteria for positional accuracy, and 2) "movement points", a subset of location points for which the straight line rates of travel from the one point to the next point were > 100 m hr^{-1}. The use of "movement points" was intended to assess use of the landscape when sheep are actually traveling, as opposed to when they may be foraging or resting.

Our assumption in testing the linkage model was that good model performance would be indicated by sheep preference for corridor value classes in the order expected. In other words, sheep would significantly prefer the "high" class to "moderate", would significantly prefer the "moderate" class to "low", and so on.

Comparison of Corridor Maps

We conducted a visual comparison of the corridor map derived from the linkage model with the telemetry-based corridor map. We accomplished this by looking for differences in broad patterns of corridor delineation as well as for specific corridors that were present in one model but absent from the other.

Identification of Restoration Priorities

We considered the possible need for ecosystem restoration along bighorn sheep spring and fall movement corridors. We first used a GIS to identify a set of candidate polygons based on terrain and vegetation attributes. In particular, we mapped polygons that had south-west, south, or south-east aspects, slope angles greater than 15^o, and elevations between 800 and 2000 m. We then selected from these polygons areas with forest canopy closure greater than 50%, on the assumption that sites with suitable terrain but with thick forest cover would be the best candidates for restoration treatments such as thinning or prescribed burning. Of all polygons meeting these criteria, we identified those polygons along active, heavily used corridors as the highest restoration priorities, and those along relatively infrequently used corridors or adjacent to historic winter range as secondary priorities.

Finally, we considered the need to maintain sheep access to pockets of historic winter range located up to 15 km south of Radium Hot Springs. We located this winter corridor by using telemetry point sequences from several rams that travelled it, and interpolated between points by using terrain features, by connecting forest openings, and by avoiding agricultural lands.

Results

Linkage Model

The final output from the linkage model was a map representing, on a seasonal basis, the spatial distribution of "corridor values" across the study area (Fig. 3). Although separate maps were produced for summer and winter, we present only the former here since the latter was not subjected to the model testing exercise. Corridor values ranged from 0 to 1, representing no value and optimal value, respectively, and were assigned a rating as per Table 1. Based on this map and additional site-specific information, we identified 12 potential movement corridors for bighorn sheep within the study area (Fig. 4).

Delineation of Travel Routes from GPS Location Sequences

All study animals except 1 exhibited migratory behaviour, moving between winter range in the Columbia River valley bottom and summer range in alpine areas of the Brisco or Stanford ranges. One study animal, a ram estimated at 7 years of age, was killed on highway 93/95 on 1 August 2002 having never moved to the high country. Five of 7 rams in 2002 and 2003 made brief winter excursions at least 6 km south of the Radium winter range; in 2004 most ram radio collars were removed in October and so early to mid-winter movements of these animals were not recorded. No marked females travelled more than 2 km south of the Radium winter range.

In summer, all study animals selected habitats either in the Brisco Range north of highway 93, or in the Stanford Range south of highway 93. There was little spatial overlap of summer habitat use by males and females, illustrated through the 95% kernel density functions depicted in Figures 5 and 6. Most habitats selected by females in summer were in the northern half of the study area but relatively close to the Radium Hot Springs winter range. Males selected habitats in summer that were generally more distant from Radium Hot Springs. Consequently, the male network of migration corridors was longer and somewhat more complex than that of females.

Sheep sometimes made rapid movements of several km in 2 to 6 hours between habitat patches or seasonal ranges, especially in summer. Frequently travelled routes typically linked winter range to lambing or summer range, or linked summer range to mineral lick sites (Figures 6 and 7). Visual observation of groups of sheep throughout the summer confirmed that these animals frequently visited two sites to obtain minerals: the salt shed at the Parks Canada Highways Service Centre compound, and the highway 93 roadside approximately 12 km east of Radium Hot Springs village. Lambing sites, as inferred from telemetry data and visual observation of sheep, occurred mainly on west and south aspects in the Brisco Range, in steep terrain < 300 m below tree line. Most movement routes were along ridge crests, and along steep, indistinct ridges or slopes that represented the most direct routes from alpine terrain to valley bottom sites.

Testing the Linkage Model

The classification scheme used for the corridor value surface resulted in a high proportion of the study area (67.0%) being classified as very low corridor value and only a small proportion classified as very high (0.8%), with the remaining classes falling in between (Table 2). Some individual animals were not recorded within the "very high" class, therefore we executed the compositional analysis after collapsing the high and very high classes into a single category.

At the scale of individual home ranges, bighorn sheep use of the linkage model's probability classes was significantly non-random ($\lambda = 0.14$, $F = 36.66$, $p < 0.001$, Table 3). Sheep showed a preference for the moderate class over all other classes and the combined high and very high class ranked above the low and very low classes. Although the very low class was ranked higher than the low class, the difference was not significant.

Similarly, at the scale of the entire study area, bighorn sheep exhibited selection for corridor value classes ($\lambda = 0.13$, $F = 41.85$, $p < 0.001$, Table 4), and class rankings were similar to the individual home range scale.

Overall, considering both scales of analysis, the moderate class was the most strongly selected for, followed in order by the combined high and very high class, the very low class, and the low class. Selection differences between the low and very low classes generally were not significant but differences in selection between other classes were significant.

We obtained similar results when the analyses were repeated on a subset of sheep GPS points that included only points associated with substantial sheep movement as calculated from successive point locations. For these movement points sheep exhibited selection for corridor value classes both at the individual home range scale ($\lambda = 0.13$, $F = 27.84$, $p < 0.001$, Table 5) and at the scale of the entire study area ($\lambda = 0.065$, $F = 57.40$, $p < 0.001$, Table 6). At the home range scale sheep preferred the moderate class to very low or low classes and preferred the combined high and very high class to low; all other differences among class preferences were not significant. At the study area scale sheep preferred the moderate class relative to all others, and preferred the combined high and very high class to very low. Other differences among class preferences were not significant.

Table 7 summarizes all compositional analyses, showing the rank order of sheep preference for the various classes, including identification of significant versus non-significant differences among consecutive classes.

Development of Restoration Priorities

We completed the selection and prioritization of candidate sites for restoration and show these in figures 7 and 8. Two high priority sites were identified on the north side of Sinclair Creek and would be expected to improve security and forage opportunity as sheep migrate between the Radium Hot Springs area and high elevation ridges in the Brisco Range. A third high priority site is intended to provide similar benefits to a linkage between the village and the upper slopes of Redstreak Mountain in the Stanford Ranges.

Discussion

Comparison of Linkage Model and GPS Telemetry Corridor Maps

At a scale encompassing the entire study area, some broad patterns of corridor delineation were similar in the two approaches. The most obvious similarity was that both maps showed a predominantly north-south movement axis following the natural orientation of major ridge systems. Additionally, the network of corridors in both maps converged on the winter range areas near Radium Hot Springs.

We also found a number of dissimilarities between the two maps. First, the telemetry-based approach mapped separate corridor networks for males and females, with striking differences between the two, as discussed above. In contrast, the linkage model-based map did not distinguish between male and female corridors. This represents an obvious limitation of the linkage model.

A second difference was that the telemetry-based map included a number of small corridors that provide east-west linkage at mid to high elevations between major ridge systems. In contrast, the linkage zone model depicted a single east-west corridor following highway 93 along Sinclair Creek up towards the height of land at Sinclair Summit. Although sheep frequently occurred along Sinclair Creek, telemetry data showed that sheep rarely used it as a travel route above the confluence with McKay Creek. Instead, sheep followed ridges down to Sinclair Creek where they accessed minerals at several locations along the side of highway 93. The presence of sheep along the highway has created the apparently mistaken impression among even long-time observers that the sheep use the highway corridor as a travel route.

A third discrepancy we observed was that the linkage model map predicted a higher elevation corridor linking the Radium area south to Stoddart Creek via Redstreak Mountain, in addition to the low elevation corridor that the telemetry-based map also depicted. The lack of sheep use of the high elevation corridor likely reflects the diminished status of the Stoddart Creek area as winter range, thereby reducing the need for sheep to travel there. The telemetry-based map depicted sheep use of a low elevation corridor north of Radium as well, running approximately parallel to highway 95 near the foot of the Brisco Range in the Columbia Valley. The linkage model map did not predict this corridor, likely due to its presence within zones of thick forest cover, flat terrain and, for some portions, far from escape terrain.

Fourth, the linkage model predicted corridors extending further north and south of the Radium Hot Springs area than was found in the telemetry-based analysis. These corridors are likely indicative of potential long distance travel routes linking the Radium herd to other sheep populations, but that were unused by our study animals.

Finally, at a finer scale, the linkage model predicted the occurrence of a set of corridors within the village of Radium Hot Springs and immediate surrounding areas. The telemetry-based analysis did not have the resolution to map corridors at this scale, although the data exists to conduct such a finer-scale analysis in future. However, use of the village by sheep is sufficiently heavy that it will likely prove difficult to separate fine-scale movements from foraging activity.

Linkage Model Performance

The generally poor performance of the linkage model can be attributed to a number of limitations, some of which are inherent to all models and some more specific to the linkage model itself.

One of the most significant limitations of any model is that it is usually based on several, often untested, assumptions. At the time of model development, very little information was found in the literature describing the factors driving the selection of movement habitat by bighorn sheep. Most of the existing research we reviewed to create the theoretical model focused on habitat selection, home range size, or behavioural and physiological responses to human-related disturbances. The selection of movement habitat by sheep had not received much attention and was generally poorly understood. This dearth of information on wildlife movements required us to make a number of tenuous assumptions. Three such assumptions that influenced the performance of the model are described below.

The first assumption, which formed the basis of the habitat routine, was that sheep choose to travel through areas of suitable, rather than unsuitable, habitat.

This assumption, which has been applied to other corridor modelling efforts (e.g. Walker and Craighead 1997, Callaghan et al. 1998), is based on the belief that movement corridor habitat should be similar to core habitat in providing optimal cover and forage. However, this assumption did not hold true for our telemetry data, which showed that the Radium sheep often underwent rapid migrations through largely unsuitable, “risky” habitat.

The second assumption was that empirical data collected in other areas could be applied to the present study, i.e. that bighorn sheep located within the present study area select habitat and travel routes and react to humans in the same way as their counterparts living outside the Radium study area. However, it is possible that the literature failed to capture some of the particularities of the Radium herd, most notably its high level of habituation to human presence, particularly on its lower-elevation winter and transitional ranges.

A third important assumption of the linkage model was that male and female bighorn sheep have similar movement patterns and use the same criteria in the choice of travel routes. However, sexual segregation in bighorn sheep is well documented. Rams and ewes have different biological requirements, a situation that leads to differences in foraging strategies and the use of different ranges during much of the year (Main et al. 1996). Such differences result in distinct movement patterns for rams and ewes. In support of this, our telemetry results show that males and females exhibited sexual segregation in summer when their respective ranges were separated by, typically, 1 to several km.

Beyond its reliance on untested assumptions, another factor that might have contributed to the poor performance of the linkage model is its dependence on existing data sets. While such an approach was necessary for time and resource considerations, it also entailed a number of constraints, which were particularly evident in the case of the habitat suitability data. Due to the multijurisdictional nature of the study area, the habitat suitability ratings used in the model were derived from a combination of provincial and federal data sets. These data sets required a number of manipulations in order to meet the needs of the model, which inevitably led to a loss of accuracy. Moreover, the habitat suitability ratings in the existing data sets were not assigned on a seasonal basis but rather, on a carrying capacity basis. As a result, winter range habitats, which generally support higher densities of ungulates, were systematically assigned higher ratings than summer habitats. This system made it difficult to differentiate between high and low quality habitats for a given season.

Another possible reason explaining the poor performance of the linkage model may be its lack of focus on a specific scale of movement. In retrospect, we would recommend taking a multi-scale approach to modelling corridors which would distinguish between large-scale inter-range dispersal movements, medium scale movements between seasonal ranges, and, at the finest scale, movement routes linking key habitats within seasonal ranges.

Finally, perhaps one of the most important limitations of using a spatial modeling approach for identifying corridors stems from its inability to adequately account for non-spatial factors such as predator-prey relationships, learned behaviours passed on from generation to generation, behavioural differences amongst individuals, knowledge of the landscape, and motivation to reach a particular destination. It is easy to conceive how some or all of these factors could affect the choice of travel lanes and yet, such factors are not readily accounted for in a spatial model.

In spite of the many limitations discussed above, a theoretical modelling approach to corridor delineation can offer some important advantages over a more empirical approach. One such advantage is that a theoretical model tells the researcher something about where the animals should be moving rather than simply where they are moving. For example, wildlife may be avoiding optimal corridors because of human-related impediments, or may be forced to use sub-optimal corridors because no alternatives exist.

