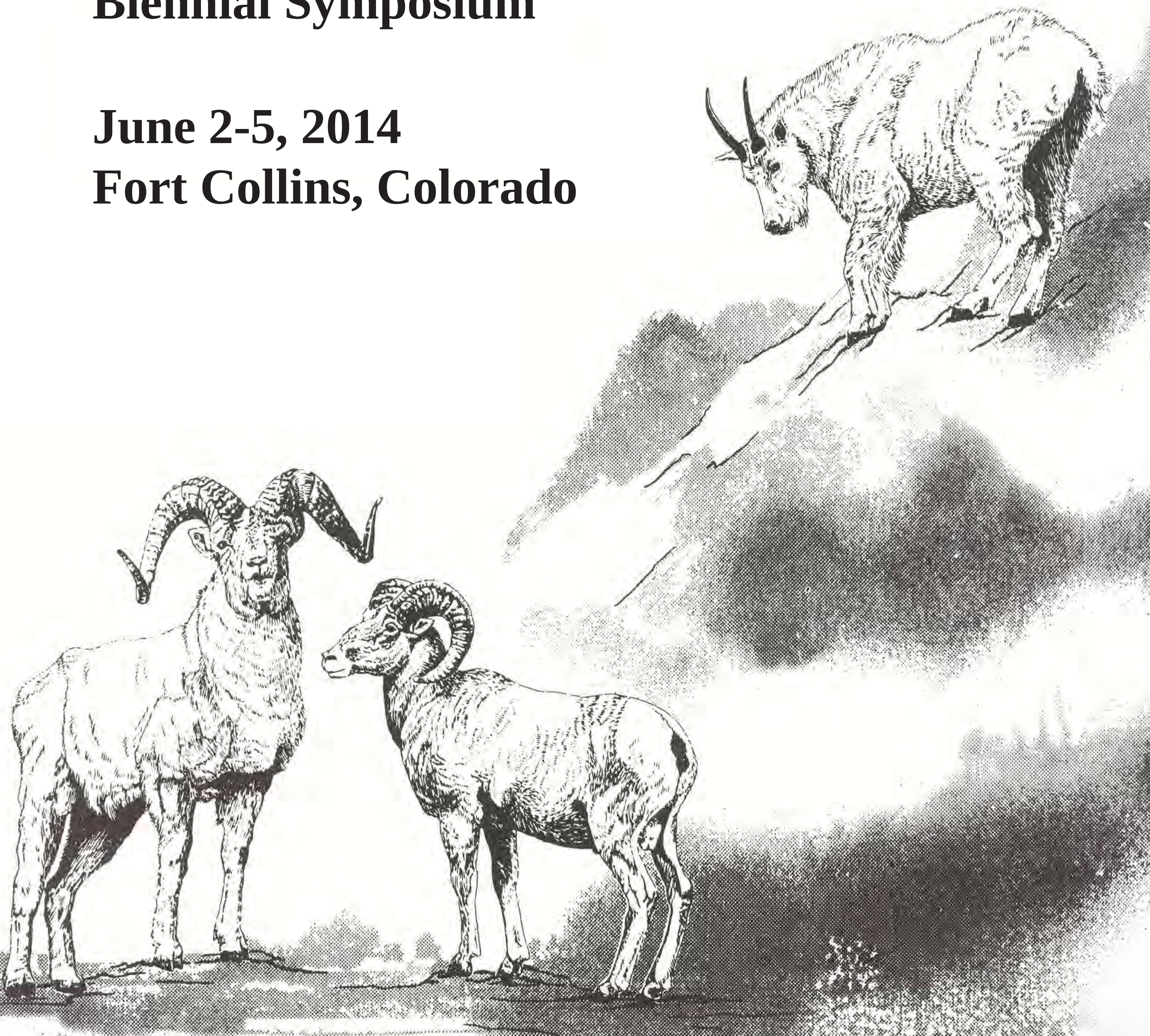
Northern Wild Sheep and Goat Council

Proceedings of the Nineteenth Biennial Symposium

June 2-5, 2014
Fort Collins, Colorado



Northern Wild Sheep and Goat Council

PROCEEDINGS OF THE 19TH BIENNIAL SYMPOSIUM

JUNE 2–5, 2014
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Symposium Chair: Janet George

Host: Colorado Parks and Wildlife

Scientific Program Co-chairs: Andy Holland, Mike Miller

Editors: Bruce Watkins, Ricki Watkins

Committee members: Wendy Figueroa, Michelle Gallagher, Andy Holland, Nancy Howard, Ben Kraft, Mike Miller, Mark Vieira, Stephanie Fererro, Kevin Hurley

Proceedings assembly: Ricki Watkins

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Northern Wild Sheep and Goat Council

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Colorado Parks & Wildlife

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NORTHERN WILD SHEEP AND GOAT COUNCIL SYMPOSIA

Date	Symposium	Location	Symposium Coordinator/ Chair	Proceedings Editor(s)	NWSGC Exec. 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 Schoonveld	
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/DaleToweill/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	Kevin Hurley
June 7-11, 2010	NWSGC 17	Hood River, OR	Craig Foster	Vern Bleich	Kevin Hurley
March 12–15, 2012	NWSGC 18	Kamloops, BC	Steve Gordon/Mari Wood	Steve Wilson/Mari Wood/Steve Gordon; Vanessa Craig (compiler)	Kevin Hurley
June 2-5, 2014	NWSGC 19	Fort Collins, CO	Janet George	Bruce Watkins/Ricki Watkins	Kevin Hurley

 Northern Wild Sheep and Goat Council 

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 its 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.

Northern Wild Sheep and Goat Council

FOREWORD

The papers or abstracts included in these proceedings were presented during the 19th Biennial Symposium of the Northern Wild Sheep and Goat Council, held June 2-5, 2014 at the Fort Collins Marriot, Fort Collins, Colorado, USA.

Heart-felt thanks are extended to the sponsors of, and all those participating in, this highly successful 19th biennial symposium. Special thanks to Janet George (Symposium Chair) for leading the dedicated Colorado organizing committee and delivering another in a long series of first-class symposia. Michelle Gallagher deserves special recognition for handling so many of the logistics and Mark Vieira for being point on the field trip. Thanks also to Andy Holland and Mike Miller (Scientific Program Co-chairs), Wendy Figueroa (Poster Session Chair) and all of the platform and poster presenters for assembling and sharing relevant new science on wild sheep and goat ecology and management.

The Proceedings were edited and assembled by Bruce Watkins and Ricki Watkins. All manuscripts were edited by Bruce Watkins, Ricki Watkins, and volunteer NWSGC members prior to publication. Peer-reviewers included Stephen Arthur, Alyson Courtemanch, Karen Fox, Robert Garrott, Heather Johnson, Tom Lohius, Kathryn Schoenecker, Julie Stiver, and Steve Wilson. Suggested editorial comments were provided to each senior author; senior authors had opportunity(ies) to accept or reject suggested edits, prior to submission of their final manuscripts. Formatted page proofs were forwarded to respective senior authors prior to inclusion into the final proceedings. Final content, particularly verification of literature citations, is the responsibility of the authors.

While NWSGC strives for professional, scientific presentations at our symposia, followed up with quality manuscripts for our proceedings, NWSGC Guidelines do not rigidly specify format, minimum data requirements, or thresholds of statistical analysis for subsequently-included manuscripts. Thus, NWSGC Proceedings may contain manuscripts that are more opinion-based than data- or fact-based; critical evaluation of information presented in these proceedings is the responsibility of subsequent readers.

Kevin Hurley
NWSGC Executive Director
August 3, 2015

Northern Wild Sheep and Goat Council

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DISEASE MONITORING & MANAGEMENT, *Lisa L. Wolfe, Colorado Parks & Wildlife, moderator*

Evaluating Apparent Competition in Limiting the Recovery of Endangered Bighorn Sheep

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ABSTRACT Predation can disproportionately affect endangered prey populations when generalist predators are numerically linked to more abundant primary prey. Apparent competition, the term for this phenomenon, has been increasingly implicated in the declines of endangered prey populations. We examined the potential for apparent competition to limit the recovery of Sierra Nevada bighorn sheep (*Ovis canadensis sierrae*), a U.S. federally endangered subspecies. Using a combination of location, demographic, and habitat data, we assessed whether cougar (*Puma concolor*) predation on bighorn sheep was a consequence of their winter range overlap with abundant mule deer (*Odocoileus hemionus*). We found that bighorn sheep populations with higher spatial overlap with deer exhibited higher rates of predation, which in turn had additive effects on adult bighorn sheep survival. Indeed, bighorn sheep killed by cougars were primarily located within deer winter ranges. Variation in sympatry between bighorn sheep and deer appeared to be largely driven by differences in habitat selection among bighorn herds. Herds experiencing the highest predation rates and greatest overlap with deer also exhibited the strongest selection for low elevation habitat. Although predator-mediated apparent competition may limit some populations of Sierra Nevada bighorn sheep, it is not the primary factor limiting all populations, suggesting that the dynamics of different herds are idiosyncratic.

Biennial Symposium of the Northern Wild Sheep and Goat Council 19:1; 2014

KEY WORDS bighorn sheep, conservation, cougar, *Ovis canadensis sierra,* predation, Sierra Nevada.

Publication citation:

Johnson, H.E., M. Hebblewhite, T.R. Stephenson, D.W. German, B.M. Pierce, and V. C. Bleich. 2013. Evaluating apparent competition in limiting the recovery of an endangered ungulate. Oecologia 171: 295-307.

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Comparative Ecology of Mountain Goats in Coastal Alaska

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ABSTRACT Mountain goats (*Oreamnos americanus*) are among the least studied large mammals in North America and, in most parts of their range, basic knowledge about the species ecology is needed to advance conservation efforts. Mountain goat populations are often isolated at relatively small geographic scales. Consequently, simultaneous study of discrete populations provides an opportunity to further our knowledge of factors that influence mountain goat ecology. In this study, we examine the comparative ecology of 6 genetically distinct mountain goat populations in coastal Alaska. We collected data from 270 radio-marked mountain goats during 2005-2014 to examine how ecological characteristics varied between populations. Specifically, we analyzed data relative to nutrition, morphology, migration strategies, reproduction, survival, and population dynamics in a comparative context. Overall, we detected differences in ecological characteristics of certain populations that appear to be related to winter climate, carnivore community assemblage, genetic isolation, and population history. These findings are important for describing the natural variability of the quasi-archipelagic mountain goat populations in coastal Alaska and have key implications for informing site-specific conservation strategies.

Biennial Symposium of the Northern Wild Sheep and Goat Council 19:2; 2014

KEY WORDS Alaska, geology, migration, mountain goat, *Oreamnos americanus*, reproduction, survival.

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Identifying Genomic Signatures of Natural Selection on Dall's Sheep

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ABSTRACT Reliable identification of genes underlying genomic signatures of natural selection is a necessary component of understanding adaptation to local conditions and provides critical information for assessing population resilience. To identify and determine the geographic distribution of adaptively differentiated Dall's sheep (*Ovis dalli)* populations throughout their range, we used next-generation sequencing to develop DNA markers in candidate adaptive genes to test for patterns of selection at the molecular, population, and landscape levels. Using an exon capture re-sequencing approach, we discovered single nucleotide polymorphisms (SNPs) in >3,000 genes and refined the set of candidate adaptive genes to develop a SNP-chip panel for genes associated with known immunological, metabolic, and growth functions in ovids. We then applied this panel to genotype 87 Dall's sheep from 11 sampling locations across Alaska and the Yukon Territory. We detected a total of 12 outlier loci potentially under selection using multiple corroborating computational approaches. We additionally identified 8 SNPs that were significantly associated with precipitation and temperature environmental variables, as well as latitude and longitude, suggesting local environmental adaptation and natural selection. We identified 4 distinct groups at the broad subspecies geographic range based on putatively neutral SNPs that largely aligned with major mountain ranges (pairwise F_{ST} = 0.159-0.264). When comparing the patterns of differentiation and variation between neutral and adaptive genetic structure by including adaptive loci, we detected additional genetic sub-structuring in the northwestern and central portions of the Dall's sheep range. Characterizing local adaptations and adaptive gene distributions from novel genetic techniques will facilitate investigation of the influence of environmental variation on local adaptation of a northern alpine ungulate throughout its range.

Biennial Symposium of the Northern Wild Sheep and Goat Council 19:3; 2014

KEY WORDS adaptive variation, Alaska, Dall's sheep, landscape genomics, next-generation sequencing, *Ovis dalli*, Yukon Territory.