A case in point may be the bighorn sheep herd in our study, which essentially used only 3 seasonal ranges: winter, lambing, and summer. They made little use of mid-elevation habitats, instead making rapid migrations between valley floors and alpine regions – a situation which may have placed additional pressure on limited, crowded winter ranges. The traditional migration routes, now degraded through coniferous in-growth, provide risky travel for bighorn sheep since the routes do not provide for good visibility and predator detection. Risky migration routes may eventually be abandoned by sheep (Risenhoover et al. 1988), leading to a suite of problems associated with sedentary populations. Although we have not yet detected increases in sedentary behaviour by the Radium sheep, this problem may yet emerge if sheep corridors in our study area continue to deteriorate.

Long-distance Movements

On a broader scale, the spatial distribution of bighorn sheep in western Canada and western North America appears to be consistent with a classic metapopulation structure (Bleich et al. 1996; Demarchi et al. 2000). Interchange between herds is believed to be essential to maintaining a functioning metapopulation (Bleich et al. 1996) through mechanisms including demographic rescue or re-colonization of declining or extirpated herds and the exchange of genes among relatively isolated subpopulations (Epps et al. 2005). We did not detect any dispersal or interchange between the Radium herd and other herds, despite acquiring daily location data for 9 to 10 animals of both sexes per year for a total of 4 years. However, the lack of evidence of interchange between herds in our study does not necessarily mean that none occurs, especially given that dispersal appears to be rare among bighorn sheep (Geist 1971; Singer et al. 2000). Our sample size may have been too small relative to the rarity of such events, particularly in the age-sex classes (3 year old males [Geist 1971]) most likely to move long distances. Moreover, there exists reliable historical evidence of occasional sheep movements between our study area and other sheep ranges, such as the Kicking Horse canyon located over 100 km to the north (Stelfox et al. 1985; Tremblay 2001).

A second, more worrisome, explanation for our failure to document inter-range movements may be that such movements are increasingly impeded by the degradation, through conifer encroachment and various urban and recreational developments, of the low elevation and valley bottom corridors that likely provide the linkage between neighbouring herds. This situation may prove difficult to address as human developments can severely constrain landscape managers in the application of prescribed fire to mitigate the coniferous in-growth problem. Ever-increasing demand for permanent homes and recreational properties in the region will likely exacerbate the problem in the future.

Bighorn sheep in our study area sometimes chose valley floor travel routes, even where it appeared that more secure, higher elevation ridge routes were available. These valley floor routes carried increased risk of contact with domestic livestock, highway crossings with risk of collisions with motor vehicles, and, presumably, predation. The reasons why sheep chose these high-risk routes are not clear although we speculate that habitat degradation due to forest ingrowth on the adjacent mountain slopes may be a factor.

Management Implications

The results of our study point to a number of recommendations aimed at improving functional landscape connectivity for bighorn sheep in the present study area as well as other areas where wild sheep persist in heavily human-impacted landscapes. We begin by providing specific recommendations for habitat restoration in the Radium area. We then discuss other important management issues pertaining to sheep movements. Finally, we present recommendations on the continued use of models to inform future restoration efforts.

Our recommendation for priority habitat restoration in the Radium area is burning and thinning of coniferous ingrowth within the currently utilized seasonal migration corridors. Of particular concern are mid-elevation slopes located immediately adjacent to current winter range areas (Figure 7). Secondary priorities are mid-elevation slopes that connect summer ranges to current or historic winter ranges, but are not currently being utilized by the Radium herd to the extent expected. We also recommend restoration of the narrow, low elevation corridor connecting winter habitat at Radium with historic winter ranges at Stoddart, Shuswap, and Windermere Creeks (Figure 8). A longer term project is recommended to extend restoration of this corridor further south to provide linkage to the Columbia Lake bighorn sheep herd near Fairmont Hot Springs, British Columbia. Both sections of this low elevation corridor would likely require emphasis on low-risk mechanical thinning techniques due to proximity to built facilities.

Our results illustrate that wild sheep in our study area are at considerable risk of coming into close contact with domestic sheep ranches in the Columbia Valley. While we recognize that progress has been made recently at identifying high-risk areas (e.g., working with local ranchers, and, in one instance, replacing a local domestic sheep herd with cattle), risk levels remain high. Lowering the risk for disease transmission will require continued and coordinated interagency effort across all jurisdictions that contain land considered important for sheep movements. Restoration work, as described above, will also be an important part of the solution if it enables bighorn sheep to choose travel routes that are further removed from the valley floor.

In our view, the frequent occurrence of bighorn sheep in proximity to humans is a significant conservation challenge for the Radium herd. The concentration of sheep on very small areas of artificial habitats for 7 to 8 months each year exacerbates problems of animal-vehicle collisions, spread of disease, habituation of sheep to humans, and may also serve as a disincentive to migratory behaviour. Strategies to improve the separation of humans and bighorns could include limited sections of highway fencing and land use planning to minimize human encroachment into areas important to sheep. Habitat restoration work in areas outside local communities could also provide sheep with opportunities to forage in areas with less human activity and that can be reached without having to cross major highways.

Finally, we recommend the development of improved models of bighorn sheep habitat and movement corridors as important planning tools for future restoration work. Although we have identified a series of priority areas for restoration that are likely to occupy forest managers for several years, improved modelling tools could enable refinement of secondary priorities for restoration such as highway mitigation, human use management, and land use planning. Moreover, although an empirical resource selection function (RSF) habitat model for the Radium study area was developed by Dibb (2007), improved empirical models could incorporate some or all of the following: (1) separate models for males and females, (2) model biologically relevant seasons, (3) model corridors by collecting GPS location data more frequently during migratory periods, and (4) focus corridor modelling on a particular scale of movement, such as seasonal migration.

Acknowledgments

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Associate Editor:

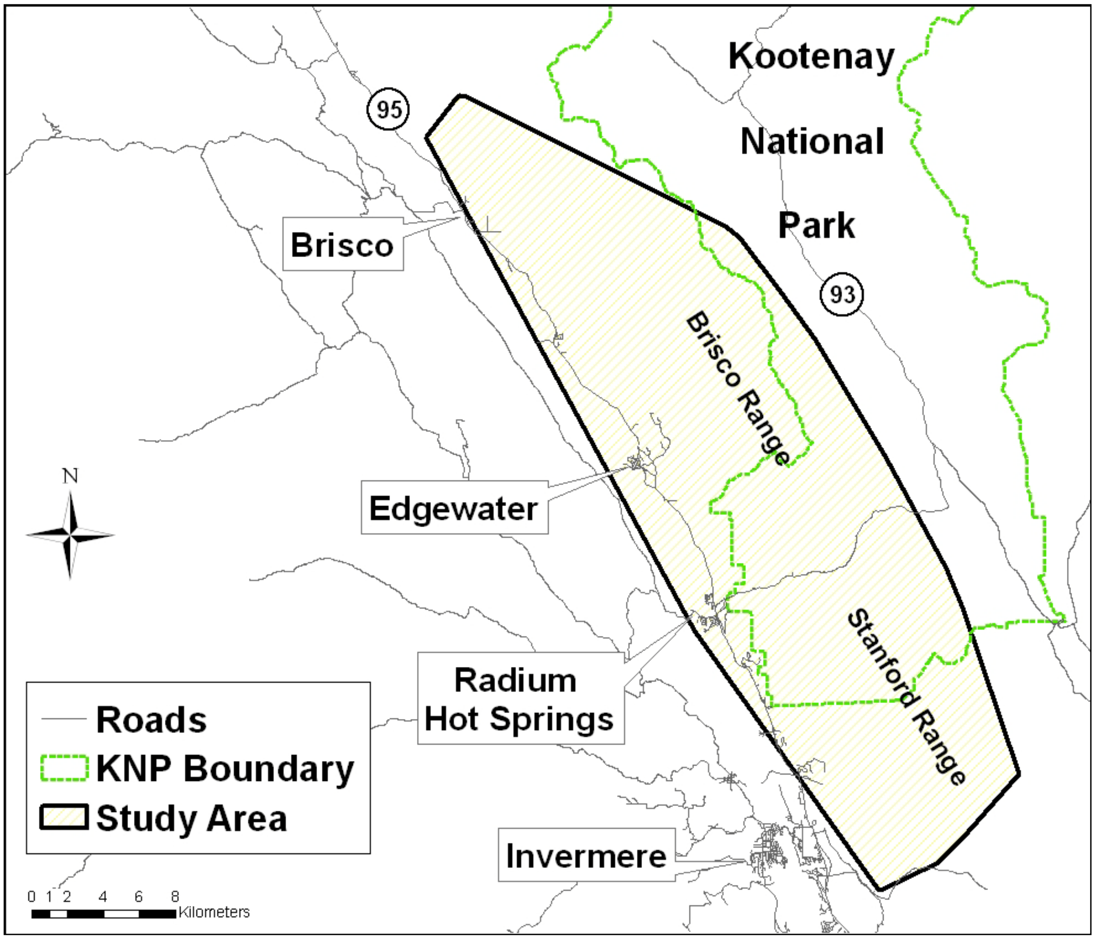

Figure 1. Study Area.

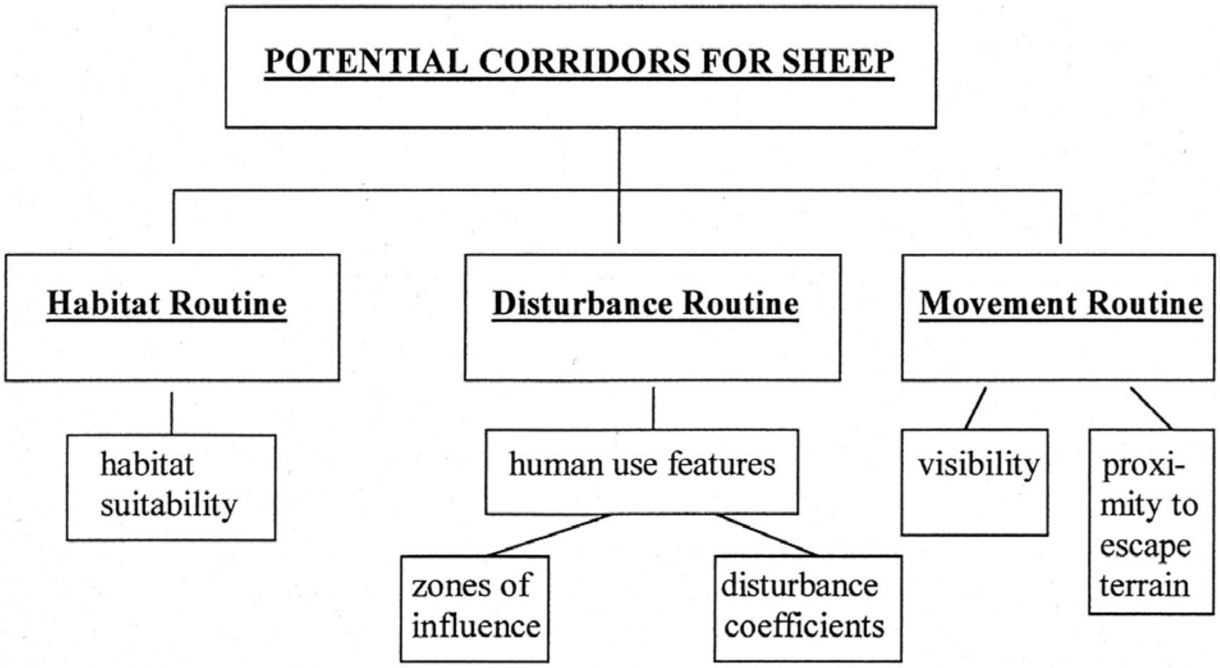

Figure 2. Conceptual diagram of the bighorn sheep linkage model.

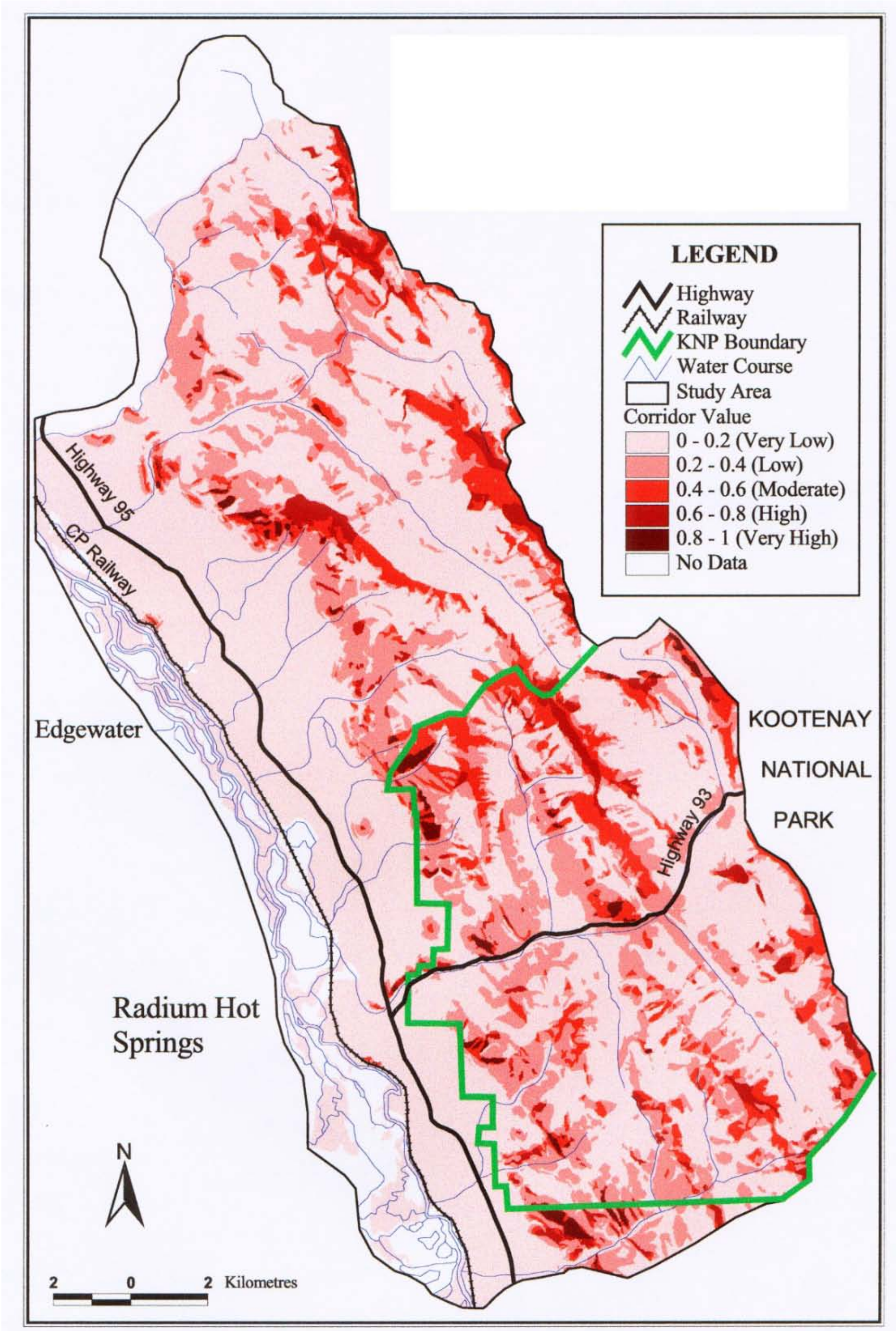

Figure 3. Map of corridor values generated from the theoretical bighorn sheep linkage model.

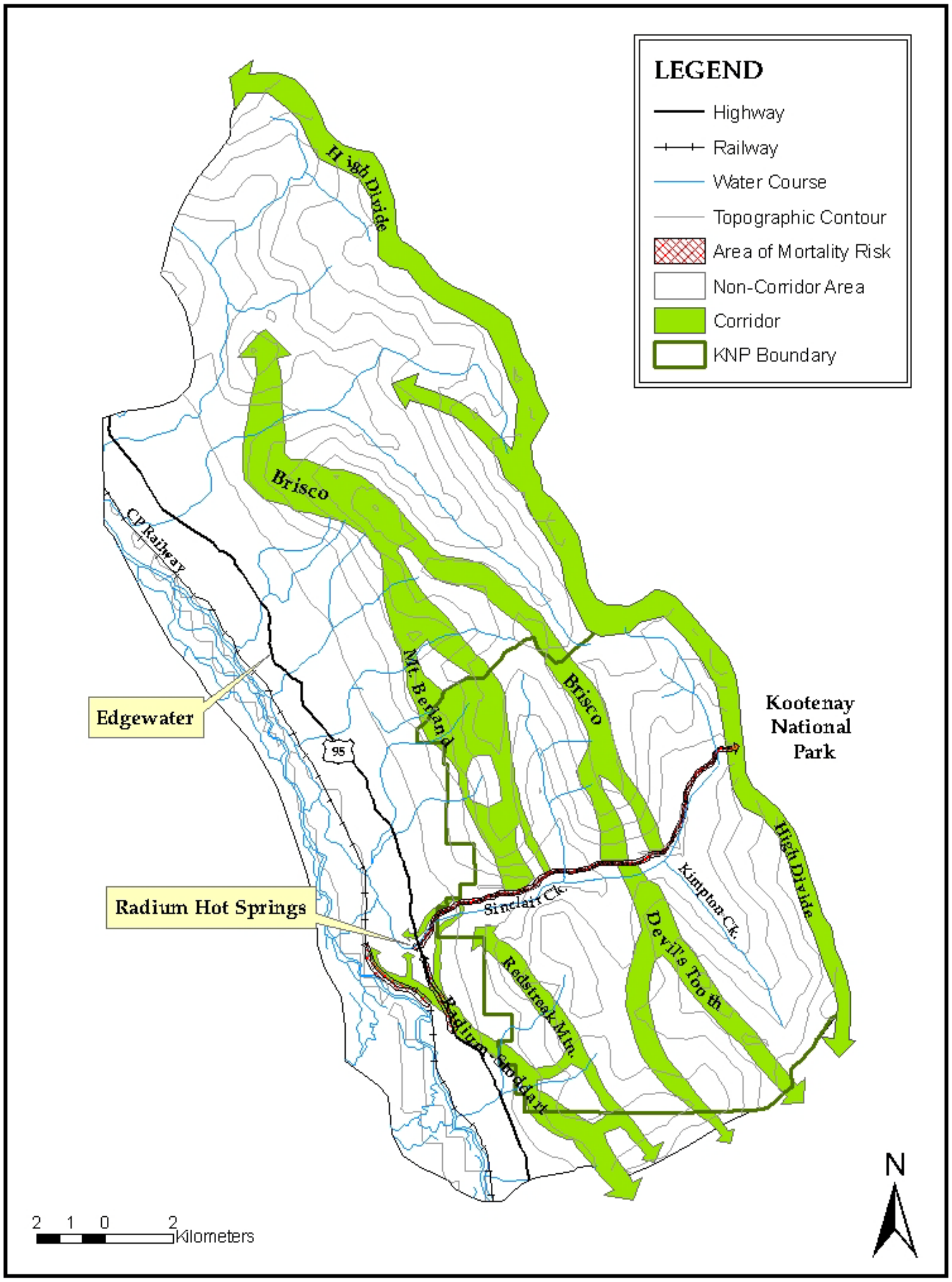

Figure 4. Potential corridors for bighorn sheep based on the linkage model corridor values, site-specific information, and personal observations.

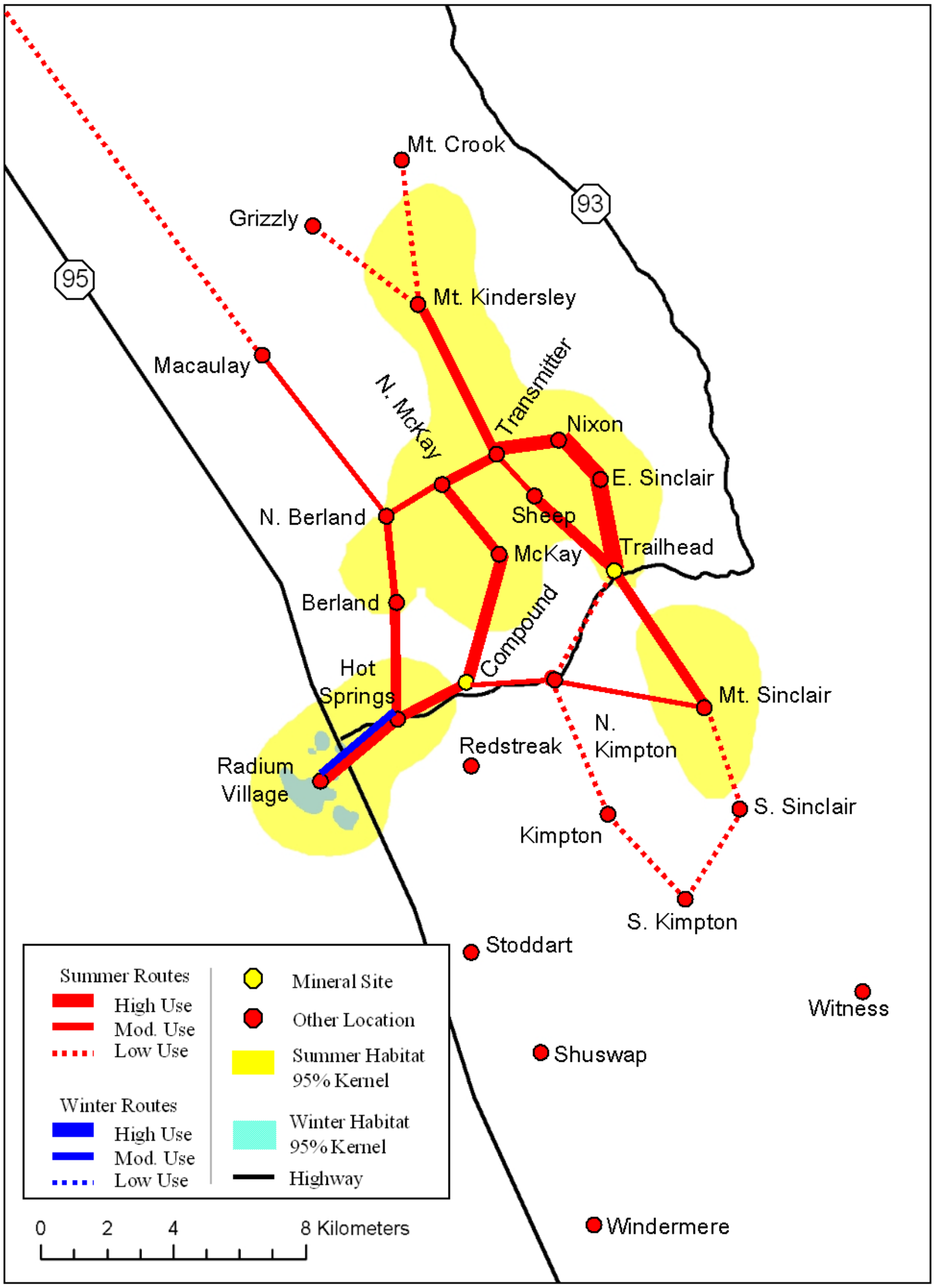

Figure 5. Female movement routes and core ranges from GPS location sequences.

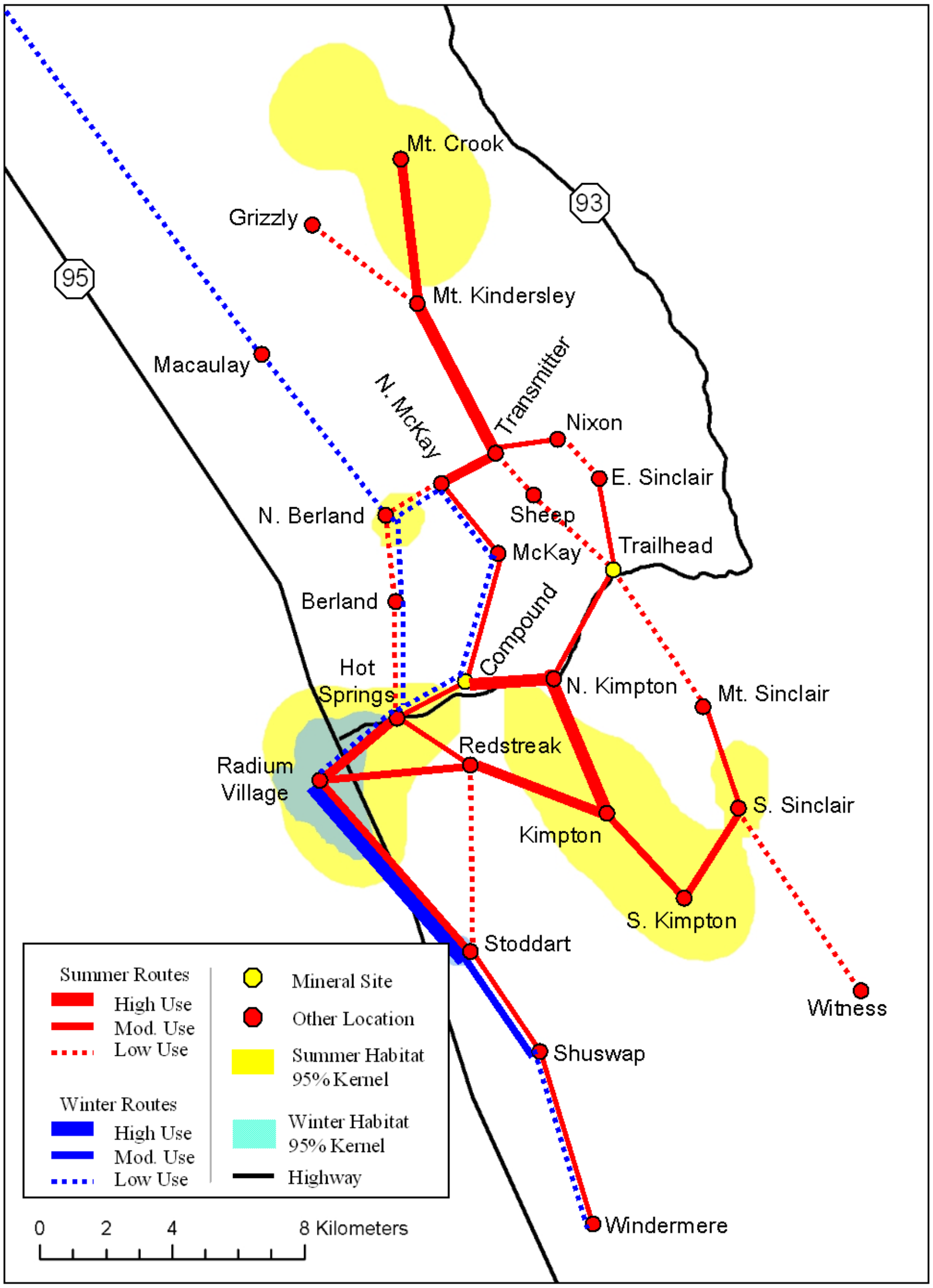

Figure 6. Male movement routes and core ranges from GPS location sequences.