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Phylogenetic Analyses Reveal Evidence for Multiple Glacial Refugium for Thinhorn Sheep

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ABSTRACT Past glaciation events have played a major role in shaping the genetic diversity and distribution of wild sheep in North America. The advancement of glaciers can isolate populations in ice-free refugia, where they can survive until the recession of ice sheets. Thinhorn sheep (*Ovis dalli*) populations were previously thought to have survived glacial periods in the major Beringia refugium. While isolation in the major refugium can account for much of the genetic and morphological diversity seen in extant thinhorn sheep populations, mounting evidence suggests the persistence of populations in smaller minor refugia. We investigated the refugial orgins of thinhorn sheep via a cross species application of the domestic sheep ovine high density single nucelotide polymorphism array to genotype 52 thinhorn sheep and 5 bighorn sheep (*Ovis canadensis*) samples. Maximum parsimony and Bayesian phylogenetic analyses reveal evidence for 2 distinct clades of thinhorn sheep, which is consistent with the survival of thinhorn sheep in 2 glacial refugia. Bayesian admixture analysis also indicates the southeast Yukon to be a zone of contact as thinhorn sheep population recolonized North America subsquent to the recession of the ice sheets. The results of this study highlight the intricate role glaciation events can have on the evolutionary history of thinhorn sheep and the need to look beyond established refugia.

Biennial Symposium of the Northern Wild Sheep and Goat Council 19:4; 2014

KEY WORDS admixture, glacial refugia, *Ovis dalli,* phylogeography, single nucleotide polymorphism, thinhorn sheep.

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Modeling Summer Habitat Selection of Sympatric Bighorn Sheep and Mountain Goats in the Greater Yellowstone Area

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ABSTRACT As introduced mountain goat (*Oreamnos americanus*) populations continue to expand throughout the mountainous regions of the Greater Yellowstone Area (GYA), wildlife managers have expressed a need for reliable information specific to this region to understand mountain goat ecology, as well as any potential impacts to native species, including native and restored bighorn sheep (*Ovis canadensis*). In response, we developed and implemented rigorous occupancy survey methodologies in 2 study areas for 3 field seasons (2011-2013). A total of 611 surveys captured spatially precise locations of 128 bighorn sheep groups and 286 mountain goat groups. These data are being used to develop fine-scale summer habitat selection models for both mountain goats and bighorn sheep that account for imperfect detection. The models will provide insight into the potential for resource competition between the 2 species and allow the prediction of mountain goat range expansion into the extensive ranges of bighorn sheep in the eastern mountains of the GYA where small numbers of colonizing mountain goats have recently been observed. We report on the accomplishments from the 3 field seasons, including preliminary analyses and the next steps to completing a full analysis of the data.

Biennial Symposium of the Northern Wild Sheep and Goat Council 19:5; 2014

KEY WORDS bighorn sheep, expansion, habitat selection, introduced, mountain goat, occupancy, *Oreamnos americanus, Ovis canadensis*, potential competition, resource selection.

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Impact of Winter Backcountry Recreation on a Formerly Migratory Bighorn Sheep Population in Wyoming

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ABSTRACT Many ungulate populations have lost or are at risk of losing their traditional migrations. The Teton bighorn sheep (*Ovis canadensis*) population in northwest Wyoming is one such example. It has lost access to its historical winter range and now resides year-round in its high-elevation summer range, wintering exclusively on windswept ridges above 3,000 m. Backcountry skiing is expanding in the Teton Range and is a growing concern for this isolated population. We sought to investigate the impacts of backcountry skiing on bighorn sheep winter habitat selection and movements. We outfitted 28 ewes with Global Positioning System (GPS) collars from 2008-2010 and collected concurrent GPS tracks of backcountry skiers. We modeled winter habitat selection for GPS-collared ewes as a function of habitat attributes and distance to backcountry ski routes using a design II resource selection function with a discrete choice model. Results indicated that distance to ski routes, elevation, snow cover, and distance to escape terrain best predicted winter habitat use. Results suggested bighorn sheep avoid backcountry ski routes even in otherwise relatively high-quality habitat. Ewes exposed to more intense skiing activity exhibited higher daily movement rates. It appears that backcountry skiing activity has further limited winter habitat for this formerly migratory population.

Biennial Symposium of the Northern Wild Sheep and Goat Council 19:6; 2014

KEY WORDS backcountry skiing, bighorn sheep, habitat, migration, *Ovis canadensis*, recreation, resource selection function, Wyoming.

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A Case Study Assessing the Use of Fire as a Conservation Tool for Bighorn Sheep Habitat in Western Colorado

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ABSTRACT We evaluated the efficacy of using woodland fire to alter vegetation composition in a manner that augments desert bighorn sheep (*Ovis canadensis nelsonii*) habitat in the Black Ridge Canyons Wilderness Area in western Colorado. We applied generalized linear mixed models to estimate pre-fire ewe habitat selection and then simulated a hypothetical widespread fire to spatially predict where fire would be most beneficial in expanding habitat. We found that ewes were avoiding habitats with high woodland stand density, which is the habitat most likely to be removed by fire. Given the removal of all woodlands, it is likely that habitat expansion would occur in areas near topographic escape terrain. Coupled with this analysis, we addressed concerns regarding potential negative effects of fire in this system by comparing vegetation composition of unburned habitats to burned habitats that were treated with a native seed mixture. We found that foliar cover in burned habitats was on average 2 times greater than in unburned habitats and that post-fire seeding likely allowed for these differences to be proportionally similar between native and non-native grass species. Our results provide an encompassing view of the effects of fire for a common management situation in which both land and wildlife values are of mutual interest.

Biennial Symposium of the Northern Wild Sheep and Goat Council 19:7; 2014

KEY WORDS *Bromus tectorum*, cheat grass, fire management, habitat quality, *Ovis canadensis nelsonii*, piñon juniper woodlands, resource selection.

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Application of the Bighorn Sheep Risk of Contact Tool and Best Available Science to a Domestic Sheep Allotment Analysis Process

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ABSTRACT The need to maintain effective separation between domestic sheep and Rocky Mountain bighorn sheep (*Ovis canadensis*) in free-range conditions is widely recognized as the most prudent action that can be taken to reduce the potential for interspecies disease transmission. To achieve this objective, the Forest Service currently utilizes a risk assessment process with management objectives that include maintenance or enhancement of bighorn sheep populations. Historical accounts suggest that bighorn sheep were common on what is now the Rio Grande National Forest, Colorado during the early settlement period of the mid- to late 1800s. As in many areas of the western United States, these herds were largely decimated by the early 1900s. Currently, 11 bighorn sheep herds containing an estimated 1,100 individuals occur or partially occur on the Forest with ample unoccupied habitat available. Domestic sheep grazing has also been an important local cultural and economic activity since the early settlement period. Domestic sheep numbers peaked at about 245,000 during the 1920s; however, the Forest still supports approximately 11,500 sheep on roughly 26 different allotments. Some of these allotments occur in proximity to or even overlap known or suspected bighorn sheep core herd range and/or summer source habitat. This paper focuses on: 1) our recent quantitative analysis involving the Fisher-Ivy/Goose Allotment; 2) our use of the recently produced Bighorn Sheep Risk of Contact Tool to help inform the risk analysis and decision; and 3) the qualitative aspects of the analysis that we consider important. Our use of the Risk of Contact Tool is a first for the Forest Service Rocky Mountain Region and we discuss why we suggest its use and application to be representative of the best available science in informing this issue on a larger landscape.

Biennial Symposium of the Northern Wild Sheep and Goat Council 19:8; 2014

KEY WORDS bighorn sheep, Colorado, domestic sheep, effective separation, risk of contact, Rio Grande National Forest, *Ovis canadensis.*

For copies of the environmental analysis and supporting National Environmental Protection Act documentation for this project please contact the Rio Grande National Forest, 1803 W. Highway 160, Monte Vista, CO, 81144 (phone: 719-852-5941). Please reference the Fisher-Ivy/Goose Sheep & Goat Allotment Analysis, September 2013. Information can also be found on the Rio Grande National Forest website at:
http://www.fs.usda.gov/wps/portal/fsinternet/projects/riogrande/landmanagement/projects?sortby=1&archive=1

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Summary Report: Bighorn Sheep Respiratory Pathogen Sampling and Health Assessment Workshop

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ABSTRACT September 2013, a bighorn sheep disease sampling and health assessment workshop was conducted at the request of the Western Association of Fish and Wildlife Agencies, Wildlife Health Committee (WAFWA WHC) to prioritize and standardize testing protocols for respiratory pathogens of bighorn sheep (*Ovis canadensis*). Specific concerns included: 1) numerous tests for a variety of pathogens are available but interpretation of results is challenging; 2) laboratories do not have standard methodology; and 3) the 2009 WAFWA WHC Sheep Sampling Guidelines required updating.

The workshop included wildlife health professionals from 9 western states and 2 Canadian provinces. Members of the WAFWA Wild Sheep Working Group were surveyed prior to the workshop. Funding was secured from the Wild Sheep Foundation to support attendees with travel restrictions.

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The group produced documents: 1) outlining sampling protocols for various herd management goals; 2) listing important terms and their concise definitions; 3) standardizing necropsy protocols; and 4) providing a concise article on herd health monitoring recommendations. The group also identified several tests and protocols requiring future research, as well as topics and techniques for agency staff training to support consistent approaches to sample collection and handling. These products will support recommendations across agencies for different management practices and provide a valuable resource and reference for all wildlife health and management professionals.

Biennial Symposium of the Northern Wild Sheep and Goat Council 19:9-10; 2014

KEY WORDS bighorn sheep, disease sampling protocols, herd health, *Ovis canadensis*, pneumonia complex, Western Association of Fish and Wildlife Agencies, Wildlife Health Committee.

Enhanced Bacterial Pathogen Detection via Improved Sample Collection and Laboratory Diagnostics

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ABSTRACT Culture and isolation of the common bacterial pathogens responsible for pneumonia in bighorn sheep (*Ovis canadensis*) can be difficult. Our laboratory increased diagnostic sensitivity for these pathogens by integrating polymerase chain reaction (PCR) into our laboratory regimen and improving field-sampling techniques. We used published PCR protocols to screen all the bacterial growth from culture plates for *Mannheimia* and *Bibersteinia* spp. leukotoxins, followed by *Mannheimia* spp. specific leukotoxin, and finally a PCR to detect *M. haemolytica*. The addition of these PCRs to our standard culture protocol resulted in the detection of 29% more leukotoxin positive *Mannheimia* spp. (including *M. haemolytica*) than by gross identification of bacterial colonies on Columbia Blood Agar (CBA) or Columbia Selective Agar (CSA). In addition, we optimized our sample collection techniques in the field to ensure microbial viability and recovery. Optimization steps included multiple swabs from the tonsillar crypts and immediate inoculation of CBA or CSA plates. Culture plates were placed in a mobile incubator held at 37° C with 10% CO_2. Phenotypic colonies were removed and recultured every 24 hours until delivery to the laboratory. These improvements in field and laboratory techniques have increased our ability to detect potential pathogens in bighorn sheep populations.

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KEY WORDS *Bibersteinia*, bighorn sheep, leukotoxin, *Mannheimia*, *Ovis canadensis*, pneumonia, polymerase chain reaction.

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A Collaborative Regional Initiative to Correlate Respiratory Pathogens with Demographic Attributes of Bighorn Populations

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ABSTRACT Bighorn sheep (*Ovis canadensis*) conservation and management has been plagued with seemingly unpredictable outbreaks of pneumonia in herds throughout the range of the species. These disease events can vary from persistent low-level mortality to infrequent catastrophic all-age die-offs reducing populations by 50-90%. Some populations appear to recover well from pneumonia events after a period of poor lamb recruitment in subsequent years, while other populations never seem to regain demographic vigor. Managers routinely sample affected bighorn herds in an attempt to gain insight into the respiratory pathogens responsible for die-offs and poor demographic performance, as well as to assess both donor and recipient herds prior to translocations of animals. Bighorns host a suite of respiratory pathogens and there is little consensus on the role of these organisms in pneumonia events. We describe an ongoing collaborative effort to employ standardized field and laboratory protocols to sample respiratory pathogens in bighorn herds throughout Montana and Wyoming. The sampled herds occupy diverse ecological settings with varying management histories, demographic attributes, and histories of pneumonia. These data will be used to explore potential correlations between respiratory pathogens detected in each herd and its demographic performance in the years immediate prior to and after the sampling event.

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KEY WORDS bighorn sheep, demography, die-offs, health, Montana, *Ovis canadensis*, pneumonia, recruitment, respiratory pathogens, Wyoming.