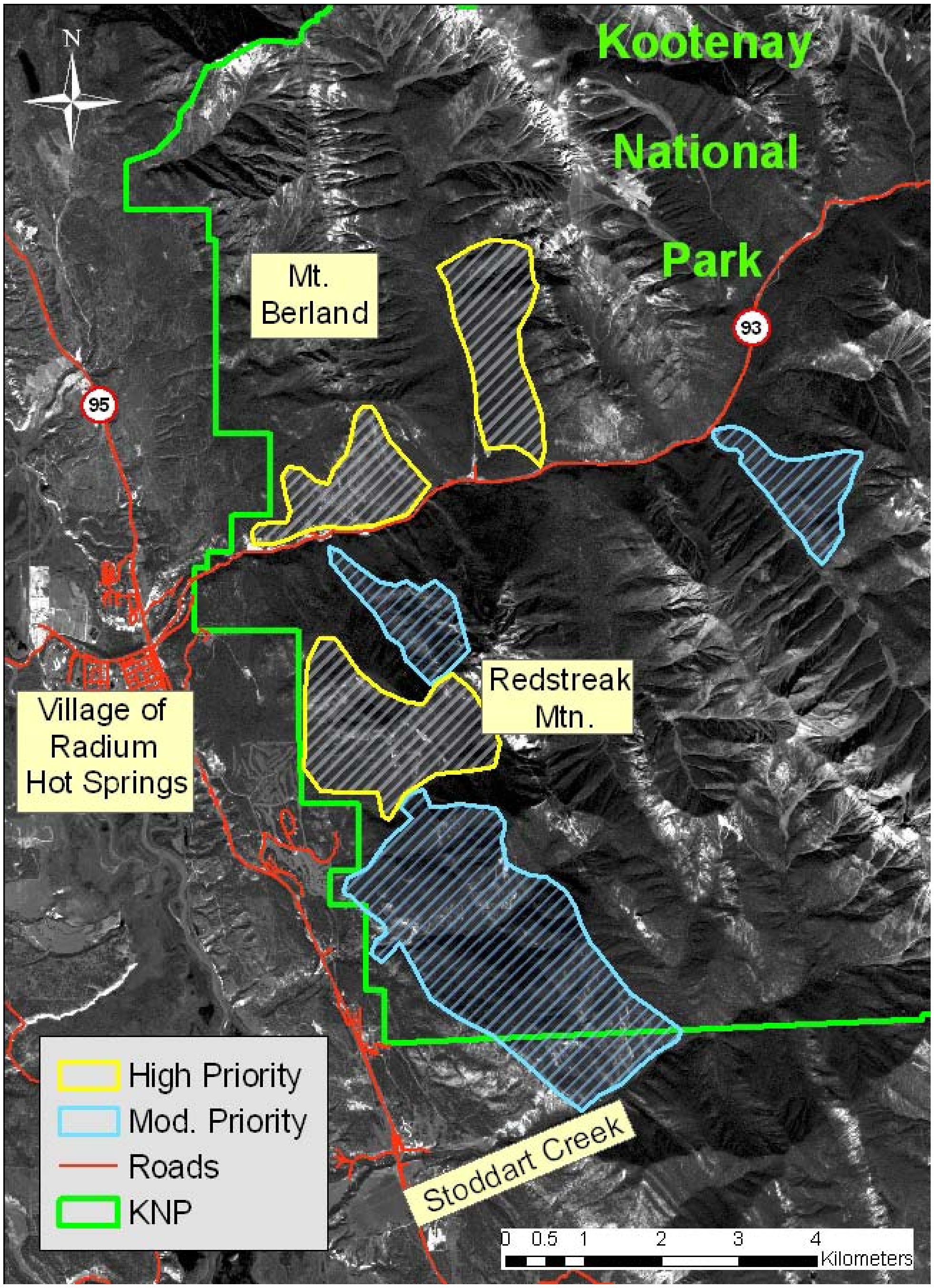

Figure 7. Map of recommended mid-elevation sites for restoration treatments.

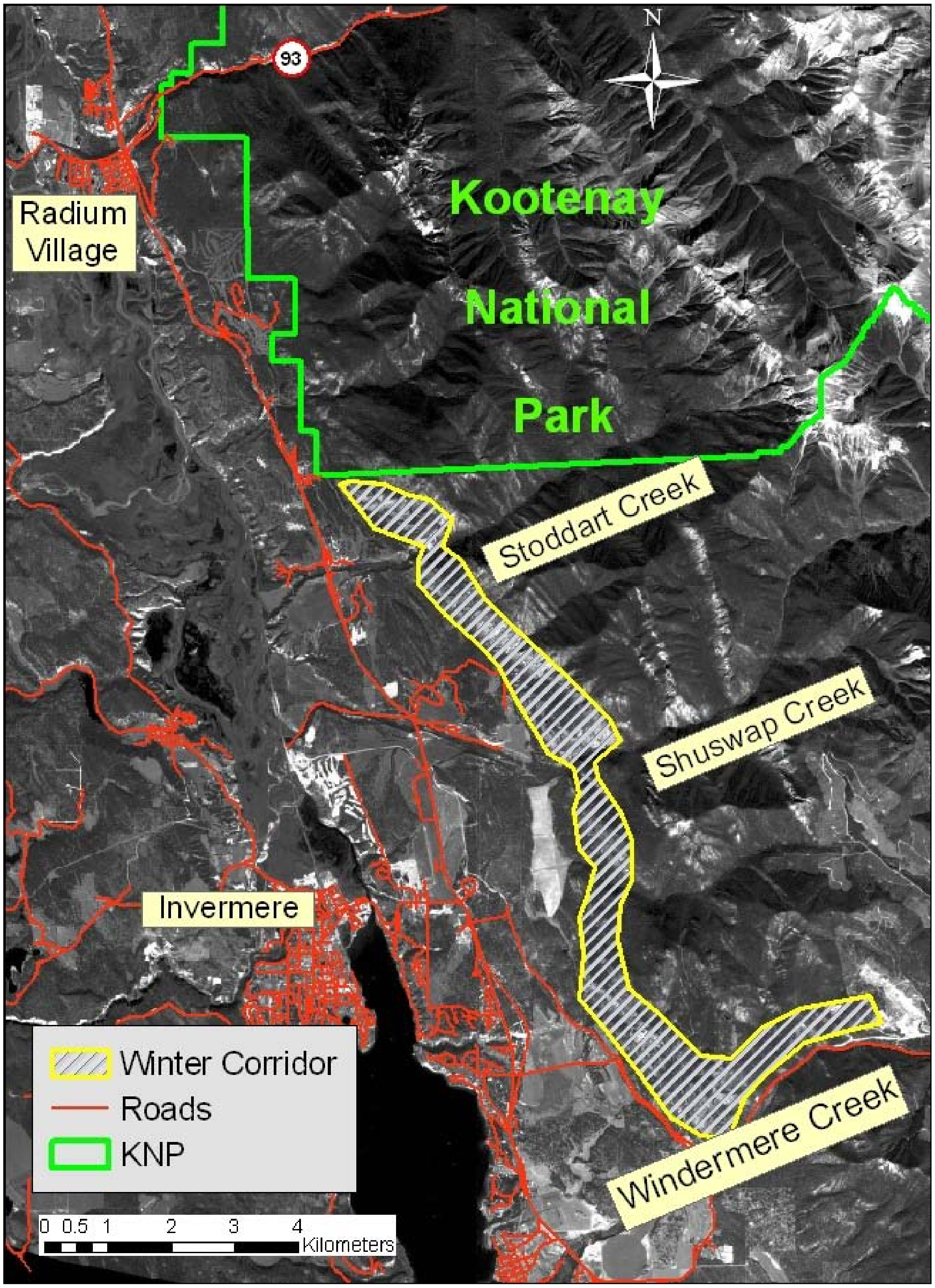

Figure 8. Map of corridor connecting historic winter ranges.

Table 1. Rating scheme for corridor values of the bighorn sheep linkage model presented in Fig. 3.

Corridor Value	Rating
0.0 - 0.2	Very Low
0.2 - 0.4	Low
0.4 - 0.6	Moderate
0.6 - 0.8	High
0.8 - 1.0	Very High

Table 2. Proportions of summer telemetry points in each class of the bighorn sheep linkage model, all study animals, 2002-2004.

	Availability	Use					
		All Telemetry Points			Movement Points		
Tremblay Model Class	Proportion of Study Area Per Class	Proportion of Points Per Class (N = 22311)	Use / Availability Ratio	Rank (0 - 4)	Proportion of Points Per Class (N = 1957)	Use / Availability Ratio	Rank (0 - 4)
1 (very low)	0.670	0.408	0.609	0	0.586	0.874	2
2 (low)	0.211	0.178	0.843	1	0.159	0.753	1
3 (moderate)	0.076	0.271	3.563	3	0.170	2.232	3
4 (high)	0.033	0.128	3.867	4	0.082	2.494	4
5 (very high)	0.008	0.016	1.950	2	0.004	0.450	0

Table 3. Simplified ranking matrices for bighorn sheep proportional use of linkage model corridor value classes to available proportions of corridor value classes within individual MCP home ranges. Linkage model "high" and "very high" classes were collapsed into a single class. Classes are ranked from least preferred (1) to most preferred (4). Classes that differ significantly in preference from random at p = 0.05 are indicated by either "+++" or "---". Classes that differ in preference from random at p > 0.05 are indicated by either "+" or "-". GPS telemetry data is from 2002-2004.

HSI Model Class	1 (very low)	2 (low)	3 (moderate)	4 (high, v. high)	Rank
1 (very low)	.	+	---	---	2
2 (low)	-	.	---	---	1
3 (moderate)	+++	+++	.	+++	4
4 (high, v. high)	+++	+++	---	.	3

Table 4. Simplified ranking matrices for bighorn sheep proportional use of linkage model corridor value classes to available proportions of corridor value classes within entire study area. Linkage model "high" and "very high" classes were collapsed into a single class. Classes are ranked from least preferred (1) to most preferred (4). Classes that differ significantly in preference from random at p = 0.05 are indicated by either "+++" or "---". Classes that differ in preference from random at p > 0.05 are indicated by either "+" or "-". GPS telemetry data is from 2002-2004.

HSI Model Class	1 (very low)	2 (low)	3 (moderate)	4 (high, v. high)	Rank
1 (very low)	.	-	---	---	1
2 (low)	+	.	---	---	2
3 (moderate)	+++	+++	.	+++	4
4 (high, v. high)	+++	+++	---	.	3

Table 5. Simplified ranking matrices for bighorn sheep proportional use of linkage model corridor value classes to available proportions of corridor value classes within individual MCP home ranges. Utilization was quantified based on movement points only, 2002-2004. Linkage model "high" and "very high" classes were collapsed into a single class. Classes are ranked from least preferred (1) to most preferred (4). Classes that differ significantly in preference from random at p = 0.05 are indicated by either "+++" or "---". Classes that differ in preference from random at p > 0.05 are indicated by either "+" or "-".

Tremblay Model Class	1 (very low)	2 (low)	3 (moderate)	4 (high, v. high)	Rank
1 (very low)	.	+	---	-	2
2 (low)	-	.	---	---	1
3 (moderate)	+++	+++	.	+	4
4 (high, v. high)	+	+++	-	.	3

Table 6. Simplified ranking matrices for bighorn sheep proportional use of linkage model corridor value classes to available proportions of corridor value classes within entire study area. Utilization was quantified based on movement points only, 2002-2004. Linkage model "high" and "very high" classes were collapsed into a single class. Classes are ranked from least preferred (1) to most preferred (4). Classes that differ significantly in preference from random at p = 0.05 are indicated by either "+++" or "---". Classes that differ in preference from random at p > 0.05 are indicated by either "+" or "-".

HSI Model Class	1 (very low)	2 (low)	3 (moderate)	4 (high)	Rank
1 (very low)	.	-	---	---	1
2 (low)	+	.	---	-	2
3 (moderate)	+++	+++	.	+++	4
4 (high)	+++	+	---	.	3

Table 7. Summary of compositional analysis class rankings from tables 2 through 5. "MCP" = Minimum Convex Polygon; "SA" = Study Area; "<" indicates that the difference in preference between two consecutive classes is not significant to p < 0.05; "<<" indicates that the difference in preference between two consecutive classes is significant to p < 0.05.

Table Number	Scale (MCP vs. SA)	Movement Points	Least Preferred Class --> Most Preferred Class						
2	MCP	.	L	<	VL	<<	H	<<	M
3	SA	.	VL	<	L	<<	H	<<	M
4	MCP	Y	L	<	VL	<	H	<	M
5	SA	Y	VL	<	L	<	H	<<	M

Bighorn Sheep Distribution and Movement in the Nikanassin Range, of Alberta's Rocky Mountains

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Abstract: Reclamation after open pit coal mining in west-central Alberta has created new and vacant bighorn sheep habitat. Bighorn sheep (*Ovis canadensis*) have colonized the reclaimed land but also use these lands in conjunction with nearby alpine ranges. Bighorn sheep distribution, movement patterns, seasonal use and habitat use were examined in the Nikanassin Mountain Range of the Canadian Rocky Mountains. Nineteen VHF collars were placed on 12 rams and 7 ewes of all ages on the Luscar and Gregg River Mines from September 1992 to October 1993 covering different areas on the mines and different seasons. Additionally, ear tags were placed on 16 rams and 25 ewes from February 1992 to November 1994. Collared animals were visually located every two weeks from mid-September 1992 to December 30, 1994. Home range was analyzed using Program Home Range. Male home ranges (17-461 km^2; 95% harmonic mean) were larger than females (40-140 km^2). Core areas represented 20% to 40% of the area of the home range of individual sheep indicating the importance of these areas. 62% to 67% of observations for 15 of the sheep occurred in their core area while for four sheep, 44% to 58% of observations occurred in their core area. Bighorn sheep using the reclaimed lands consist of several home range groups of ewes and rams. Rams interacted with four and possibly five home range groups, while ewes interacted with three and possibly four home range groups. Ewe groups using the reclaimed lands belonged to two distinct subpopulations that were linked by emigration. Rams using the reclaimed lands interacted with 7 subpopulations, movements occurring more frequently during the spring, summer and rut. Rams used six rut ranges found on the reclaimed lands (2), adjacent mountain ranges (2), and nearby Jasper National Park (2). There was no evidence that bighorn sheep abandoned previously occupied range.

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Metapopulation Structure of Bighorn Sheep in Waterton-Glacier International Peace Park

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Abstract: Metapopulation structure and function are important considerations when managing bighorn sheep. However, detailed studies of bighorn metapopulations are largely lacking, particularly for native herds with intact traditions of seasonal movements, and whose genetic and disease profiles are uncomplicated by artificial translocation. In a 5-year study in Waterton-Glacier International Peace Park, we used 88 GPS-collared animals (45 ewes, 43 rams), nuclear and mitochondrial DNA, and disease assays to study metapopulation structure of a strictly native herd. Telemetry data (n=142,190 locations) revealed 10 distinct ewe groups and 6 ram groups, and together with visual observations suggested the existence of several others. At a broader spatial scale, telemetry data also revealed evidence of 4 subpopulations, each comprised of multiple ewe and ram groups, and exhibiting varying degrees of insularity. Evidence of segregation between the North Glacier and South Glacier subpopulations was bolstered by differences in nuclear DNA (n=8 animals and 17 microsatellite loci for each subpopulation, F_{ST} =0.12), incidences of distinct mtDNA haplotypes (north: n= 11, incidence of haplotype 1 = 1.00, 95% CI = 0.76-1.00; south: n =11, incidence of haplotype 1 = 0.18, 95% CI = 0.02-0.28), and incidences of exposure to *Anaplasma ovis* (north: n = 40, incidence = 0.53, 95% CI = 0.36-0.68; south: n = 17, incidence = 0.00, 95% CI = 0.00-0.16). Analyses of DNA from *Pasteurella trehalosi* type 2 non-hemolytic-the form of *Pasteurella* most commonly isolated from oropharyngeal swabs taken during animal captures-revealed a genotype associated solely with animals whose home ranges included Waterton Lakes National Park. Together with our telemetry data, the spatial distribution of this genotype supported the existence of 1 subpopulation straddling the U.S.-Canada border in the area north and west of Belly River, and another occupying areas west of Waterton Lakes. Overall, our findings revealed a surprising degree of metapopulation structure at multiple spatial scales. We discuss some implications of these findings relative to managing and monitoring bighorn populations.

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Introducing Ungulates to Unfamiliar Environments: Behavioral and Endocrine Responses in Bighorn Sheep

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Abstract: Restoring bighorn sheep to their former range requires active metapopulation management involving frequent translocations between subpopulations and reintroduced to new areas. One strategy is to maintain a closely monitored non-hunted subpopulation in a predator-a and disease free environment, such as Antelope Island State Park (AISP) in Utah, for use as a source from which to regularly translocate batches of selected animals. Potential problems, however, include (1) susceptibility to cougar predation when naïve bighorns are released, (2) decreased immunocompetence caused by poor nutrition and elevated stress when adults are released during winter into unfamiliar environments with new social hierarchies, and (3) dispersal of introduced animals into areas occupied by domestic sheep, leading to further disease concerns. A study is currently underway to compare pre- and post-translocation vigilance behavior and fecal glucocorticoid profiles in a group of 35 bighorns recently translocated from AISP. The same comparisons are also being made between animals raised on AISPand those "wild-raised" in the release area (Stansbury Mountains, UT), while post-release ranging patterns of AISP-raised animals are being compared with those of "wild-raised" residents. Data collection is stratified by age and sex class to identify the optimal composition of groups for future translocation efforts.

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The Use of Molecular Markers in Wild Sheep Research in North America: A Review

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***Abstract*:** Molecular markers increasingly have been used in ecological research as new technologies have improved automation and lowered costs. Researchers in applied disciplines such as wildlife management and conservation biology have begun to utilize genetic tools to address questions that are difficult or impossible to answer with more traditional approaches. For wild sheep in particular, molecular markers such as allozymes, mitochondrial fragments or sequence data, and microsatellites or gene sequences from the nuclear genome have been used to characterize genetic diversity, define population structure, and investigate natural history, behavior, and evolution of these species across North America. We review the literature on the use of molecular markers in North American wild sheep research, discuss the role molecular markers may play in wild sheep research and management in the future, and provide a detailed list of mitochondrial and microsatellite markers that have been used successfully to elucidate various aspects of wild sheep ecology and conservation.

Key words: Molecular markers, wild sheep, North America, review.

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Population declines in the 1800's and early 1900's dramatically reduced North American wild sheep populations occurring south of Canada, extirpating numerous local populations throughout the range of the species in the United States. Fortunately, reintroduction and translocation efforts, beginning in the early 1920's, largely have reestablished wild sheep throughout much of their historical range (Toweill and Geist 1999, Krausman 2000). However, the process of restoring wild sheep herds has not been easy and the success rate for individual translocations over the past 80 years has been estimated to be only about 50% (Rowland and Schmidt 1981, Risenhoover et al. 1988). The most cited problems faced by wild sheep, especially newly established populations, include disease transmission from livestock (namely domestic sheep; Onderka and Wishart 1988, Jessup 1985), inbreeding (Berwick 1968, DeForge et al. 1979, DeForge et al. 1981, Hass 1989), and fragmentation of native habitats once connected by corridors (Risenhoover et al. 1988, Epps et al. 2006).

Over the past few decades, modern genetic tools involving a variety of molecular markers from the mitochondrial and nuclear genomes increasingly have been used to assist wildlife biologists in addressing many critical conservation and management issues facing wild sheep in North America (Ramey 1995, Gutiérrez-Espeleta et al. 2001, Coltman et al. 2003). "Molecular marker" is a generic term used to describe a variety of DNA attributes that can be used to infer differences in the genetic code at the molecular level. Over evolutionary timescales, mutations arise in the genetic code creating variations in the DNA sequence (Hedrick 2005). Mutation rates vary widely for different regions of DNA, thus offering opportunities to examine evolution at varying time scales by selectively examining molecular markers from regions of DNA with mutation rates pertinent to the time scale of interest (Avise 2004). By selectively utilizing molecular markers associated with evolutionary processes occurring at different rates, researchers can discern signatures of past mutational events that reveal information at the species, population, and even individual levels. Thus, geneticists are constantly striving to understand the forces acting to create genetic variation and to develop new molecular markers that more accurately quantify changes that have occurred in the DNA code.

Genetic diversity is a metric used to describe the amount of genetic variation revealed by a particular molecular marker at a specific level of biological resolution (e.g., species, population, individual). There is abundant theoretical (Lacy 1987, Lacy 1997) and empirical evidence (see review by Frankham 2005) supporting the concept that increased levels of genetic diversity are important for individual fitness and population persistence. The relative abundance or paucity of genetic diversity is of particular importance in the context of wild sheep conservation efforts, where populations created through reintroduction or translocation efforts often are small and may have been established using only a few individuals (Fitzsimmons et al. 1997, Ramey et al. 2000). The concern for wild sheep populations is driven by the fact that small populations are highly susceptible to genetic problems including founder effects (starting from few individuals), bottlenecks (passing through few reproducers), and genetic drift (loss of genetic diversity due to stochastic differences in reproductive success or survival among individuals; Frankham 2005). The negative impacts of reduced genetic diversity, especially for small populations, have been well documented (reviewed by O’Grady 2006).

Although molecular tools have been used to study questions in evolutionary biology for decades, the formal recognition that molecular markers can be used to address questions of a purely ecological nature is a remarkably recent phenomenon. For instance, *Molecular Ecology*, a periodical dedicated to publishing ecological investigations that used molecular markers, only printed its first edition in 1992. The increased use of molecular markers in ecological research has been fueled in part by technological and methodological advances that have improved automation and reduced costs associated with molecular genetic analyses and the discovery of new markers that can provide information content relevant to studies conducted at population and individual levels. For example, many early molecular markers used by geneticists were capable of quantifying genetic variation only at very coarse levels of resolution; useful only for investigating broad taxonomic relationships such as those occurring at the species or subspecies level. Alternatively, many molecular markers available today can be used for individual identification, allowing researchers to examine population attributes such as fine scale genetic structure and reproductive variance among individuals contributing genes to subsequent generations.

Our overall goal is to review the literature in which molecular markers have been used to study North American wild sheep: including, desert bighorns (*O. c. nelsoni*), California bighorns (*O. c. californiana*), Rocky Mountain bighorn (*O.*

c. canadensis), Dall's sheep (*O. dalli dalli*), and Stone's sheep (*O. d. stonei*). When reviewing the progressive integration of genetic markers into management and conservation issues pertaining to wild sheep, a logical approach is to follow the sequence of development for the genetic markers used in such investigations. Thus, we have structured our review into a temporal sequence beginning with research utilizing the structural conformation of proteins to infer underlying patterns of diversity in nuclear DNA, moving to studies utilizing variation in the DNA sequence of the mitochondrial genome, and finishing with research employing a variety of molecular markers based on DNA variation in the nuclear genome. We also discuss several potential growth areas for the future use of molecular markers in wild sheep research and management. Finally, we provide an extensive list of microsatellite and mitochondrial markers (along with their primer sequences, annealing temperatures, and approximate sizes) that have been used successfully in wild sheep research in North America (Appendix).

Proteins

Protein electrophoresis was one of the earliest molecular methods adopted for genetic evaluation of wildlife populations. Through the cellular processes of transcription and translation, DNA from specific nuclear genes acts as a blueprint by which amino acids are assembled into proteins. In the laboratory, small amounts of soft tissue (such as liver) are homogenized to create a mix of cellular contents containing the proteins of interest: usually an enzyme (an assembly of several proteins) that acts to carry out cellular processes. Homogenized tissue from different individuals are placed side-by-side in a semi-solid medium such as a thin sheet of starch or agarose-based gel. Enzymes constructed from even slightly different sequences of DNA will vary in their shape and/or charge and will migrate through the medium at different rates during electrophoresis. After a specified length of time, the electrophoresis is stopped and the medium is soaked in a chemical solution designed to visibly dye the particular enzyme of interest (called an allozyme). Recipes for staining more than a hundred allozymes are available in the literature. The process results in a pattern of dark bands corresponding to the different conformations of the protein produced from the individual's DNA. Because proteins examined using electrophoresis of allozymes are products of nuclear genes, the underlying DNA sequences for the genes are biparentally inherited and are expressed as genotypes representing the contribution of one allele from each parent. A genotype is constructed for each individual based on the number and configuration of bands, and the relative distance they migrated through the medium. Thus, separating and visualizing the protein products from an individual is an effective method to document the underlying genetic diversity which created the different protein forms.