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Mountain Goats at the Livestock-Wildlife Interface: A Susceptible Species

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ABSTRACT Mountain goats (*Oreamnos americanus*) were first introduced into the East Humboldt and Ruby Mountains of Elko County, Nevada in the 1960s. These contiguous mountain ranges are also home to other ruminant species, including native mule deer (*Odocoileus hemionus*) and introduced Rocky Mountain bighorn sheep (*Ovis canadensis*), and are surrounded by both public and private rangelands utilized for domestic cattle, sheep, and goats. Permitted and stray domestics have been documented between an elevation range of 2,743 m and 3,0481 m which is well within utilized habitat of the mountain goats. Since 2010, we have documented infection by *Mycoplasma ovipneumoniae* in adult (n = 13) and kid (n = 1) mountain goats. Nasal (i.e., all animals) and lung (i.e., kid) swabs from these animals were used to identify *M. ovipneumoniae* by reverse transcription polymerase chain reaction (RT-PCR) following broth enrichment. In addition to bronchointerstitial pneumonia, the kid had suppurative and hemorrhagic enteritis with lymphoid necrosis. Type 1a BVD virus was isolated from the kid's spleen. A female adult goat presented with ulcerative cheilitis and pseudocowpox virus was identified in this lesion by PCR and sequencing. These disease surveillance data suggest that interactions resulting in disease transmission occur between mountain goats and domestic ruminants and should be discouraged as part of a comprehensive management program for this species.

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KEY WORDS bovine viral diarrhea, livestock-wildlife interface, mountain goat, *Mycoplasma ovipneumoniae,* Nevada, *Oreamnos americanus,* polymerase chain reaction, pseudocowpox virus.

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Bighorn Sheep Sinus Tumors are Associated with Co-Infections by Pneumonia-causing Bacterial Agents in Upper Respiratory Tract

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ABSTRACT Bighorn sheep (*Ovis canadensis*) sinus tumors are hyperplastic to neoplastic, predominantly stromal masses of the paranasal sinuses that expand the sinus lining and obstruct the sinus cavities. Obstruction of the sinus cavities and disruption of normal sinus lining anatomy may interfere with clearance of bacterial pathogens from the upper respiratory tract. To examine this possibility, we explored whether or not the presence of sinus tumor features (tumor score) affected the likelihood of detecting potentially pathogenic bacteria from upper respiratory sinus lining tissues in bighorn sheep. We developed or used existing polymerase chain reaction assays for the detection of leukotoxigenic *Pasteurellaceae* and *Mycoplasma ovipneumoniae* in sinus lining tissues collected from 97 bighorn sheep in Colorado from 2009 to 2012. Using logistic regression analyses, we found that tumor score was a good predictor of the probability of detecting potentially pathogenic bacteria in sinus lining tissues; we were more likely to detect potentially pathogenic bacteria from samples with high tumor scores. These findings add to our understanding of possible mechanisms for the maintenance and shedding of bacterial agents from the upper respiratory tracts of bighorn sheep.

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KEY WORDS bighorn sheep, leukotoxin, *Mycoplasma ovipneumoniae*, *Ovis canadensis*, *Pasteurellaceae*, polymerase chain reaction, sinus tumors.

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The Effect of Zuprevo, a Macrolide Antibiotic, on Bighorn Sheep Lamb Survival Following a Bacterial Pneumonia Outbreak

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ABSTRACT We investigated the effect of macrolide antibiotic Zuprevo on bighorn sheep (*Ovis canadensis*) lamb survival in 2 herds in the Pine Ridge region of western Nebraska following a bacterial pneumonia outbreak. Respiratory disease is a major cause of mortality in bighorn sheep lambs in Nebraska, threatening the success of the state's bighorn sheep restoration efforts. In 2012, lamb survival rates were documented at 7.3% and 3.1% in the Barrel Butte and Fort Robinson herds, respectively. From 22 June to 30 July 2013, 12 of 33 lambs in the Barrel Butte and Fort Robinson herds were darted using CO_2 rifles that fired injection and marking darts that administered 0.5 cc of Zuprevo into the lambs upon impact. Lamb survival of darted and un-darted lambs was then monitored to 1 November 2013. Initial results indicate a positive relationship between darted lambs and lamb survival. High pneumonia-related mortality of bighorn sheep lambs may pose the single greatest threat to population recovery of bighorn sheep herds in the western United States. Our findings suggest that antibiotic treatment of bighorn lambs following a pneumonia outbreak may improve lamb recruitment in these herds. Further research is needed to assess the overall affect and long term impact to bighorn sheep herds.

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KEY WORDS antibiotic, bighorn sheep, lambs, Nebraska, *Ovis canadensis*, pneumonia, Zuprevo.

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Experimental Management of Pneumonia in Bighorn Sheep

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ABSTRACT Following introduction of pneumonia, disease can persist in bighorn sheep (*Ovis canadensis*) populations for years or even decades through annual or sporadic pneumonia epidemics in lambs. Recurring years of depressed recruitment due to high rates of pneumonia-induced mortality in lambs is a major obstacle to population recovery. Currently, 2 management strategies are most commonly implemented in response to this problem: do nothing or eradicate the population and release new sheep. We are investigating the feasibility of another management alternative: removal of individual “super-spreaders.” Individual variation in infection and transmission is well documented in human diseases (e.g., “Typhoid Mary”). We are testing the hypothesis that pneumonia epidemics in lambs are initiated by transmission of pathogens from a few “chronic-shedder” ewes. We plan to 1) identify whether we can detect chronic-shedders through repeated testing; 2) determine whether removal of chronic-shedder ewes improves lamb survival; and 3) monitor health status and growth of a new population established with non-shedders from an infected population. This is the first year of a 5-year project being conducted in 6 Hells Canyon bighorn sheep populations. We present results from the initial phase of the study, including confirmation of individual variation in pathogen shedding consistent with our hypothesis.

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KEY WORDS bighorn sheep, chronic carrier, disease ecology, disease transmission, Idaho, *Ovis canadensis,* recruitment.

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Factors Predicting Success of Mountain Goat Reintroductions

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ABSTRACT We adopted a retrospective approach to assess factors associated with success of mountain goat (*Oreamnos americanus*) reintroductions into native habitats during 1950-2010. We excluded translocations into areas not historically inhabited by mountain goats, as well as projects best considered augmentations. To supplement published and unpublished literature, we requested data on translocations from staff at state and provincial wildlife agencies likely to have access to information otherwise unavailable. Where data allowed, we estimated post-translocation growth rates, *r*. Because most projects did not allow the quantification of growth, we also categorized reintroduction projects as successful or not, reintroduced populations as extant or extirpated, and released animals as having displayed site fidelity or dispersing soon after release. We examined a suite of hypothesized explanatory variables for these outcomes, including number of males, females, juveniles, and kids, as well as number of separate releases, number of source populations (assumed a proxy for genetic variation), and whether source populations themselves originated as translocations. In contrast to earlier work that suggested no demographic predictor of mountain goat translocation success (Guenzel 1980), we found that the number of adult founders was strongly predictive of long-term success. Releases of just a few animals were relatively likely to have been extirpated within the time duration studied. Evidence suggested that releasing juveniles and kids along with adults produced no improvement in probability of a successful outcome.

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KEY WORDS founder size, mountain goat, *Oreamnos americanus*, reintroduction, translocation.

Translocations, augmentations, and reintroductions all have long histories of use in wildlife conservation but assessing determinants of their effectiveness is problematic. Case-study approaches (e.g., Jorgenson and Quinlan 1996, Whiting et al. 2011) reveal details that apply in any given situation but it is often challenging to find generalizations that are widely applicable. Instead, most studies of translocations and reintroductions have been retrospective, gathering existing data on a number of individual projects, and making inferences based on selected characteristics of the projects and quantitative or qualitative measures of success (Griffith et al. 1989; Wolf et al. 1996, 1998).

Translocations of large mammals began shortly after wildlife management emerged as a serious profession (Bolen and Robinson 2003) but projects during the first few decades were often poorly documented. The work of Griffith et al. (1989) spurred a renewed interest in quantitative analyses of wildlife translocations, generally across a wide range of taxa (Singer et al. 2000, Armstrong and Seddon 2007). Although details have differed, most analyses

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have broadly concluded, not surprisingly, that translocations and reintroductions are more likely to succeed when: 1) wild, rather than captive animals are used as the source; 2) more, rather than fewer animals, are released; 3) genetic variation among founders is higher rather than lower; 4) habitat quality at the release site is higher rather than lower; and 5) patch area in which animals are released is larger rather than smaller (Wolf et al. 1996, 1998; Fischer and Lindenmayer 2000).

In North America, mountain goats (*Oreamnos americanus*) have been among the more commonly translocated large mammals (Hurley and Clark 1996), both within portions of their native range where populations had become depressed and outside their native range into mountains that appeared suitable and where public interest was strong. To date, however, the only published evaluation of mountain goat translocations remains that of Guenzel (1980). Working with 11 projects that were considered successful, Guenzel (1980) found that no demographic factors from the released animals predicted subsequent population growth. This surprising finding would seem at odds with prevailing wisdom that the number and possibly sex or age composition of founders would influence success or rate of growth. Of particular relevance for mountain goats, Komers and Curman (2000) observed that founder size, proportion of mature individuals, and proportion of males among adults were all positively associated with growth rates among 33 reintroductions involving Northern Hemisphere artiodactyls. In an evaluation of bighorn sheep (*Ovis canadensis*) translocations, Singer et al. (2000) found that, in addition to habitat characteristics particular to bighorns, founder size was positively associated with eventual success, though number of source populations for founders was not.

Our study was motivated by the question: Do the results obtained by Guenzel (1980) indicate that mountain goats are an exception to the expected patterns in wildlife translocations? Alternatively, might the failure of Guenzel (1980) to find any relationships between source populations and subsequent success have resulted from choice of metric (instantaneous rate of growth), choice of populations (successful, largely released in non-native mountain ranges), or lack of statistical power (i.e., low sample size)? Our objective was to revisit the question of whether certain characteristics of mountain goat releases made them more or less likely to succeed. Our approach was a retrospective analysis, similar conceptually to those of Guenzel (1980), Griffith (1989), Komers and Curman (2000) and others, in which we applied simple statistical tests to existing documentation of mountain goat releases and subsequent population performance. We limited our focus to releases of mountain goats into native habitat.

METHODS

Data Sources

We reviewed published and unpublished literature for reports on mountain goat translocations, augmentations, and reintroductions. We supplemented this search with e-mails to wildlife agency staff in western US states and Canadian provinces likely to have access to unpublished records. In these cases, we sent a blank database to respondents and asked them to enter the following information for each project: dates and location of releases, number of released animals by age and sex, information on source populations, as well as any information on size and quality of the targeted release area. We also requested data on any and all follow-up surveys on released animals.

Definitions

We defined any deliberate release of mountain goats into non-captive settings as a translocation. Regardless of the language used

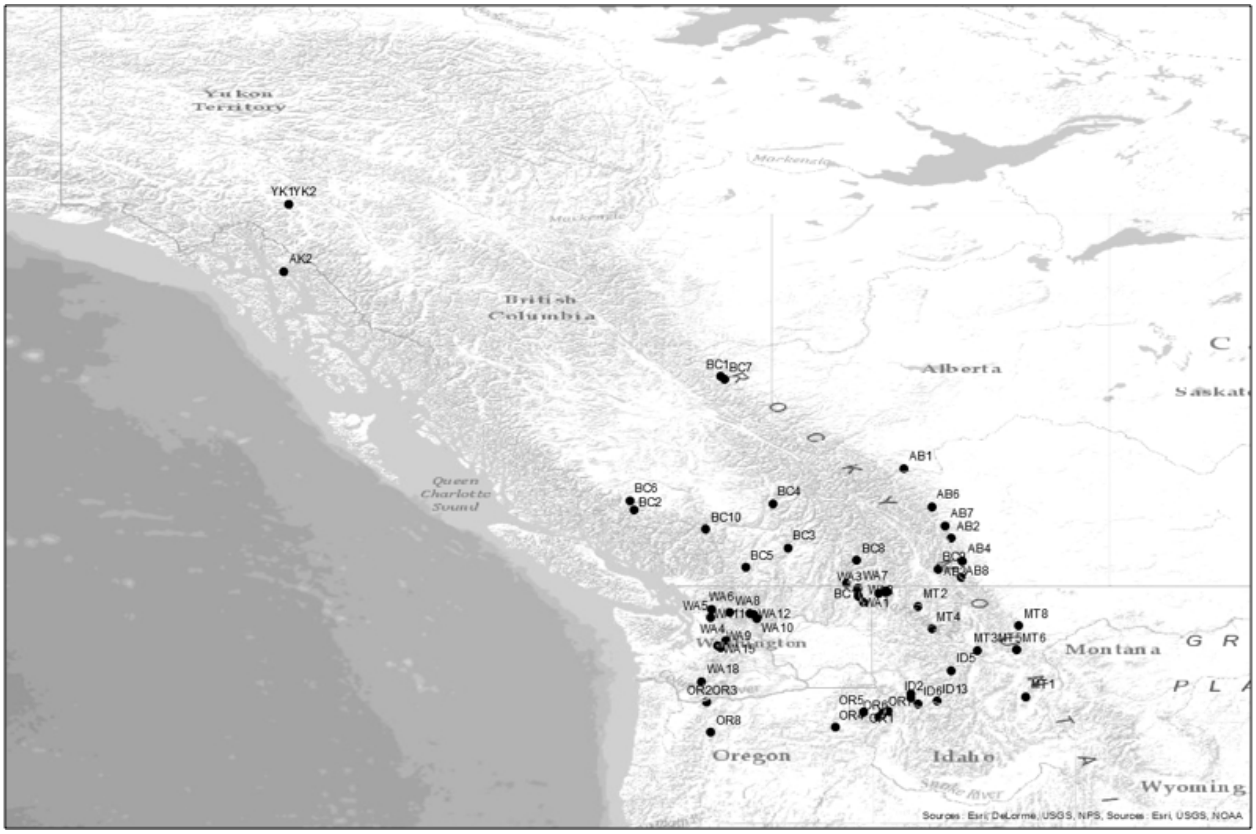

Figure 1. Sketch map showing approximate locations of mountain goat reintroduction projects considered in this analysis, 1950-2010. Some projects not shown to reduce clutter; projects in Alaska not shown. Project codes refer to Appendices.

in the source documentation, we considered any translocation in which some goats were known or suspected to exist in the target area at the time of the translocation as an augmentation. Following Armstrong and Seddon (2007), we reserved the term reintroduction for projects in which mountain goats were moved to areas known to be part of their historic range but from which they were known or suspected to have been extirpated.