Allozymes reflect the functional product of one or more genes and are subject to selection when the genetic code changes enough to result in a different protein conformation. It is generally held that the vast majority of gene-code mutations that could result in a change in enzyme conformation are deleterious. Thus, selection is thought to reduce variation in allozyme conformation. Mutations that do not alter the conformation of the enzyme, called silent mutations, are retained in the genome, but this genetic variation is undetectable using allozymes. Therefore, allozymes have a lower resolution than other molecular markers. For this reason, studies using allozymes are generally limited to identifying patterns of genetic variation at or above the population level. In wild sheep research, allozymes have been used to address questions related to 1) phylogeny and 2) the effect of reintroductions and harvest on genetic variation.

Phylogeny.--Sage and Wolff (1986) used allozymes to substantiate the hypothesis that glacial events reduced species wide genetic variability in Dall's sheep and other North American mammals. Jessup and Ramey (1995) also used allozymes to test the validity of sub-specific boundaries for bighorn sheep established from morphological characters. In a meta-analysis of studies using allozymes, Tiedemann et al. (1996) found that the proportion of polymorphic loci and the ratio of heterozygosity to the proportion of polymorphic loci within species were predicted by body size, feeding type (carnivory vs. herbivory), mating system, and the geographic distribution of the mammalian species investigated. These papers illustrate the utility of allozymes for addressing questions at the scale of subspecies or higher.

Reintroductions and harvest.--Persistence of bighorn sheep herds following reintroduction is a major concern in the ongoing effort to repopulate vacant sheep habitats (Berger 1990, Wehausen 1999). Small numbers of founding individuals (i.e., mean=15.2, SD=10.6 for 611 translocations of Rocky Mountain bighorn sheep calculated from Ramey 1993) involved in reintroductions coupled with low success rates for establishing new herds (Risenhoover 1988) has raised concerns about the role of founder effects and genetic bottlenecks in the persistence of these new populations. Fitzsimmons et al. (1997) used allozymes to document reduced heterozygosity relative to source populations in 3 of 4 reintroduced herds in Wyoming. Ramey et al. (2000) used allozymes (and other molecular markers) to investigate the possibility of a genetic bottleneck following reintroduction of bighorn sheep to the Badlands National Park. Luikart et al. (1998) used allozyme data from mountain sheep to test different methods for detecting genetic bottlenecks within populations. In a study documenting a positive correlation between allozyme heterozygosity and horn size in bighorn rams, Fitzsimmons et al. (1995) described the potential for loss of heterozygosity in small populations where large horned rams, the demographic group that was most heterozygous, are selectively harvested. In these studies, genetic data derived from allozymes were useful in describing genetic changes resulting from management activities, but also for informing potential management strategies for the remediation of those changes. Although analysis of allozymes using protein electrophoresis is a powerful tool for describing genetic variation, advances in technology and molecular methods have greatly reduced the use of this technique.

Mitochondrial DNA

Mitochondria are the source of energy for animal cells. They are located in the cell's cytoplasm separate from the nucleus and contain their own circular piece of DNA – almost all of which is functional (as opposed to non-coding). Because mitochondria are located in the cytoplasm and replicate via their own DNA, the only way for an offspring to acquire mitochondria is via the egg supplied by their mother. Sperm from the father usually contain little else besides nuclear DNA. Therefore, molecular markers based on mitochondrial DNA are maternally inherited, as opposed to the biparental inheritance that occurs with nuclear molecular markers.

Because of maternal inheritance and the highly conserved nature of many of the genes located in the mitochondrial genome, mitochondrial markers often can be used to resolve relationships spanning very long time periods and are relevant when considering questions of phylogenetic and taxonomic importance. In wild sheep research, mitochondrial markers have been used to 1) identify subspecies and other taxonomic relationships and 2) to describe genetically meaningful management units to facilitate conservation efforts.

Taxonomic relationships.--Describing taxonomic boundaries is important for mountain sheep conservation because conservation funding and management efforts usually are allocated relative to taxonomic designations. Ramey (1995), in the first published use of mitochondrial DNA markers in the wild sheep literature, questioned the validity of subspecific boundaries based on morphological data as established by Cowan (1940). Additionally, his results suggested strict philopatry among bighorn ewes as evidenced by haplotype differences between proximal habitats. Loehr et al. (2006), using DNA sequence data from the mitochondrial genome, found patterns of mitochondrial variation indicating a previously unsuspected glacial refuge for Dall's sheep in British Columbia, Canada, which they hypothesized may have been the source population from which Dall's sheep recolonized available habitats after the ice sheets retreated. In another recent paper, Latch et al. (2006) used mitochondrial DNA sequence data to assign a naturally recolonizing herd to one of 2 subspecies in Arizona and recommended caution in translocation efforts to preserve subspecific integrity. Finally, Groves and Shields (1996) sequenced mitochondrial DNA from 9 species of wild sheep to develop a molecular phylogeny for the subfamily of all North American wild sheep: Caprinae.

Describing genetically meaningful management units.--Mitochondrial markers are powerful tools for detecting relationships at the subspecies level, but also can be useful at the population level when enough sequence diversity exists. Bleich et al. (1996) combined Ramey's (1995) dataset with an analysis of historic and current sheep distributions in California to inform conservation efforts and make recommendations on how management efforts could improve connectivity of current wild sheep metapopulation in California. Boyce et al. (1999) used data from mitochondrial markers to demonstrate female philopatry in desert bighorn sheep and contended that conservation efforts in the southwestern United States should focus on retaining unique haplotypes and promoting connectivity among populations where evidence supports the existence of historical gene flow. Luikart and Allendorf (1996) analyzed mitochondrial DNA variation throughout the range of Rocky Mountain bighorn sheep and described the frequency and distribution of haplotypes within and among populations of this subspecies across their entire range. They suggested that observed patterns resulted either from fragmentation of a previously undivided (in evolutionary time) metapopulation, or from current rates of gene flow high enough to prevent fixation of haplotypes within populations but also low enough to allow haplotype frequencies to differ among populations.

Nuclear DNA

Nuclear DNA is biparentally inherited and molecular markers based on nuclear DNA from specific gene coding or non-coding regions are expected to segregate in a mendellion fashion. Although several types of molecular markers from the nuclear genome are available, short, tandem, repetitive regions within the nuclear genome known as microsatellites currently are the most popular molecular marker for ecological studies (Avise 2004). Microsatellites are relatively small (<500 base pairs), non-coding portions of the nuclear genome composed of a series of short repeats in the base pair sequence. Microsatellites were first described in the late 1980's (Jarne and Lagoda 1996), but it wasn't until PCR methods became automated that their utility as a molecular marker was fully realized.

Because microsatellites reside in non-coding regions of the nuclear genome, are biparentally inherited, and segregate in a mendellion fashion, each individual receives 1 copy of the microsatellite repeat (called an allele) from each parent for a total of 2 alleles. These alleles are specific to a particular microsatellite and occupy a particular location (called a locus) in the genome. Therefore, an individual will have 2 alleles at every microsatellite locus. The genotype at each microsatellite locus may be composed of two alleles of the same length (a homozygous genotype) or two alleles of different lengths (a heterozygous genotype). It is the physical structure of microsatellites that makes them useful to molecular ecologists: microsatellites have a much higher rate of mutation (10^{-3}-10^{-4}; Dietrich et al. 1992, Weissenbach et al. 1992) than other portions of the genome. The high mutation rate is likely results from their repetitive sequence causing mistakes such as slippage and unequal crossing over during DNA replication and meiosis, respectively. The relatively high mutation rate of microsatellite alleles results in large amounts of polymorphism at most microsatellite loci (i.e., lots of alleles of different lengths). It isn't atypical for a given microsatellite locus to exhibit >20 alleles in a single population. When large numbers of microsatellite loci (plural) are used to evaluate genetic parameters of individuals within and among populations—a typical population genetics study uses between a few and 20 loci—microsatellites provide incredibly powerful resolution for quantifying genetic diversity.

Microsatellites are ideal molecular markers to identify patterns of genetic variation within and among populations, and have been applied to numerous questions pertaining to wild sheep management such as: 1) identification of subspecies boundaries; 2) conservation of established, reintroduced, and harvested populations; 3) investigation of natural history traits that are difficult to measure by traditional means; and 4) characterization of genetic variation associated with disease resistance genes. As a consequence of the number of markers available for wild sheep and the ease of access to genetic samples, several geneticists also have used data sets from wild sheep populations to address theoretical aspects of microsatellite evolution; these studies only will be cited as their results are beyond the scope of this review (Forbes et al. 1995, Forbes and Hogg 1999, Kalinowski and Hedrick 2001).

Subspecies boundaries.--Accurate classification of subspecies is an imperative for the conservation of wild sheep because conservation funding and efforts often are allocated along taxonomic lines. Worley et al. (2004) described concordance between genetic classification of Stone's and Dall's sheep using microsatellites and the supported current classification as separate subspecies derived from morphological characters. Conversely, Gutiérrez-Espeleta et al. (1998) and Gutiérrez-Espeleta et al. (2000) did not find evidence to substantiate current boundaries for 3 putative subspecies of desert sheep (Mexican (*O. c. mexicana*), desert, and Peninsular (*O. c. cremnobates*) bighorn sheep), suggesting that subspecies assignments based on morphology in desert sheep were inadequate.

Conserving established, reintroduced, and harvested populations.--Identifying factors that decrease the potential for interpopulation gene flow is of singular importance in the conservation of mountain sheep populations. Decreased gene flow is problematic especially for mountain sheep because the widely dispersed, insular habitats they now occupy strongly suggests they occur in a metapopulation-like structure (Levins 1970, Bleich et al. 1996) where movement between relatively small, isolated herds is imperative to avoid loss of genetic diversity due to genetic drift and inbreeding. Drift and inbreeding can combine in small populations to reduce fitness in the short term (Lacy 1997, Keller and Waller 2002) and theoretically reduce evolutionary potential in the long term (Lacy 1997). Epps et al. (2005) used a combination of microsatellites and mitochondrial markers to infer greatly reduced gene flow between desert bighorn populations bisected by human-constructed barriers (e.g., major highways, urban development, etc.). Epps et al. (2006) also used microsatellites to further describe the importance of habitat connectivity in maintaining genetic diversity among 25 desert bighorn populations in the face of climate change.

While genetic analyses using molecular markers can inform ongoing conservation efforts for established populations of wild sheep, such analyses also may contribute to efforts targeted at repopulating vacant mountain sheep habitat through reintroductions. Reintroduction of wild sheep throughout historic ranges is an ongoing effort, and to be most effective, source populations with adequate levels of genetic diversity must be identified to avoid genetic complications in newly established populations. Hedrick et al. (2001) investigated the suitability of the Tiburon Island population of desert bighorn sheep for continued use as a source population in reintroduction efforts. The population was founded using 20 individuals from the mainland in 1975 and apparently increased in size rapidly. However, results of genetic analysis suggest the Tiburon Island population suffers from low genetic diversity, likely due to a founder effect, and that it should be used as a source herd for reintroductions only in combination with another herd containing greater genetic diversity (Hedrick et al. 2001). In another study examining suitability of populations for use as sources for wild sheep reintroductions, Boyce and Ostermann (2002) described genetic variation in two populations of desert bighorn sheep and determined one was inadequate as a source due to low genetic diversity. These investigations are exemplary of conservation efforts informed using molecular markers. Establishing new populations from genetically depauperate stock can only exacerbate the potential for genetic problems (e.g., drift and inbreeding) in reintroduced herds.

Whittaker et al. (2004) examined genetic diversity in 5 California bighorn sheep herds established largely by within-state translocation in Oregon and compared them to 1 herd in Nevada, established from putatively more diverse stock. They reported extremely low levels of genetic diversity for the Oregon herds compared with levels exhibited within the Nevada herd and proposed the use of provisional, experimental efforts to increase genetic diversity in 2 of the Oregon herds through genetic management (defined as management action intended to increase genetic diversity; Frankham et al. 2002) via supplementation of more genetically diverse individuals into those populations. In a comprehensive assessment of the potential for genetic management to benefit Rocky Mountain bighorn sheep in the National Bison Range in Montana, USA, Hogg et al. (2006) analyzed a 25-year, pedigree-based data set supplemented using data from a suite of microsatellites. They documented increased fitness for outbred individuals measured by increased adult reproductive success, survival, and many other life-history traits, suggesting that genetic management efforts for wild sheep may be a viable means to enhance population persistence (Hogg et al. 2006).

Finally, Coltman et al. (2003) described phenotypic effects of ram harvest on a population of bighorn sheep inhabiting Ram Mountain in Alberta, Canada. They demonstrated, using a quantitative genetics approach (discussed in the next section), that over time selective harvest of rams with the highest genetic quality for traits such as weight and horn growth resulted in a population level decline in those traits (Coltman et al. 2003). This study exemplifies the power of studies using molecular markers, although, in most circumstances, the population under investigation will not have the resolution of demographic data available from Ram Mountain.

Investigating natural history traits.--Some aspects of natural history are difficult or impossible to investigate without using molecular markers. For example, in avian species extra-pair paternity was believed a rarity before parentage analysis (based on data from molecular markers) revealed it to be relatively common (Birkhead and Møller 1992). To investigate mating behavior in 2 populations of Rocky Mountain bighorn sheep, Hogg and Forbes (1997) used microsatellite data to determine paternity of 142 lambs. Examination of microsatellite paternity assignments in conjunction with extensive field observations revealed a surprisingly high success rate (range, 28% to 47%) for the alternative mating tactic called coursing, suggesting a high cost (as exhibited by defensive lapses) associated with the traditional mating tactic called defending (Hogg and Forbes 1997). In a study that similarly used microsatellites for paternity assignment coupled with extensive behavioral observations, Coltman et al. (2002) documented age-specific differences in mating success in the Ram Mountain herd of bighorn sheep. They suggested selective pressures might change with age, with younger rams increasing reproductive fitness by participating in alternative mating tactics while older rams acquire increased reproductive fitness by having larger horns (Coltman et al. 2002). These investigations of wild sheep natural history demonstrate the utility of microsatellites: useful not only in population analyses, but also in analyses focusing in scale down to the individual.

Disease resistance.—Disease epidemics resulting from contact with domestic sheep are cited as a major cause for declines in North American wild sheep populations and continue to be problematic when domestic sheep occur in areas of bighorn sheep reintroductions (Buechner 1960, Onderka and Wishart 1988, Jessup 1985). While much work has focused on the diseases affecting wild sheep from a disease pathology perspective (Bunch et al. 1999), molecular markers also have provided insights into the susceptibility of wild sheep to disease. For example, Luikart et al. (2008a) demonstrated a negative relationship between heterozygosity and parasite load in a population of bighorn sheep that had undergone a recent bottleneck.

The major histocompatability complex (MHC) is a linked set of genes important for immune response in mammals.

It functions to identify pathogens and mobilizes the immune system to destroy them. MHC regions of the genome are highly variable and thought to confer greater disease resistance (e.g., in a functional sense, different sequences can recognize different pathogens; Hedrick 1994). Variability of disease resistance genes may be particularly important in the context of wild sheep conservation where small founding population sizes and reduced connectivity limit overall genetic variation in many populations.

A variety of techniques have been used for analysis of nuclear DNA involved in immune function in wild sheep, not all involving microsatellites. Although microsatellites are non-coding portions of DNA, they can be useful if they are located within or in close proximity to the gene or genes of interest, in this case the MHC. Molecular markers located close to (i.e., linked to) areas under selection will “hitchhike”; acting as though they too are under selection (Maynard Smith and Haigh 1974, Slatkin 1995). Therefore, microsatellites, normally thought of as neutral markers, when located next to sections of DNA under selection (such as MHC) should behave as a proxy for the variation expected in those genes under selection.

Boyce et al. (1997) used a MHC linked microsatellite, 2 non-linked microsatellite loci, and a restriction fragment length polymorphism (RFLP) analysis (an older form of molecular marker with low levels of resolution) of a MHC gene to investigate patterns of variation within the MHC relative to that observed in the 2 neutral microsatellites. They found no evidence for variation at the MHC gene beyond that observed in the 2 neutral microsatellite loci and concluded that strong selection had not been acting on the MHC gene in bighorn sheep (Boyce et al. 1997). However, unlike the more modern technique of directly sequencing genes—a process that identifies the underlying base-by-base code of DNA—analysis of RFLPs revealed only a small portion of the genetic variation present at the MHC gene.

Gutiérrez-Espeleta et al. (2001) attempted to address the shortcomings of Boyce et al. (1997) by sequencing all alleles identified in a region of the MHC similar to that investigated by Boyce et al. (1997) using a technique known as single strand conformational polymorphism analysis (SSCP) to identify alleles. SSCP analysis is used to separate single strand sequences of DNA that differ in their molecular conformation much like protein electrophoresis separates different protein conformations. The method is useful because sequencing only unique alleles identified through SSCP confers a cost savings relative to sequencing every individual. They found high levels of variation within the MHC and discounted the hypothesis that population declines of bighorn sheep in the United States were related to low disease resistance resulting from low MHC variation (Gutiérrez-Espeleta et al. 2001).

Finally, Worley et al. (2006) analyzed DNA sequence data from three separate immune-functioning regions and a suite of neutral microsatellites in an attempt to detect balancing selection on immunity genes. After accounting for variation observed in their suite of neutral microsatellites, they could not detect effects of selection on the immune-functioning genes and cautioned against interpretations pertaining to the magnitude of selection in maintaining levels of MHC variation within populations without the context provided by simultaneously analyzing neutral markers from the same individuals (Worley et al. 2006).

The Future of Molecular Markers in Wild Sheep Research

Research using molecular markers already has affected conservation and management of wild sheep in North America. The potential for future contributions of molecular genetics to wild sheep conservation and management will only increase as molecular methods become more accessible, cost effective, and practical. Several areas of molecular ecology that seem particularly ripe with applications for bighorn sheep management are noninvasive genetic sampling, quantitative genetics, and landscape genetics. Noninvasive genetic sampling (NGS) is the process of recovering DNA from animals without capturing, handling, or even necessarily observing them (Waits and Paetkau 2005). Typical sources of DNA used in wildlife studies involving NGS are plucked hair, feathers, and feces as opposed to the tissue or blood typically collected. The growing use of NGS to obtain DNA from rare or difficult to capture species has hastened development of effective sample storage (i.e., Frantzen et al. 1998, Piggott and Taylor 2003), extraction, and data screening (i.e., Roon et al. 2005) techniques to overcome two drawbacks associated with the use of NGS: the amount and quality of DNA generally is lower for samples collected noninvasively than for conventional samples. The promise of adapting NGS for collection of DNA for genetic analyses of wild sheep seems high. Wehausen et al. (2004) determined an effective method for extracting DNA from wild sheep fecal pellets and Luikart et al. (2008b) documented low error rates when using 18 microsatellites to genotype fecal samples from bighorn sheep. Effective extraction methods and lower error rates should allow NGS to become more prominent in wild sheep genetics research.

Quantitative genetics is a field in which researchers attempt to determine underlying contributions of specific genes or gene regions to morphological traits that vary quantitatively (i.e., height, weight, number of flowers, etc.). Previously this field was the dominion of animal breeders where complete pedigrees facilitated the determination of trait inheritance, or heritabilities. The primary application of quantitative genetics to animal breeding was for determining the potential for artificial selection (i.e., breeding programs) to produce a desired change in a specific trait. With the advent of molecular markers, complete pedigrees can be partially assembled via parentage analysis in wild populations. With data available from wild populations, researchers may be able to apply quantitative genetic methods to document the effects of natural selection (as opposed to artificial selection) on traits of interest. Pelletier et al. (2007) used data from the Ram Mountain bighorn sheep population where complete pedigrees were known from intense observation and paternity analysis was facilitated by microsatellites to address the evolutionary significance of body mass plasticity. Using this approach they found higher rates of recruitment among ewes with greater seasonal mass changes, suggesting selection favoring body mass plasticity (Pelletier et al. 2007). This is an example of classic quantitative genetics approach applied to a wild population of bighorn sheep with unusual levels of data. Where quantitative genetic methods likely exhibit the most potential to impact wild sheep management is in construction of marker-based estimates of heritability: estimates that do not require complete pedigrees. Coltman (2005) addressed this possibility with a large (n = 32) suite of microsatellites and was unable to produce estimates consistent with those based on pedigrees. However, rigorous marker-based estimates of heritability may yet be possible as techniques such as genome mapping facilitate the construction of libraries of single nucleotide polymorphisms (SNP's; markers based on variants at a single nucleotide position). Some researchers feel SNP's have the potential to become the next molecular marker of choice for such applications in ecological studies (i.e., Seddon et al. 2005) because of their tractability for high-throughput analyses. This may be especially true for mountain sheep because of the relative ease with which molecular markers can be co-opted from those developed for domestic sheep. SNP's offer exciting possibilities for quantitative genetics and some ecological applications, but their utility may be limited in population genetics (Glaubitz et al. 2003, Schlötterer 2004), at least with current technologies and analytical methods.

Landscape genetics is the combination of landscape ecology and population genetics. Its application lies in the combination of spatially explicit biological and behavioral information with molecular data for the purpose of elucidating the relationship between biological and behavioral processes and genetic parameter estimates. Traditional approaches to population genetics require *a priori* identification of populations, whereas landscape genetics allows researchers to infer spatial genetic patterns using data from many individuals over large spatial scales without assigning preexisting population membership. Epps et al. (2007) applied landscape genetics to populations of desert bighorn sheep to document landscape features associated with gene flow between populations. Their analysis identified landscape features associated with corridors for and barriers to gene flow among desert bighorn populations and thus, can facilitate future efforts to maximize population connectivity. As new analytical methods are developed to facilitate landscape level analyses of molecular data, this field undoubtedly will increase its contributions to wild sheep conservation and management.

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Appendix. Microsatellite (nDNA) and mitochondrial (mtDNA) markers used in wild sheep research in North America. Primer sequences, annealing temperature, sizes, reference in which they were first used for wild sheep and the citation for their original description (if applicable) are listed. Microsatellite information is from the original description unless specified. Information for microsatellite TCRBV624 (Luikart et al. 2008b) was unavailable.

Locus	Forward Primer	Reverse Primer	T_A	Allele (bp) Min	Allele (bp) Max	Reference	Original Description
nDNA							
ADCYAP1	CCAGACGCCGACT TCGCCCGAGG	GCCTGAAGTCCACT GAGAAGAAAGGAG	60	85	115	Hogg et al. 2006	Wood and Phua 1993
BM1225[1]	TTTCTCAACAGAG GTGTCCAC	ACCCCTATCACCAT GCTCTG	54	245	259	Coltman et al. 2002	Bishop et al. 1994
BM1818[1]	AGCTGGGAATATA ACCAAAGG	AGTGCTTTCAAGGT CCATGC	54	257	273	Coltman et al. 2002	Bishop et al. 1994
BM203	GGGTGTGACATTTT GTTCCC	CTGCTCGCCACTAG TCCTTC	58	217	247	Boyce and Ostermann 2002	Bishop et al. 1994
BM4025	TCGAATGAACTTTT TTGGCC	CACTGACTATCTGA CTTTGGGC	50	140	230	Coltman et al. 2003	Bishop et al. 1994
BM4107	AGCCCCTGCTATTG TGTGAG	ATAGGCTTTGCATT GTTCAGG	55	144	178	Boyce and Ostermann 2002	Bishop et al. 1994
BM4505[1]	TTATCTTGGCTTCTG GGTGC	ATCTTCACTTGGGA TGCAGG	54	265	277	Coltman et al. 2002	Bishop et al. 1994
BM4513[1]	GCGCAAGTTTCCTC ATGC	GCGCAAGTTTCCTC ATGC	54	139	153	Coltman et al. 2002	Bishop et al. 1994
BM6506	GCACGTGGTAAAG AGATGGC	AGCAACTTGAGCA TGGCAC	58	199	217	Boyce and Ostermann 2002	Bishop et al. 1994
BM848[1]	TGGTTGGAAGGAA AACTTGG	CCTCTGCTCCTCAA GACAC	54	219	237	Coltman et al. 2002	Bishop et al. 1994
BMC1009	GCACCAGCAGAGA	ACCGGCTATTGTCC	58	274	282	Boyce and	Bishop et