Releases for a single project often spanned >1 year. In these cases, we considered multiple releases in adjacent years in nearby areas to constitute a single reintroduction. Releases separated by >5 years, even if at a single site, were considered independent projects.

In addition to quantitative measures of post-release population trajectory (below), we developed 3 binary categories to summarize each project. We defined "extant" as documented evidence that, at the most recent report, some released animals or their offspring were still present (this contrasted with "extirpated," which was when all evidence suggested that no animals remained). In some cases this categorization could not be confidently made. Based on text in the original documentation, we distinguished reintroductions in which most or all animals remained at or near the intended site ("site fidelity") from those in which many or all animals, though perhaps surviving and even reproducing, scattered widely. Finally, we defined each reintroduction as successful or unsuccessful. Successful reintroductions were those that were: 1) defined that way in writing by an agency-employed author of a report; 2) subsequent surveys across >6 years suggested a positive rate of growth and the population had at least doubled in size; or 3) notwithstanding lack of data, the population was clearly known

Table 1. Mountain goat reintroductions (by jurisdiction), 1950-2010, categorized by two criteria: A) assessed as a success or failure and B) known to be extant or extirpated.

	A			B			
Jurisdiction	**Success**	**Failure**	**Undetermined**	**Extant**	**Extirpated**	**Unknown**	**Total**
Washington	2	7	9	5	5	8	18
British Columbia	4	4	3	7	2	2	11
Montana	2	1	5	3	0	5	8
Idaho	1	5	7	2	5	6	13
Oregon	4	2	2	5	2	1	8
Alberta	1	6	1	6	1	1	8
Yukon	1	1	0	2	0	0	2
Alaska	1	1	0	1	0	1	2
Total	16	27	27	31	15	24	70

to be thriving by the responsible agency. Unsuccessful reintroductions were those: 1) described as such by agency documentation; 2) known to be extirpated; or 3) displaying negative trajectory >10 years since release. If none of these conditions applied, we categorized the reintroduction success as undetermined.

Analyses

When existing documentation was sufficient, we calculated the instantaneous rate of change, *r*, as $\ln\left(\frac{Ns}{Nr} / t\right)$, where *Nr* was the number of reintroduced animals surviving the initial reintroduction effort; *Ns* was the number counted in a subsequent survey; and *t* was the number of years elapsed between the two. When multiple post-reintroduction surveys were documented, we examined trends visually and selected surveys that appeared to reflect the trajectory post-release (i.e., before hunting was initiated or major habitat changes took place). To examine correlates of population trajectory, we examined a suite of multiple regression models in which *r* was the response variable, and predictor variables were total number of animals released, number of adults released, number of adult females and males released, sex ratio of adults released, number of separate releases (within an individual reintroduction), number of separate sources (which we used as a proxy for genetic variation), and whether sources were themselves native or resulted from previous translocations.

Because relatively few projects provided sufficient information to estimate *r*, and because *r* was itself an imperfect metric as a response variable (see Discussion), we also examined the 3 binary response variables (extant and extirpated, site fidelity and scattered, successful and unsuccessful) with multiple logistic regression, using the same suite of explanatory variables. We examined the

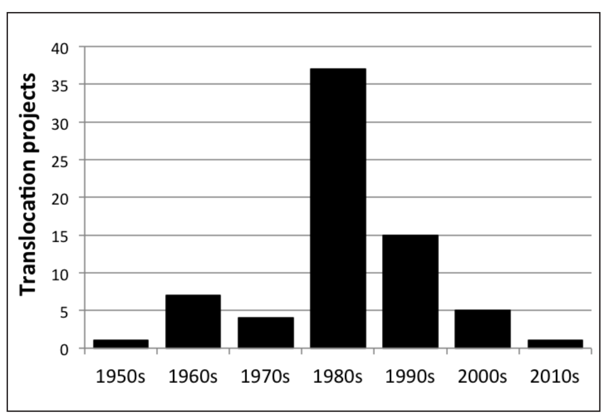

Figure 2. Frequency of mountain goat translocations into native habitat in North America by decade.

strength of evidence among competing logistic regression models with Akaike Information Criterion corrected for sample size (AIC_c) but also examined whether individual regression coefficients overlapped zero. Because the sex of all adult founder goats was missing in 10% of cases, and the sex or age were missing in some of the founder goats in a separate 18% of cases (i.e., the total number of founders exceeded the sum of known sex/age goats), we conducted logistic regression models using the missing data imputation approach contained in Program AMELIA (http://gking.harvard.edu/amelia; see also Honaker and King 2010, Nakagawa and Frecklton 2011) when models contained these variables. For this approach, we reasoned that missing data may have been related to the level of detail recorded by the project staff which, in turn, may have affected success; thus, we could not assume that data were missing at random across the entire data-set. However, within cases that were independently classified as having the same outcome (i.e., successful, unsuccessful, undetermined), we found it reasonable to assume that variables were missing at random.

Few translocation projects documented the size or quality of the habitat in which releases took place and our attempts to systematize recording of these when following-up with respondents in writing were unsatisfactory. Thus, we had no direct way to examine habitat size, quality, or configuration as predictors of reintroduction success.

We conducted linear regressions and computed Student's t-tests using STATISTIX 7.1 (Analytical Software, Tallahassee, FL) and multiple logistic regression analysis to assess the strength of competing models explaining binary outcomes using R (version 3.01, R Development Core Team 2008). When we tested hypotheses, we used $\alpha = 0.05$. Because the normal approximation may be unreliable when interpreting results from logistic regression, we examined percentiles from bootstrapping ($n = 500$) to examine confidence bounds.

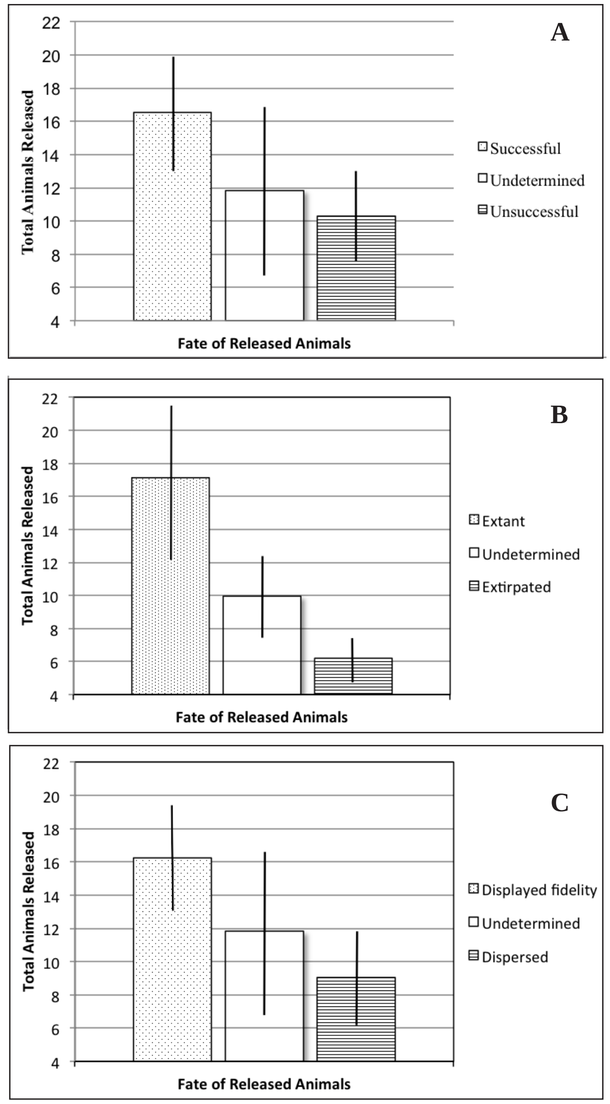

Figure 3. Mean (boxes) and 95% confidence intervals (vertical lines) of the total number of mountain goats released during 1950-2010 within native habitat in North America, among projects categorized as A) successful, unsuccessful, or undetermined; B) goats extant, extirpated, or undetermined; and C) released goat displaying site fidelity, dispersing, or undetermined.

RESULTS

We obtained information on a total of 108 mountain goat translocations within historically occupied range in North America during 1950-2010. Of these, 28 occurred where mountain goats were not considered native and thus

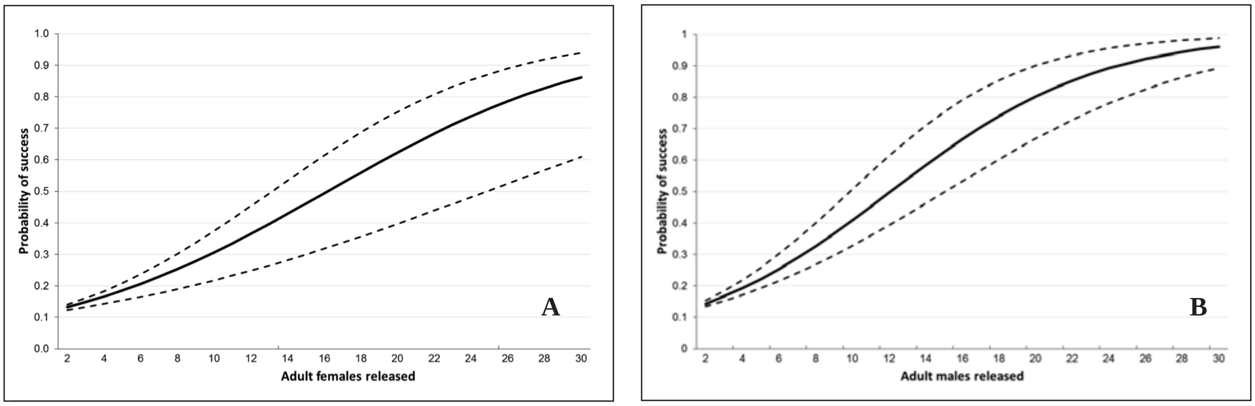

Figure 4. Estimated probability of a mountain goat reintroduction during 1950-2010 within native habitat in North America being successful (see text for definition) as a function of (A) the number of adult females released, and (B) the number of adult males released. Approximate 95% confidence intervals for the probability of success are shown as dashed lines. Models that included the number of juveniles and/or kids did not yield statistically significant improvements in model fit relative to the adult-only models.

were excluded from further analyses. Of the remaining 76 translocations, 6 occurred where a remnant population of native goats existed at the time and were thus best viewed as efforts to augment an existing population. Thus, we categorized 70 projects as reintroductions (Fig. 1, Appendix A). Documentation for all 70 reintroductions included the number of goats released, but we were only able to obtain complete age and sex data of released animals for 46 of these. The remaining 24 projects included various combinations of animals with known sex and age and unclassified animals. A total of 863 goats were reintroduced in these 70 projects, of which 374 were classified as adult females, 193 as adult males, 45 as yearling females, 32 as yearling males, and 51 as kids or undifferentiated "juveniles." Goats reintroduced by each project varied from 1 to 69 ($\bar{x}$ = 12.3, SD = 9.7), with the most common releases being 6 to 10 animals. Frequency of mountain goat reintroduction projects peaked in the 1980s (Fig. 2).

We categorized 15 of the 70 reintroductions as successful and 27 as unsuccessful; 27 others could not be categorized with confidence (Table 1, Appendix B). Fifteen of the 70 reintroduced populations were known to have been extirpated, 31 were known to be extant when most recently surveyed, and 24 were unknown (Table 1). In 21 of the 70 reintroductions, goats were characterized as displaying fidelity to the intended reintroduction area, whereas considerable dispersing from the area characterized 20 others, and 29 could not be categorized.

Only 20 of the 70 projects were documented sufficiently to allow an estimate of growth rate over time (12 of which we categorized as successful, 5 as unsuccessful, and 3 as undetermined). The time elapsed between reintroduction and surveys used for estimation of *r* varied from 6 to 29 years ($\bar{x}$ = 14.5, SD = 7.3). Growth rates ($\lambda = e^r$) varied from 0.89 to 1.19.

Predictors of Population Growth Rate

We found no evidence that population trajectory (*r*) following reintroduction was related to the total number of animals released, total number of adult females released, total number of adult males released, or adult sex ratio (all $P > 0.50$ and $r^2 < 0.03$). Similarly, population trajectory was unrelated to the number of separate releases (1-4) involved in each reintroduction ($F = 1.0$, df = 1,19, $P = 0.33$); the number of sources (up to 3 when multiple releases were made; $F = 1.09$, df = 1,19, $P = 0.31$); or whether source populations were native or themselves resulted from previous translocations ($F = 1.78$, df = 1,19, $P = 0.20$).

Predictors of Reintroduction Success

Reintroductions with larger numbers of goats released were more successful than those with fewer (Fig. 3). Among reintroductions judged successful, total number of goats released averaged 16.8 (SD = 6.9), compared with a mean of 9.6 (SD = 6.1) goats released in unsuccessful projects ($t = 2.92$, $P = 0.006$). Similarly, among reintroductions displaying area-specific fidelity, mean number of goats released averaged 16.2 (SD = 6.9), compared with 9.1 goats (SD = 6.2) for those characterized by extensive dispersal ($t = 3.49$, $P = 0.001$). Reintroductions characterized as extant averaged 15.0 (SD = 7.4) goats compared with 6.2 (SD = 2.4) goats among those that had been extirpated ($t = 4.67$, $P < 0.001$). Logistic regressions indicated that neither the probabilities of reintroduction success, extirpation, nor animals remaining near the release site were predicted by the number of founding populations represented in the release (success on number of sources $\beta = 0.163$, SE = 0.530, $P = 0.759$; extant on number of sources $\beta = 0.670$, SE = 0.667, $P = 0.315$; resident on number of sources $\beta = 0.122$, SE = 0.579, $P = 0.833$).

Logistic regressions indicated that reintroduction success was a positive function of the number of released animals. The best-supported model predicting success included only the number of adult males released, though strength of evidence was almost the same for models with the number of adult females released and with the total number of adults released (Table 2). We felt justified in examining a model including both number of adult males and adult female founders because the correlation among these predictor variables was not strong (Pearson's $r = 0.41$, $n = 39$). In all models, the explanatory variables were positively related to success (Table 3) but the effect magnitudes were greatest for models including only adult goats. The model relating total number of goats (including juveniles and kids) released to success had

Table 2. Strength of evidence of top logistic regression models relating success of mountain goat reintroductions, 1950-2010 in native habitat within North America (see text for definition) to candidate explanatory variables. Shown are Akaike's Information Criterion corrected for small sample size (AIC_c) and number of parameters (*k*).

Model	Deviance	*k*	AIC_c	ΔAIC_c
Number of adult males released	48.147	3	52.15	0.00
Number of adult females released	48.851	3	52.85	0.70
Number of adult males and females released	49.401	4	53.40	1.25

Table 3. Coefficients of best fitting models, top logistic regression models relating success of mountain goat reintroductions, 1950-2010 in native habitat within North America (see text for definition) to candidate explanatory variables.

Model	β	Lower 95%	Upper 95%
Total animals released (all ages)	0.141	0.056	2.524
Adult females released	0.130	0.086	0.162
Adult and juvenile females released	0.139	0.078	0.194
Adult males released	0.178	0.144	0.218
Adult and juvenile males released	0.199	0.035	0.301
Juveniles released	0.020	-0.003	0.049

much weaker support and the confidence intervals around the coefficient that included juveniles overlapped zero (Table 3). Odds-ratios similarly indicated that the probability of a successful reintroduction increased with both the number of adult females and adult males released (Fig. 4). Our model relating the number of adult males and females released to success suggested that, on average, 25 males and 33 females were required to achieve a 50% probability of success. All other things being equal, any given future reintroduction project would have to release somewhat more than this number to attain a high probability of success.

DISCUSSION

Guenzel (1980) concluded that demographic variables characterizing mountain goat releases did not explain subsequent population growth, and speculated that habitat quality and environmental factors would have been better predictors. We similarly lacked data that could be used to address differences in habitat quality among mountain goat reintroductions but, unlike Guenzel (1980), found that success of reintroductions was predicted, at least in part, by demographic characteristics of the founders. As Guenzel (1980) had done, we examined population trajectories following reintroduction, finding – as he had – no meaningful relationships. However, using our binary response variable of reintroduction success, we found that the number of adult females and males, but not the number of juveniles and kids, were significant predictors of success.

Although population trajectory (quantified either by r or λ) would seem intuitively to be an objective assessment metric, we argue that our use of the qualitative measure "success" is more likely to be meaningful. First, the monitoring of goat populations varied considerably and few goat surveys included corrections for imperfect detection or incomplete coverage of the area actually occupied. Thus, reported goat numbers almost certainly contained a great deal of unacknowledged sampling variation, such that analyses with trajectory as the response variable reflected false precision. More critically, goat populations receiving follow-up surveys were unlikely to have been a random sample of all reintroduction efforts. Rather, translocations known or believed to be failing were less likely to be surveyed formally than those doing well, or if a survey was conducted of a failing population, it may not have been documented. Such a bias is suggested in the greater proportion of projects categorized as successful (12 of 20 projects, with 5 unsuccessful) among those allowing estimation of trajectory than among those lacking quantitative follow-up surveys (3 of 50 projects, with 23 unsuccessful).

We failed to find evidence that the number of source populations represented in the reintroduction was a significant predictor of subsequent population trajectory or of any of our binary measures of success. This might seem to suggest that genetic variability among founders was unimportant, contrary to the findings of Biebach and Keller (2012) for reintroduced alpine ibex (*Capra ibex*). We would caution against this interpretation for a number of reasons. First, we found that size of founder populations was a reliable predictor of success (even if not of growth rate) and was likely to incorporate both demographic and genetic benefits (Allendorf and Luikart 2007). Second, though one would intuitively imagine that genetic diversity of founders from >1 source ought to be greater than that from a single source, this may not be true if separate founder populations are highly related to one another. Third, the number of sources for goat reintroductions considered here may have been too coarse a measure of the genetic diversity actually passed on to subsequent generations. We suspect that genetic diversity does play a role in determining reintroduction success, even if our data failed to capture that information.

MANAGEMENT IMPLICATIONS

Despite the frequency with which mountain goats have been the objects of translocation efforts, many releases into historical native habitat (i.e., reintroductions) have failed. Determinants of success are no doubt complex, and probably include factors beyond the biological (e.g., agency management capacity, support of local communities), and even within the realm of biology, factors we could not evaluate with data at hand (e.g., habitat quality). It goes without saying that managers wishing to restore mountain goat populations where they have been depleted need to carefully consider the habitat suitability of target release areas, as well as social, organizational, and economic factors that ultimately will play large roles. However, it appears that programs are likely to fail, regardless of other issues, when only a few goats are released. This retrospective analysis provides evidence that reintroduced mountain goats are likely to persist and expand when >30 females older than yearling class are released. Further, though a sex ratio favoring females is supported, releasing too few adult males can also reduce the chance of success. We recommend that no fewer than 15 adult males also form the nucleus of the new herd (Fig. 4b). Although not specifically supported by our data, we believe it is likely that efforts to enhance the genetic diversity of founders are also worthwhile.

Our quantitative analysis was not designed to unearth the ultimate factors causing small mountain goat reintroductions to fail. It seems reasonable to expect, as with any taxon, that initial survivorship will be lower than expected from individuals with established home ranges (e.g., Smith and Nichols 1984, Paul 2009). Specifically for mountain goats, where documentation has been sufficient (e.g., Fielder and Keesee 1988, Jorgenson and Quinlan 1996), it has often been noted that released goats are prone to dispersing widely. Thus, even if individuals experience high initial survival, they may fail to establish the social cohesion evidently needed to ensure recruitment of future adults (Komers and Curman 2000, Armstrong and Seddon 2007) and thus long-term population persistence and growth.

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Appendix A. Mountain goat reintroductions used in analyses, 1950-2010. Shown are reintroduction site, numbers of released animals by sex and age (M = male, F = female), number of releases, number of source populations, and whether source population was native or reintroduced.

State or Prov		Mountain range	Population name	Year	Total released	Age 2+		Yrlg		Kid		Unaged		Unsexed kid	Unknown	Releases	Sources	Native?
						M	F	M	F	M	F	M	F					
Alaska																		
	1	Kenai	Cecil Rhode Mtn	1983	16	3	6	1	6							1	1	Y
	2	Mt Juneau		1989	11	2	8	1								1	1	Y
Alberta																		
	1	Shunda Mtn	near Nordegg	1972	7	2	5									1	1	Y
	2	Highwood	Picklejar Lakes I	1986	2		2									1	1	Y
	3	Livingstone I	Livingstone I	1987	13	5	4	1	1						2	3	2	Y
	4	Livingstone II	Livingstone II	1993	13	2	9		2							4	2	Y
	5	Highwood	Picklejar Lakes II	1993	21	2	11	4	4							1	1	Y
	6	Highwood	Head Mt/Trap Ck	1995	20	4	9	4	3							2	2	Y
	7	Highwood	Nihahi Ridge	1995	20	3	14		3							2	2	Y
	8	Highwood	Barnaby Ridge	1995	6	1	5									1	1	Y
British Columbia																		
	1	Peace	Bullmoose Mtn	1983	20	3	7								10	1	1	Y
	2	Cariboo	Potato Mtn	1984	5	1	4									1	2	Y
	3	Okanogan	Shorts Ck	1984	5	2	3									1	1	Y
	4	Thompson	Dunn Pk	1985	30	7	23									4	4	Y
	5	Okanogan	Snass Mtn/ Tulameen	1986	8										8	1	1	Y
	6	Cariboo	Nemaea/ Tsuniah	1988	13	2	3							1	7	2	1	Y
	7	Peace	Mt Spieker	1989	8	4	4									1	3	Y
	8	Kootenay	Slocan Valley	1990	20	3	10							1	6	3	1	Y
	9	Kootenay	Mt Broadwood	1990	17	3	10							4		3	3	Y

Appendix A — Cont.

State or Prov		Mountain range	Population name	Year	Total released	Age 2+ M	Age 2+ F	Yrlg M	Yrlg F	Kid M	Kid F	Unaged M	Unaged F	Unsexed kid	Unknown	Releases	Sources	Native?
	10	Thompson	Fountain Ridge	1994	8	2	6									1	1	Y
	11	Kootenay	Trail	1999	15										15	1	1	Y
Idaho																		
	1	Clearwater	Seven Devils	1962	17	4	9			2	2					2	1	Y
	2	Clearwater	Dome Hill	1966	11	5	6									2	1	Y
	3	Selkirk	Lion Ck	1981	2	1	1									1	1	Y
	4	Selkirk	Bugle Ck	1985	2	2										1	1	N
	5	Clearwater	Boulder Ck	1986	7	2	5									1	1	Y
	6	Clearwater	Oregon Butte	1987	12	2	10									1	1	Y
	7	Clearwater	Seven Devils II	1989	8	8										1	1	N
	8	Selkirk	Parker Ck	1989	6		6									2	1	Y
	9	Clearwater	Big Squaw	1994	12	5	7									3	1	Y
	10	Selkirk	Ball Ck	1994	3	3										1	1	Y
	11	Clearwater	Johns Ck	1998	1	1										1	1	Y
	12	Clearwater	Big Mallard Falls	1999	18	9	9									2	1	Y
	13	Clearwater	Sheep Hill	2003	16	5	5			2	4					1	1	Y
Montana																		
	1	Silver Bow	Highlands	1962	7										7	1	1	Y
	2	Cabinets	Drift Ck	1980	7										7	1	1	?
	3	Rattlesnake	Rattlesnake	1984	18	1	6	1	3	1	6				0	2	1	N
	4	Cabinets	Cube Iron/Mt. Headley	1985	26	4	4	2	2	1	1				12	3	2	N
	5	Red Mtn	Helena NF	1989	18	8	10									2	2	N
	6	Red Mtn II	Lewis and Clark County	1990	10	1	7		2						0	1	1	N
	7	Front Range	Red Mountain	2002	15	1	4								10	2	2	N
	8	Front Range	Ear Mountain	2008	10										10	1	1	N

Appendix A — Cont.