Locus	Forward Primer	Reverse Primer	T_A	Allele (bp) Min	Max	Reference	Original Description
	GGACATT	ATCTTG				Ostermann 2002	al. 1994
BMC1222[1]	CCAATTTTGCAGATAAGAAAACA	CCTGAGTGTTCCTCCTGAGT	54	286	292	Coltman et al. 2002	de Gortari et al. 1997
CELB9[2]	TCACCTTAATATGGAGGCAGAAATA	GATGCATTTCAGATTATGGCTTATC	63	235	237	Boyce and Ostermann 2002	Tate 1997
CELJP15[2]	GGAAATACCTTATCTTTCATTCTTGACTGTGG	CCTTCTTCTCATTGCTAACTTATATTAAATATCC	63	151	157	Boyce and Ostermann 2002	J. Permberton, unpub. data
CELJP23	GAAAATCCAAGCGACAAAGG	CCGCAGAACAACTAAGCCCAAG	-	-	-	Boyce and Ostermann 2002	J. Permberton, unpub. data
DRB3	GAGAGTTTCACTGTGCAG	CGCGAATTCCCAGAGTGAGTGAAGTATCT	50	159	219	Boyce and Ostermann 2002	Ellegren et al. 1993
DS52 (ETH152)	TACTCGTAGGGCAGGCTGCCTG	GAGACCTCAGGGTTGGTGATCAG	55	190	210	Gutierrez-Espeleta et al. 1998	Steffen et al. 1993
GLYCAM1	CCTCGGTCCCAAGCTCCCTAT	GCTTGAGTCTGCCTTCTCTGGCT	58	165	215	Luikart et al. 2008	Maddox 2002
IRBP	GTATGATCACCTTCTATGCTTCC	CCCTAAATACTACCATCTAGAAG	55-65	286	290	Boyce and Ostermann 2002	Moore et al. 1992
KERA	GTACTGAACCAAATAGTACAGCAGCCAAT	GCATGGCAACCCACTCCAGTAT	63	172	196	Luikart et al. 2008a	J. F. Maddox, unpub. data
KRT2	GCCTGTAGGCGTGAGGGTTTT	AAGGGCCAAGAGTCATTCACAT	55	135	137	Luikart et al. 2008a	McLaren et al. 1997
LIF	CTGCAGGGCAAGTGATTGGATT	TCAGCCCTTGGGCGTCAGT	58	108	122	Luikart et al. 2008a	Kato et al. 1996
MAF209	TCATGCACTTAAGTATGTAGGATGCTG	GATCACAAAAAGTTGGATACAACCGTGG	63	109	135	Hedrick et al. 2001	Buchanan & Crawford 1992a
MAF33	GATCTTTGTTTCAATCTATTCCAATTTC	GATCATCTGAGTGTGAGTATATACAG	60	121	141	Hedrick et al. 2001	Buchanan & Crawford 1992b
MAF36	CATATACCTGGGAGGAATGCATTACG	TTGCAAAAGTTGGACACAATTGAGC	63	99	125	Hedrick et al. 2001	Swarbrick et al. 1991a
MAF48	GGAAACCAAAGCCACTTTTCAGATGC	AGACGTGACTGAGCAACTAAGTACG	50	122	138	Hedrick et al. 2001	Buchanan et al. 1991
MAF64	CTCATGGAATCAGACAAAAGGTAGG	AATAGACCATTCAGAGAAACGTTGAC	63	109	141	Coltman et al. 2003	Swarbrick et al. 1991b
MAF65	AAAGGCCAGAGTATGCAATTAGGAG	CCACTCCTCCTGAGAATATAACATG	60	123	135	Hedrick et al. 2001	Buchanan et al. 1992
MAF92	TAGAATGTCATGTTCTCAGCATTCCC	AACCCATGAATCATCTCTAACTAACTC	52	122	134	Coltman et al. 2003	Crawford et al. 1991
MCM527	GTCCATTGCCTCAAATCAATTC	AAACCACTTGACTACTCCCCAA	50	165	175	Coltman et al. 2003	Hulme et al. 1995
MMP9	CTTGCCTTCTCATGCTGGGACT	GTGAGGATAGCACTTGGTCTGGCT	58	189	205	Luikart et al. 2008a	Adamson et al. 2000
OarAE16[1]	CTTTTTAATGGCTC	CATCAGAGGAATGG	54	82	104	Coltman	Penty et al.

Locus	Forward Primer	Reverse Primer	T_A	Allele (bp) Min	Max	Reference	Original Description
	GGTAATATTCCTC	GTGAAGACGTGG				et al. 2002	1993
OarCP20	GATCCCCTGGAGG AGGAAACGG	GGCATTTCATGGCT TTAGCAGG	55	71	87	Hogg et al. 2006	Ede et al. 1995
OarCP26[1]	GGCCTAACAGAAT TCAGATGATGTTGC	GTCACCATACTGA CGGCTGGTTCC	54	131	163	Coltman et al. 2002	Ede et al. 1995
OarFCB11	GGCCTGAACTCAC AAGTTGATATATCT ATCAC	GCAAGCAGGTTCT TTACCACTAGCACC	63	121	143	Hedrick et al. 2001	Buchanan & Crawford 1993
OarFCB128	CAGCTGAGCAACTA AGACATACATGCG	ATTAAAGCATCTTC TCTTTATTTCCTCGC	60	99	131	Hedrick et al. 2001	Buchanan & Crawford 1993
OarFCB193	TTCATCTCAGACTG GGATTCAGAAAGG C	GCTTGGAAATAAC CCTCCTGCATCCC	65	104	118	Boyce and Ostermann 2002	Buchanan & Crawford 1993
OarFCB20	AAATGTGTTTAAGA TTCCATACAGTG	GGAAAACCCCCAT ATATACCTATAC	55	92	112	Hogg et al. 2006	Buchanan et al. 1994
OarFCB226	CTATATGTTGCCTTT CCCTTCCTGC	GTGAGTCCCATAG AGCATAAGCTC	63	119	153	Hogg et al. 2006	Buchanan et al. 1994
OarFCB266[1]	GGCTTTTCCACTAC GAAATGTATCCTC AC	GCTTGGAAATAACCC TCCTGCATCCC	54	88	100	Coltman et al. 2002	Buchanan & Crawford 1993
OarFCB304	CCCTAGGAGCTTTC AATAAAGAATCGG	CGCTGCTGTCAACTG GGTCAGGG	63	150	188	Hedrick et al. 2001	Buchanan & Crawford 1993
OarHH47	TTTATTGACAAACT CTCTTCCTAACTCC ACC	GTAGTTATTTAAAAA AATATCATACCTCTT AAGG	60	124	148	Hogg et al. 2006	Henry et al. 1993
OarHH62	TAATGAGTCAAACA CTACTGAGAGAC	AATATATAAAGAGAA AAGCTGGGGTGCC	62	114	138	Hogg et al. 2006	Ede et al. 1994

Locus	Forward Primer	Reverse Primer	T_A	Allele (bp) Min	Max	Reference	Original Description
OLADRBps	CTGCCAATGCAGAG ACACAAGA	GTCTGTCTCCTGTCTT GTCATC	62	273	295	Luikart et al. 2008a	Blattman & Beh 1992
RT9[1]	TGAAGTTTAATTTC CACTCT	CAGTCACTTTCATCC CACAT	54	118	140	Coltman et al. 2002	Wilson et al. 1997
SOMAb	GTGCTCTAATCTTTT CTGGTACCAGG	CCTCCCCAAATCAAT TACATTTTCTC	62	96	120	Luikart et al. 2008a	Lucy et al. 1998
TCRG4	AGAACAAATATCTG GAATGGTGATGCT	TGCTATAGGATGACA TGAAGGCAAAT	58	170	176	Luikart et al. 2008a	Diez-Tascón et al. 2002
TGLA116	GCACAGTAATAAGA GTGATGGCAGA	TGGAGAAGATTTGGC TGTGTACCCA	52	80	109	Ramey et al. 2000	Georges and Massey 1992
TGLA122[1]	CCCTCCTCCAGGTA AATCAGC	AATCACATGGCAAAT AAGTACATAC	54	134	150	Coltman et al. 2002	Georges and Massey 1992
TGLA126[1]	CTAATTTAGAATGA GAGAGGCTTCT	TTGGTCTCTATTCTCT GAATATTCC	54	116	124	Coltman et al. 2002	Georges and Massey 1992
TGLA137[2]	GTTGACTTGTTAAT CACTGACAGCC	CCTTAGACACACGTG AAGTCCAC	55	124	136	Ramey et al. 2000	Georges and Massey 1992

TGLA188	TCATCTGCCCTATTTTTTAATTCCAAACCTA	GATCTTTGCAAATGGTATTTCTGATAAGGGGTTAAT	-	-	-	Ramey et al. 2000	Georges and Massey 1992
TGLA387[1]	CAAAGTCTTAGAATAAACTGGATGG	GTCCCTTTGTTTACTTTGATAAAAC	54	134	154	Coltman et al. 2002	Georges and Massey 1992
TGLA427	GCCACCTTCTCATCAACAAATCCATGCAAGCGTTCTCTGCATTATGCCGCTTTTCACTCACAAGTTTTATTTTTCACTAGAGAAGCACTTAGCCCAAATAAGACAATTTGCTGTGGAAC	CCTCACTGCAGTGCTCCTATTATGATAATGGGAATTTATGCACATGAGTATTT	-	-	-	Ramey et al 2000	Georges and Massey 1992
TGLA94	CATCAAAACAGTGAAGGATGATTGCCAG	CGAATCTCTTCTAGGGATTGAGACTGTG	52	125	135	Boyce and Ostermann 2002	Georges and Massey 1992

Locus	Forward Primer	Reverse Primer	Region	Size (bp)	Reference
mtDNA					
L14724/ H15149	CGAAGCTTGATATGAAAAACCATCGTTG	AAACTGCAGCCCCTCAGAATGATATTTGTCCTA	Cyt. B	969-983	Groves and Shields 1996
L14841/ H15149	AAAAAGCTTCCATCCAACATCTCAGCATGATGAAA	AAACTGCAGCCCCTCAGAATGATATTTGTCCTA	Cyt. B		Groves and Shields 1996
L15513/ H15915	CTAGGAGACCCTGACAACTA	AACTGCAGTCATCTCCGGTTTACAAGAC	Cyt. B		Groves and Shields 1996
L15069/ H15338	GCCTATACTACGGATCATACAC	CTGTTTCGTCCACCAAGAG	Cyt. B		Groves and Shields 1996
L15275/ H15608	GACAAAGCATCCCTCACCCG	TAGGCTAGAACTCCGCCTAG	Cyt. B		Groves and Shields 1996

Locus	Forward Primer	Reverse Primer	Region	Size (bp)	Reference
mtDNA					
-	AACCTCCCTAAGACTCAAGG	GTGTGAATTTGAGTATTGAGG	Control	515	Boyce et al. 1999
-	ACTTCCAAACATATAACAC	AGGATACGCATGTTGACTAG	Control		Boyce et al. 1999
-	TGGACATACGTAATTAATGG	GTAGACTCATCTAGGCAT	Control		Boyce et al. 1999
L15712/ BETH	AACCTCCCTAAGACTCAAGG	ATGGCCCTGAAGAAAGAACC	Control	515	Epps et al. 2005
L15999/ H16498	ACCATCAACACCCAAAGCTGA	CCTGAAGTAGGAACCAGATG	Control	604	Loehr et al. 2006

[1]Annealing temperature and allele sizes from wild sheep reference
[2]Annealing temperature and allele sizes as determined in the Rhodes Lab for a test set of 30 California bighorn sheep

Multi-state and Province Bighorn Sheep (*Ovis canadensis*) Genetics Library: Potential Uses and Partnerships

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Abstract: During the late 1990's and early 2000's , researchers at the Idaho Department of Fish & Game's Wildlife Health Laboratory requested and received large numbers of bighorn sheep blood and/or tissue samples from 13 states and provinces in order to identify and assess natural disease resistance (N-ramp) genetics. DNA was extracted from samples within different species and sub-species of bighorn and thin horn sheep throughout North America. Following the conclusion of the N-ramp project, the intended use of this DNA genetics library was to assist agencies and researchers in furthering the understanding of bighorn sheep genetics. The collection currently includes over 1300 bighorn sheep DNA samples with the following composition: 55% Rocky Mountain bighorn sheep, 21% Desert bighorn sheep, 21% California bighorn sheep, 2% Stone sheep and 1% peninsular bighorn sheep subspecies. The DNA library is available for interested agencies and non-governmental groups for comparative genetics studies, forensic services, and population genetics, including: bottle-necking, founder effect. The size and scope of this collection make it ideal for state, federal, provincial and non-governmental agencies to use in support of ongoing research or as a starting point for development of new bighorn sheep genetics research.

BIENN. SYMP.NORTH. WILD SHEEP AND GOAT COUNC. 16:270

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Preliminary Evaluation of the Genetic Structure of Dall's Sheep Populations in Wrangell-St. Elias National Park and Preserve, Alaska

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Abstract: Currently little is known of the genetic structure of Dall's sheep (*Ovis dalli dalli*) populations within contiguous mountain ranges, such as the Wrangell and Chugach Mountains of Wrangell-St. Elias National Park and Preserve (WRST). Broad scale evaluations of sheep genetics are currently limited by the great expense of tissue acquisition from live sheep or the availability of archived samples. Furthermore, finer scale analyses have not been conducted on Dall's sheep. We used DNA extracted from tissue samples collected form 30 hunter-killed rams to test a set of 15 microsatellite loci used in bighorn sheep (*O. canadensis*), and to screen and develop markers to access sequence data from three mitochondrial DNA genes, including the control region. We used these markers to test the feasibility of using DNA extracted from fresh feces collected in late summer from 47 adult male and female sheep inhabiting the Chitina River drainage of WRST, an area covering approximately 20,000 km^2. All markers were assessed for genotyping or sequencing error rates in both tissue and feces. Preliminary laboratory and statistical analyses suggest we have developed a suite of markers sufficiently polymorphic and reliable for use in landscape genetics studies using fecal DNA. We will use these markers during 2008-2009 to assess levels of genetic diversity and gene flow within the sheep population, and to determine the level and spatial scale of population differentiation. Increased understanding of the presence and extent of genetic partitioning of the sheep population over a large montane landscape will provide useful assessments of natural patterns of genetic variability in Dall's sheep and the appropriate geographic scales for population monitoring and harvest management. In addition, results from analyses will provide baseline data for long-term monitoring and for comparison to sheep populations in other areas.

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