State or Prov	Mountain range	Population name	Year	Total released	Age 2+		Yrlg		Kid		Unaged		Unsexed kid	Unknown	Releases	Sources	Native?
					M	F	M	F	M	F	M	F					
Oregon																	
1	Wallowa	Chief Joseph Peak	1950	5						1	3	1			1	1	Y
2	Columbia Gorge	Tanner Butte	1969	8							2	6			1	1	N
3	Columbia Gorge	Tanner Butte	1975	7							3	4			2	1	N
4	Elkhorn	Pine Ck	1983	21							9	12			3	3	Y, N, Y
5	Wallowa	Hurricane	1985	33							13	20			3	2	N, Y
6	Snake River	Hat Point	2000	16		7	3	2					4		1	1	N
7	Snake River	Steamboat Ck	2003	18	3	7	1	3	3	1					1	1	N
8	Oregon Cascades	Mt Jefferson	2010	69	1	14		6	1	2				45	2	1	N
Washington																	
1	Selkirk	Cato Ck	1962	7	2	5									1	1	Y
2	Selkirk	Le Clerc Ck	1964	6	2	4									1	1	Y
3	Selkirk	Flume Ck (Linton)	1965	7	2	4				1					1	1	Y
4	S Cascades	Mt Margaret (GPNF)	1972	8		1	3							4	2	1	N
5	N Cascades	Mt Pilchuck (Darrington RD)	1975	7	1	1								5	2	1	N
6	N Cascades	Higgins Mtn	1981	10	1	6	2		1						1	1	N
7	Selkirk	Hooknose	1981	11	3	4	2	2							1	1	N
8	N Cascades	Lime Mtn	1981	10	5	4			1						1	1	N
9	S Cascades	Kelly Butte	1983	10	5	3	1	1							2	1	N
10	N Cascades	Lake Chelan Corral Ck	1983	5	1	2			2						1	1	N

Appendix A — Cont.

State or Prov		Mountain range	Population name	Year	Total released	Age 2+		Yrlg		Kid		Unaged		Unsexed kid	Unknown	Releases	Sources	Native?
						M	F	M	F	M	F	M	F					
	11	N Cascades	Lake Chelan Domke Mtn	1983	1		1									1	1	N
	12	N Cascades	Lake Chelan Rex Ck	1983	5	2	1	1	1							1	1	N
	13	N Cascades	Lake Chelan Round Mtn	1983	5		2	1	1		1					1	1	N
	14	N Cascades	Lake Chelan Still/Box	1983	13	3	7	1	2							1	1	N
	15	S Cascades	Rooster Comb	1983	28	5	13	3	1	3	3					2	1	N
	16	N Cascades	Lake Chelan Canoe Ck	1984	10	6	3							1		1	1	N
	17	N Cascades	Lake Chelan Pyramid Ck	1984	5	2	3									1	1	N
	18	S Cascades	Smith Ck	1985	12										12	1	1	N
Yukon																		
	1	Mt White I	BC Yukon border	1983	12	4	7			1						2	1	Y
	2	Mt White II	BC Yukon border	1990	10	2									8	2	1	Y

Appendix B. Information about mountain goat reintroductions used in analyses, 1950-2010, including whether or not population remained extant; if extant, last known population size; years of change population size monitored; estimated instantaneous rate of growth (r), whether or not population stayed resident, whether or not reintroduction was judged successful (see text), and source of information.

State/Prov	Mountain range	Population name	Year	Extant?	Pop Size	Years of change	*r*	Stayed resident	Success	Reference
Alaska										
1	Kenai	Cecil Rhode Mtn	1983	Y	53	9	0.133	Y	Y	a,b,c,d,e,f
2	Mt Juneau		1989	?	?			N	?	c
Alberta										
1	Shunda Mtn	near Nordegg	1972	Y	11	27	0.017	Y	N	g,h
2	Highwood	Picklejar Lakes I	1986	Y	2			N	N	g,h
3	Livingstone I	Livingstone I	1987	Y	12	6	0.048	Y	N	g,j
4	Livingstone II	Livingstone II	1993	Y	14	13	0.006	N	Y	g,h,i,j
5	Highwood	Picklejar Lakes II	1993	Y	?			N	N	g,h,j
6	Highwood	Head Mt/ Trap Ck	1995	?	?			N	N	g,h,j
7	Highwood	Nihahi Ridge	1995	?	?			N	?	g,h,j
8	Highwood	Barnaby Ridge	1995	N	0			N	N	g,h,j
British Columbia								?		
1	Peace	Bullmoose Mtn	1983	Y	44	6	0.131	Y	Y	k,l,m
2	Cariboo	Potato Mtn	1984	Y	70	15	0.176	Y	Y	k,l,m
3	Okanagan	Shorts Ck	1984	N	0			N	N	k,l,m
4	Thompson	Dunn Pk	1985	Y	?			?	?	
5	Okanagan	Snass Mtn/ Tulameen	1986	?	?			?	?	k,l,m
6	Cariboo	Nemaea/ Tsuniah	1988	Y	10	11	-0.024	Y	N	k,l,m
7	Peace	Mt Spieker	1989	N	0			?	N	k,l,m
8	Kootenay	Slocan Valley	1990	Y	38	8	0.080	Y	Y	k,l,m
9	Kootenay	Mt Broadwood	1990	?	?			N	N	
10	Thompson	Fountain Ridge	1994	Y	?			?	?	k,l,m
11	Kootenay	Trail	1999		35	8	0.106	Y	Y	m

Appendix B — Cont.

State/Prov	**Mountain range**	**Population name**	**Year**	**Extant?**	**Pop Size**	**Years of change**	***r***	**Stayed resident**	**Success**	**Reference**
Idaho										
1	Clearwater	Seven Devils	1962	Y	71	17	0.084	Y	Y	n,o
2	Clearwater	Dome Hill	1966	?	?			?	?	n,o
3	Selkirk	Lion Ck	1981	N	0			N	N	n,o
3	Selkirk	Lion Ck	1981	N	0			N	N	n,o
4	Selkirk	Bugle Ck	1985	N	0			?	N	n,o
5	Clearwater	Boulder Ck	1986	N	0			N	N	n,o
6	Clearwater	Oregon Butte	1987	?	?			?	?	n,o
7	Clearwater	Seven Dev-ils II	1989	Y	?			?	?	n,o
8	Selkirk	Parker Ck	1989	N	0			?	N	n,o
9	Clearwater	Big Squaw	1994	?	?			?	?	n,o
10	Selkirk	Ball Ck	1994	N	0			?	N	n,o
11	Clearwater	Johns Ck	1998	?	?			?	?	n,o
12	Clearwater	Big Mallard Falls	1999	?	?			?	?	n,o,p,q
13	Clearwater	Sheep Hill	2003	?	?			?	?	n,o,p,q
Montana										
1	Silver Bow	Highlands	1962	?	?			?	?	r
2	Cabinets	Drift Ck	1980	?	?			?	?	r
3	Rattlesnake	Rattlesnake	1984	Y	10	29	-0.020	Y	N	r, s, t
4	Cabinets	Cube Iron/ Mt. Head-ley	1985	?	32.5	25	0.009	Y	Y	u
5	Red Mtn	Helena NF	1989	?	?			?	?	V
6	Red Mtn II	Lewis and Clark County	1990	Y	28	18	0.057	Y	?	r,s,t
7	Front Range	Red Moun-tain	2002	?	?			?	?	w,x
8	Front Range	Ear Moun-tain	2008	?	?			?	?	
Oregon										
1	Wallowa	Chief Jo-seph Peak	1950		?					y,z,aa
2	Columbia Gorge	Tanner Butte	1969	N	0			N	N	y,z
3	Columbia Gorge	Tanner Butte	1975	N	0			N	N	y,z,aa
4	Elkhorn	Pine Ck	1983	Y	301	25	0.107	Y	Y	y,z,aa,ab

Appendix B — Cont.

State/Prov	Mountain range	Population name	Year	Extant?	Pop Size	Years of change	*r*	Stayed resident	Success	Reference
5	Wallowa	Hurricane	1985	Y	106	9	0.130	Y	Y	y,z,aa,ab
6	Snake River	Hat Point	2000	Y	?			Y	Y	aa,ab
7	Snake River	Steamboat Ck	2003	Y	?			Y	Y	aa,ab
8	Oregon Cascades	Mt Jefferson	2010	?	?			?	N	ac
Washington										
1	Selkirk	Cato Ck	1962	N	0			?	N	ad,ae
2	Selkirk	Le Clerc Ck	1964	N	0			?	N	ad,ae,af
3	Selkirk	Flume Ck (Linton)	1965	N	0			?	N	ad,ae,af,ai
4	S Cascades	Mt Margaret (GPNF)	1972	N	?			?	N	ad,af,aj
5	N Cascades	Mt Pilchuck (Darrington RD)	1975	Y	small			?	?	ad,af
6	N Cascades	Higgins Mtn	1981	?	?			?	N	af,ah
7	Selkirk	Hooknose	1981	N	0			N	N	ad,ak
8	N Cascades	Lime Mtn	1981	?	?			?	?	ad,af
9	S Cascades	Kelly Butte	1983	Y	34	15	0.082	Y	?	af,al, am,an
10	N Cascades	Lake Chelan Corral Ck	1983	?	?			N	?	ag,ah,ao
11	N Cascades	Lake Chelan Domke Mtn	1983	?	?			N	?	ag,ah,ao
12	N Cascades	Lake Chelan Rex Ck	1983	?	?			N	?	ag,ah,ao
13	N Cascades	Lake Chelan Round Mtn	1983	?	?			N	?	ag,ah,ao
14	N Cascades	Lake Chelan Still/Box	1983	Y	?			Y	Y	af
15	S Cascades	Rooster Comb	1983	Y	17	15	-0.033	Y	N	af,am,an
16	N Cascades	Lake Chelan Canoe Ck	1984	?	?			N	?	ag,ah,ao

Appendix B — Cont.

State/Prov	Mountain range	Population name	Year	Extant?	Pop Size	Years of change	*r*	Stayed resident	Success	Reference
17	N Cascades	Lake Chelan Pyramid Ck	1984	?	?			N	?	ag,ah,ao
18	S Cascades	Smith Ck	1985	Y	30	18	0.051	?	Y	af,ap,aq
Yukon										
1	Mt White I	BC Yukon border	1983	Y	6	6	-0.116	Y	N	ar,as
2	Mt White II	BC Yukon border	1990	Y	27	10	0.099	Y	Y	as

[a]Smith and Nichols 1984; [b]ADFG 2010; [c]Paul 2009; [d]ADFG 2011; [e]McDonough and Selinger 2008; [f]T. J. McDonough, Alaska Department of Fish and Game, Homer, AK, January 2013; [g]Smith et al. 1996; [h]Alberta Fish and Wildlife Division 2003; [i]Smith 2008; [j]Jorgenson and Quinlan 1996; [k]Mountain Goat Management Team 2010; [l]Hatter and Blower 1996; [m]Blood 2001; [n]Oldenburg 1996; [o]Toweill 2009; [p]Toweill 2010; [q]Toweill 2012; [r]McCarthy 1996; [s]Firebaugh et al. 1991; [t]Firebaugh et al. 2003; [u]Sterling, pers. comm; [v]Gadbow 2005; [w]Nielsen et al 1986; [x]Nielsen et al 1987; [y]Coggins et al. 1996; [z]Matthews and Coggins 1994; [aa]ODFW 2009; [ab]ODFW 2010; [ac]ODFW and CTWS 2010; [ad]Johnson 1983; [ae]Base and Zender 2007; [af]Johnson 1996; [ag]Fielder and Keesee 1988; Fielder 2001; [ah]Shirk, pers. comm; [ai]Anon 1975; [aj]Wadkins 1985; [ak]Zender 1985; [al]Spencer 1998; [am]Spencer 1986; [an]Vales, pers. comm; [ao]Moorhead 1989; [ap]Miller 2003; [aq]Miller 2004; [ar]Carey 1996; [as]Yukon Wildlife Branch 2006.

Using Long-Acting Neuroleptics and Other Drugs to Facilitate Bighorn Sheep Capture and Translocation

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ABSTRACT Capture and translocation are important tools for managing bighorn sheep (*Ovis canadensis*) in many jurisdictions. Over the last 10 years we have been exploring uses of long-acting neuroleptics (LANs) and other tranquilizers as adjuncts to bighorn sheep capture and translocation. For capture via darting, a combination of butorphanol (30 mg), azaperone (10 mg), and medetomidine (12 mg) (BAM), which constitutes a 1.1 ml dose, provides a small-volume alternative to the potent opioids. BAM immobilization can be antagonized with atipamezole (60 mg) and naltrexone (50 mg), both of which are delivered intramuscularly. To reduce stress associated with physical capture (drop net or helicopter netgunning), a combination of midazolam (40–45 mg) and azaperone (15 mg) administered immediately upon capture provides transient tranquilization and muscle relaxation during handling. For extended tranquilization (e.g., during transport and overnight holding), long-acting haloperidol (30 mg) provides sustained calming effects for 24–48 hours. In our experience, uses of these various drugs and drug combinations can be tailored to management applications on a case-by-case basis to facilitate handling, reduce stress, and improve the overall success of bighorn sheep capture and translocation.

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KEY WORDS Azaperone, bighorn sheep, butorphanol, haloperidol, long-acting neuroleptic, medetomidine, midazolam, *Ovis canadensis*, stress.

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Managing and Harvesting Mountain Goats for Traditional Purposes by Indigenous User Groups

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ABSTRACT The Tlingit Tribe in southeast Alaska, USA, has historically used mountain goat (*Oreamos americanus*) wool for weaving traditional robes. These robes are repositories of Tlingit culture, history, and aesthetics, as well as an archive of the animal itself. The twinning method of Tlingit weaving has been used for thousands of years. During regular hunting seasons, wool is either absent (late summer and fall) or is difficult to separate from guard hairs (early winter) because it is firmly attached to the hide. Late winter and early spring, which are after regular hunting seasons, are the best times to collect wool from hides for weaving. Male mountain goats shed their wool in late spring while the nannies do not lose all of their winter wool until they have weaned their kids. In addition to wool from harvested goats, wool shed during late spring and summer and wool from winter and spring mortalities can also be collected. The lack of mountain goat wool during the regular hunting season, combined with limited knowledge of shed areas, makes wool hard to come by, putting the traditional art form of mountain goat robes at risk. Since 2004, Alaska Fish and Game has made 3 goat permits per year available for the Tlingit Tribe for Unit 4 (Baranof Island) in the spring. The harvest must be affiliated with a cultural class of Tlingit weaving; hunters must be registered with the tribe; and the meat must be shared with the community. This special harvest is a step toward renewing our relationship with the mountain goat, which provides wool for weaving traditional robes, meat for the community, and harkens back to the traditions of the Tlingit Tribe to sustainably harvest mountain goats during the spring.

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KEY WORDS Alaska, mountain goat, *Oreamos americanus*, robe, Tlingit Tribe, indigenous, weaving, wool.

My name is Teri Rofkar; I am a member of the Tlingit Tribe, in southeast Alaska, USA. My Tlingit name is "Chaas' koowu tlaa." I am from the Tak'dein taan Clan, Tax Hit, a Raven from the Snail house. Our clan comes from the outside coast on the northern Gulf of Alaska. Our clan has been known for its weaving skills for thousands of years and I work towards continuing that legacy.

The Tlingit Tribe has traditionally used mountain goat (*Oreamos americanus*) wool in our weaving. The Janwu Aani robe, which took me over 900 hours to weave, is an example of a traditional mountain goat wool robe (Fig. 1). This robe is woven without the use of a loom; it is composed of two and three strand twinning, similar to spruce root basketry in my area. The Tlingit were recognized as the last active weavers using this ancient weaving technique. Examples of this twinning method using other materials have been found in archaeological sites in other parts of the Americas. These include: 1) a fragment of a twined mat dating back 11,200 years found in Fishbone Cave,

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Nevada; 2) twined mats binding remains dating back 9,400 years found in Spirit Cave, Nevada; and 3) a twined textile discovered with the Kennewick Man dating back 9,300 years ago (Kehoe 2006).

In 2008, I was asked to provide mountain goat samples from Baranof Island to be included in a DNA study (Shafer et al. 2012) and I incorporated symbols that articulated the details of the DNA study in the Janwu Aani robe I was weaving (Fig. 2). This robe has symbols that relate to the 2 mountain goat populations on Baranof Island. The side borders are an identical double helix with one flipped adenosine bridge to symbolize the 2 goat populations. I covered the stranding with beads to represent the proteins and amino acids. Windswept alpines and bear tracks are also embedded in the weaving. This is the first Raven's Tail robe woven with 100% mountain goat wool in over 200 years. I used wool from about 7 goats to weave this robe and it required about 2,000 hours to process the wool and do the weaving. This robe holds the history of the Tlingit relationship with the mountain goat of Baranof Island. It has images linked with the past but, most importantly, it documents the present for the future. Similar to other traditional Tlingit objects, this robe is a repository for cultural, historical, and aesthetic information and archives the animal itself. In 100 years this robe will still be dancing and the details of our collective relationships with the mountain goats will still be told. With the lack of wool during hunting season, combined with limited knowledge of shed areas, it took me 17.5 years to gather enough wool to weave this one robe using every wool collection method available.

Tlingit village sites date back 11,000 years on the outside coast of Glacier Bay and Icy Straits, Alaska where the ancient Tlingit weavings originated. There are 10 purely geometric robes and 4 hybrid Raven's Tail and Chilkat robes (Fig 3.). Russians collected

Figure 1. Janwu Aani robe woven from 100% mountain goat wool by Teri Rofkar, the Tak'dein taan Clan, Tlingit Tribe, Alaska, USA.

Figure 2. Detail from the Janwu Aani robe woven with 100% mountain goat wool by Teri Rofkar, the Tak'dein taan Clan, Tlingit Tribe, Alaska, USA. One of the symbols on the robe is the double helix in keeping with the tradition of robes being repositories of information.

6 of the 10 geometric robes in 1788 from Lituya Bay; they are now at the Kunstkamara Museum in St. Petersburg, Russia. As the weaving cultures encountered each other there was exploration of technique. I believe that the two techniques were both fully evolved when this exploration took place. To my knowledge, none of the existing mountain goat wool robes have been dated. I was involved in recovering a 4,700-year-old basket from the tidal zone on Baranof Island; it was woven using the exact

Table 1. Approximate percentages of useable wool and unusable waste (i.e., guard hairs and debris) for mountain goat wool collected from different sources, Alaska, USA.

Source	Waste Description	Wool %	Waste %
Winter/Spring mortality sites	Much guard hair and debris	25	75
Shed wool	Few guard hairs, some debris	33	67
Slipped hide (hunter harvest)	Much guard hair	44	56
Combed hide (hunter harvest) or live goat	Few guard hairs	85	15

twine methods as the Janwu Aani robe.

I have researched how traditional mountain goat robes were made, including the math used in creating a large geometric robe. There is natural science and biology needed to harvest the mountain goat wool. With no agriculture or domestic animals, indigenous harvesters closely followed changing environmental conditions to collect materials. The Tlingit have no words for "art" or "science" but these concepts were part of everyday life, from understanding weather patterns and harvesting seasonal foods to collecting materials for shelter and navigating the complex waterways of southeast Alaska. Thousands of years of learning are still present in the methodologies used today.

Wool Collection

Wool can be collected from 4 sources that can vary greatly in the percentages of wool and waste (i.e., guard hairs and debris) present (Table 1). Natural mortalities that occur during late winter and early spring can have useable wool present even if found later in the year. Shed wool can be found from late spring to summer near mineral deposits and summer grazing areas. Slipped wool can be obtained

Figure 3. Hybrid Raven's Tail/Chilkat mountain goat wool robe (foreground) and 2 geometric mountain goat wool robes, Tlingit Tribe, southeast Alaska, USA.

from the hides of animals harvested by hunters in the early winter. Slipping is a method of removing wool from the hide by rotting it until the wool and hair fall out together. This creates a smooth skin great for drum making. Slipping is the most labor-intensive method because many guard hairs must be removed individually from the wool. In our area, wool is available from slipped hides during the last 2-3 weeks of the regular hunting season. Combing hides of animals killed during late winter or early spring (or live animals) produces the highest quality wool with few guard hairs and little debris.

Table 2. Mountain goat hunting season dates and wool availability in Unit 4 (Baranof Island), Alaska, USA.

Dates	Hunting Season	Wool Available
Aug. 1 - Nov. 15	Regular	No
Nov. 15 - Dec. 31	Regular	Yes
Dec. 31 - April 15	None	Yes
April 15 - Aug. 1	None	No
Nov. 15 - April 15	Traditional	Yes

Harvest Seasons

Regular hunting seasons for mountain goats in Unit 4 (Baranof Island) run from early August through the end of December (Table 2).

There is an annual cycle for collecting food on Baranof Island. Summer is the season for salmon and berries, while the fall brings deer and halibut that are fat and healthy. During late fall and early winter, there are small runs of late salmon and other small animals to supplement the proteins and berries stored from the summer and fall. However, by late winter and early spring, there is a lack of fresh protein until herring arrive on the coast in late spring, bringing sea mammals and eggs for harvesting.

In the late winter and early spring, the goats move down the mountains to avoid high winds and storms; some come down as far as the beaches for salty seaweeds. The wool begins to detach from the skin in anticipation of the spring shed. These are all indications of a traditional time for hunting, based on needs rather than sport. The regular Unit 4 goat harvest season only provides two weeks to one month for collecting wool that is usable for weaving.

A respectful relationship with mountain goats includes harvesting when they have wool without jeopardizing the population. Mountain goat has been a staple in the Tlingit diet for over 10,000 years. Winter and spring are a traditional time for harvesting goats for wool and meat. However, spring is the time goats have their young and their reserves are depleted from the winter. To understand how traditional spring harvest could occur and still sustain the population, I would like to relate a story. An Elder from the Chilkat River area visited me at my studio while I was removing guard hairs from the wool of a late-hunted hide. He looked at my pile of wool and asked “Is that from a billy?” I explained I wasn’t sure because some of the hides I had slipped were from nannies. “We used billies!” was his response. When I inquired why, he answered, “It’s traditional.” I have since found the science in this tradition. The billies shed out first in the spring, while the nannies don’t lose all their winter wool until they have weaned their kids, thus creating a method of built-in sustainability (Chadwick 1983). The traditional harvesting cycle in the spring coincided with annual low tides for gathering clams, octopus, chiton, abalone, and sea urchin. With the rich proteins from the sea, it only required a few goats to feed a whole village.

Shed wool can also be an important source of wool for weaving. The elders talked about specific areas the goats would travel in the spring, seeking mineral licks and rich grazing opportunities, creating areas of shed along these corridors. Documenting shed areas with the help of biologists, hikers, and hunters would be very helpful for collecting wool in the future.

The lack of mountain goat wool during the regular hunting season, combined with limited knowledge of shed areas, makes wool hard to come by, putting the traditional art form of mountain goat robes at risk. For centuries, the Tlinget tribe harvested mountain goats during the late winter and spring without jeopardizing the sustainability of the populations. If sufficient wool for traditional robe weaving was to be available, some harvest at this time was necessary. To this end, I took my case to the Federal Subsistence Board, resulting in a Customary and Traditional Harvest Permit with the Sitka Tribe of Alaska. Since 2004, Alaska Fish and Game has made 3 permits per year available for the Tlingit Tribe for Unit 4 in the spring. The permit comes with numerous restrictions: 1) the harvest must be affiliated with a cultural class of Tlingit weaving; 2) the hunters must be registered with the tribe and the United States Forest Service; 3) the meat must be shared with the community; and 4) hunters must apply for the permit every year. From 2004-2012, the Tlingit Tribe harvested 7 male goats out of a possible 27 animals. Our numbers are added to the harvest total for each calendar year; a total of 518 mountain goats were harvested in Alaska in 2007 (Alaska Department of Fish and Game).

I would like to encourage agencies and individuals to work together to create sustainable relationships with the animals in their respective homes. Relationship, by definition, is not preservation. Therefore, maintaining a sustainable relationship can describe a different management methodology than natural resource management. This small change can make the difference between a purely economical equation and a more holistic environmental decision. We all know relationships can be complicated.

Wildlife managers can learn from indigenous groups and their ancient traditions. Underlying traditions may hold more than spiritual customs — they may hold unidentified sustainable scientific solutions and, by my definition, that is a form of spirituality.

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Observational Description of Alpine Ungulate Use at Mineral Licks in Southwest Alberta, Canada

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ABSTRACT Mineral licks are a unique resource utilized by all ungulate species in North America. The location of a mineral lick can have significant bearing on population distribution. Research on alpine ungulate mineral licks in Alberta has been limited to sampling elemental content of licks and documenting bighorn sheep (*Ovis canadensis*) attraction to man-made mineral licks (e.g., natural gas salty deposits). However, no observational studies of natural mineral licks have been conducted in the southwest region of Alberta. Current guidelines suggest a minimum forested buffer distance of 100 m from licks and restricted industrial activity, mainly helicopter seismic activity, in alpine ungulate zones from 1 July to 22 August. We demonstrate why mineral licks should be a special management concern and not simply a general categorization in industrial operating guidelines. From 2010–2012, we identified, monitored, and assessed 9 alpine mineral licks in southwest Alberta. Initial visits by both bighorns and mountain goats (*Oreamnos americanus*) generally began before licks became snow-free, while routine use commenced shortly after snowmelt, peaking in use during late June and July. Mountain goat licks were essentially visited daily at all times; bighorn licks were visited slightly less, usually during daylight hours. Analysis of animal collar and aerial survey data show both bighorns and mountain goats have high spatial fidelity to lick location. In light of the intensity with which alpine ungulates use mineral licks in southwest Alberta, both the lick itself and the proximity to surrounding topographic cover and food and water resources should be considered in land use decisions. Mineral licks are an essential component of alpine ungulate habitat. The long-term integrity and productivity of alpine ungulate populations throughout their range in North America would benefit from having mineral licks managed around guidelines that are specific to the timing of use and the species involved.

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KEY WORDS Alberta, alpine ungulate, bighorn sheep, mineral lick, mountain goat, *Oreamnos americanus, Ovis canadensis*, spatial fidelity, trail camera.

Natural mineral licks are unique habitat features that are essential to the diet of all North American ungulate species (Jones and Hanson 1985). Ungulates use mineral licks to compensate for dietary deficiencies, typically during late spring and early summer (Jones

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and Hanson 1985) when they are required to make a quick transition from their winter diet to lush green spring forage, which tends to be extremely high in potassium, carbohydrates, and protein but low in fiber (Ayotte 2004). The chemical properties of spring forage reduce the digestive efficiency of the rumen and impair absorption (Kreulen 1985). Forage digestibility is further compromised for species like moose (*Alces alces*) and mountain goat (*Oreamnos americanus*) because they consume forages high in plant defense compounds (Ayotte et al. 2006). Lick soils provide the necessary elements to help stabilize the rumen, as well as supplement demands of lactation and growth (Kreulen 1985, Ayotte et al. 2006).

The location of a mineral lick on the landscape will strongly influence the movement and distribution of ungulate populations (Heimer 1974, Simmons 1982, Watts and Schemnitz 1985). Unlike forage vegetation patterns, which are non-static and vary with natural disturbance patterns over time, mineral licks are a static resource that may be used by many generations of a population over long periods of time. Since these small, localized areas are of significance to the ecology of all ungulate species, their preservation on the landscape is critical. Developing management guidelines that safeguard mineral licks and recognize the importance of preserving connectivity around these habitat features is therefore needed (Dormaar and Walker 1996, Rea et al. 2004).

Currently, Alberta's timber harvest guidelines list mineral licks under the "other species/ sensitive site" section of the document. In this section, mineral licks are universally managed with amphibian sites, bat hibernacula, nesting areas, and wolverine dens — all of which require a forested buffer distance of 100 m (AESRD 2012, 2013). A similar approach was taken as part of the Enhanced Approval Process for industrial activities, such as oil and gas development. Although timing restrictions are in place for bighorn sheep (*Ovis canadensis*) and mountain goat range to protect critical periods like lambing, no restrictions or suggestions are in place for activity in and around mineral licks. Both bighorn sheep and mountain goats are sensitive to a wide variety of human disturbances. The type and level of disturbance can alter the behavior of bighorn sheep and mountain goats to the degree where it can displace them from desirable foraging areas, migration corridors, and secure resting areas (Schoenecker and Krausman 2002, Keller and Bender 2007, St-Louis et al. 2012, Côté et al. 2013). A lack of mineral-lick-specific guidelines is at least in part due to the state of research on mineral licks in Alberta, which has been limited to date. A study conducted in 1992 sampled the elemental content of licks in southern Alberta (Dormaar and Walker 1996); however, species-use data was not collected. One study documented bighorn sheep attraction to man-made mineral licks (e.g., natural gas salty deposits) along the eastern slopes of Alberta (Morgantini and Bruns 1988), but no studies of natural mineral licks have been conducted in the southwest region of Alberta. As a result, our understanding of temporal and spatial use of habitat surrounding mineral licks is limited.

Our objectives were to document lick locations, conduct site assessments, and establish a monitoring approach that would allow us to determine species composition, and timing, and intensity of lick use by bighorns and mountain goats. We hypothesized that the peak period of use for alpine ungulates using mineral licks would be largely driven by plant phenology (the variable timing of seasonal plant growth in the alpine). We expected to see annual variation in the date in which a lick is first visited during the season (based on spring condition and snow pack) and we expected to see consistency in the timing of peak use among years.

STUDY AREA

The study was conducted in southwest Alberta, Canada (Fig. 1). The western boundary conformed to the Alberta and British Columbia (BC) provincial border, which is also the Continental Divide, while the northern boundary was defined using the northern extent of Wildlife Management Unit (WMU) 402 (upper polygon). The southern boundary was the south boundary of Waterton Lakes National Park (lower dark polygon), which is also the Alberta and Montana border. The eastern boundary was restricted to precipitous terrain within WMUs 400 (central polygon), 402, and Waterton Lakes National Park. The Municipality of the Crowsnest Pass (49°60'N, 114°43'W) is centrally located in the study area.

The study area falls within the Rocky Mountains Natural Region of Alberta, which includes the alpine, subalpine, and montane natural sub-regions. The alpine and subalpine regions receive significant precipitation (~560 mm annually) and the growing season is short and cool in summer (Archibald et al. 1996). Open stands of Engelmann spruce (*Picea engelmannii*), subalpine fir (*Abies lasiocarpa*), and subalpine larch (*Larix lyallii*) generally occur at higher elevations and young, closed stands of fire-successional lodgepole pine (*Pinus contorta*) reside at lower elevations. Dynamic microclimates occur throughout the region as a result of varying aspect, elevation, and substrate (Natural Regions Committee 2006). Soils in the subalpine are dominantly brunisols or regosols, while soils under forest cover at lower elevations consist primarily of luvisols or brunisols (Archibald et al. 1996).

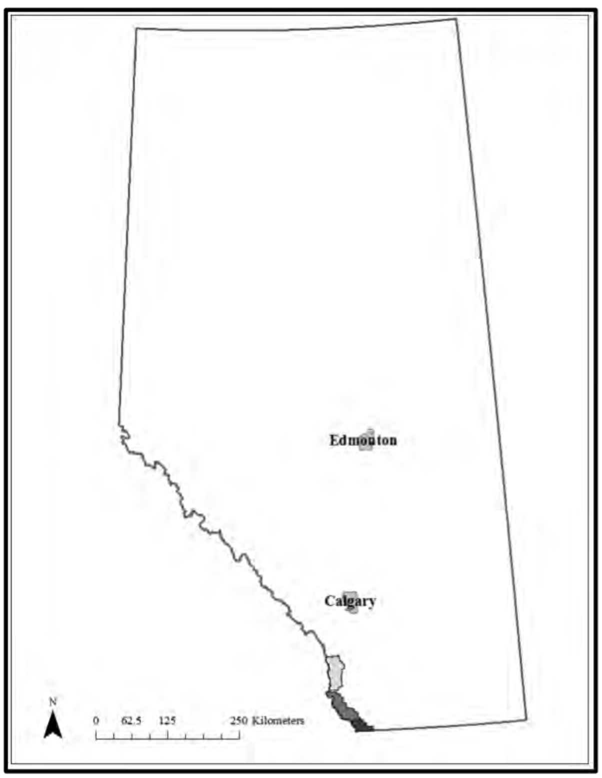

Figure 1. Study area within the province of Alberta, Canada. Wildlife Management Unit 402 (upper polygon), WMU 400 (central polygon) and Waterton Lakes National Park (lower polygon).

METHODS

Mineral lick site characteristics

We compiled a list of mineral licks from two sources: 1) through a survey of local outdoorsmen, area biologists, and area foresters (Anatum Ecological Consulting Ltd.) and 2) licks identified in Waterton Lakes National Park (B. Johnston, Parks Canada, personal communication). Initially, we visited all potential locations to confirm whether a mineral lick existed. When a lick was located, we gathered the following data: site location, animal sign, lick type, soil type, number of game trails, and the plant community surrounding the lick. We also identified whether there was probable risk of human disturbance. Soil and water samples were collected in 2013 to provide a baseline summary of elemental concentrations at mineral licks. Soil samples were collected from the area of the lick believed to have the highest use (i.e., cavities, excavations, smoothly licked, or chewed areas). All soil samples were analyzed using a digestion technique described by Horvath (2009), the Strong Acid Leachable Metals in soil method. Samples were dried at

≤60°C, sieved, and digested using a strong acid digestion that dissolves most elements that could become environmentally available (K. Beaudet, Maxxam Analytics Inc., personal communication).

Timing and duration of mineral lick use

We collected data on bighorn sheep and mountain goat use of mineral licks using remote trail cameras. We placed Reconyx PC800 and PC900 motion-triggered trail cameras at bighorn sheep and mountain goat mineral lick sites from 1 April to 31 October, 2011–2013. We programmed the cameras to obtain 3 photos per trigger at a 5-second interval between photos. The 5-second interval between images allowed time for animals to move into and about the frame, increasing the potential to confidently classify and count the number of animals in a given group. A 5-minute quiet period was set between triggers (set of 3 photos), as this significantly reduced the amount of incoming image data while still providing sufficient observational detail.

To ensure we captured the first wildlife visit at each site, we deployed our cameras in late March to early April each year. To verify that cameras were in the appropriate positions at that time of year (as the sites were still completely snow covered), we put out camera stands and security boxes the previous fall. This was advantageous as we could predetermine where the stand or security enclosure should be placed (i.e., avoiding direct sun, having the ability to clear obstructing vegetation, choosing appropriate distance and height) while the mineral lick was still detectable and snow-free. At sites where no trees were available for mounting cameras, we used portable camera stands. The portable stands were constructed of aluminum tubing and were collapsible for ease of transport. Cameras were placed on trees or stands at a distance of 10 m or less from a mineral lick to ensure animals would be within detection and infrared range.

We created a custom image database to process our camera data (Microsoft Access Version 2010). The database automatically loaded the image number, date, time, and temperature. We manually entered species and minimum group size from a single trigger event (set of 3 consecutive images). Minimum group size was determined by counting the greatest number of animals in the set of 3 photos. As bighorn sheep and mountain goats often visited in large groups, we recognized that outlying individuals could have been missed in images, so our results represent a minimum group size. Bighorn sheep and mountain goat visits were determined when the time between visits was >30 minutes. These visitations included repeat visits and same group visits.

Spatial fidelity

We compared mountain goat aerial survey locations (collected from 2004–2013) to 6 mineral licks that we monitored in Waterton Lakes National Park and WMUs 400 and 402. The timing of mountain goat aerial surveys paralleled the timing of mountain goat mineral lick and summer range use. The summer range of mountain goat nursery herds averages 18–25 km^2 while male goat range averages 3–4 km^2 (Festa-Bianchet and Côté 2008). Singer and Doherty (1985) reported strong fidelity to small annual home ranges by goats when influenced by a mineral lick (females 8.9 km^2, males 6.3 km^2). We assumed that a 3-km radius around each mineral lick represented the mineral lick zone, which is likely lick influenced fidelity, and a 5-km radius represented summer home range of those goats that used a particular lick on a recurring basis. We plotted aerial survey points collected from 2004–2013 and tallied those goat counts within a 3-km and 5-km radius of each mineral lick (ArcMap 10.1, software by ERSI).

To build upon our evaluation of alpine ungulate fidelity to mineral licks, we conducted a retrospective analysis of bighorn sheep

Figure 2. Unstable slope mineral licks were used by bighorn sheep and mountain goats, where they consumed clay at cavities.

movements in relation to mineral licks that we monitored. Site fidelity to mineral licks by wild sheep has been shown to be as high as 100% by ewes (Heimer 1974). Female sheep, in particular, will focus their summer activity around mineral licks (Heimer 1974, Simmons 1982). Bighorn ewe summer range averages 30 km^2 in size (Festa-Bianchet 1986). Our data on sheep movement came from 2 studies. First, we used movement data from 3 Global Positioning System (GPS) collared bighorn sheep from our Yarrow-Castle research (Jokinen et al. 2008). Second, we used data from 3 of 13 bighorn sheep that were collared in the Waterton Lakes National Park region (K. Keating, unpublished). These sheep were chosen because they clearly visited the mineral licks that we monitored and we wanted to illustrate bighorn use of the mineral lick zone over time.

Figure 3. Site 60 represents an example of a timber flat surface mountain lick in southwest Alberta. Note the hard packed lick area surrounded by vegetation and forest cover. These licks contained a slight seep at the source and were saturated throughout the season.

RESULTS

Mineral lick site characteristics

Across the study area, 9 alpine ungulate mineral licks were monitored using trail cameras. Of these, 3 were primarily used by bighorns, 5 by mountain goats, and 1 was shared equally between both species. A few bighorns passed through one of the mountain goat licks (site 78) but did not visit with regularity or for an extended time. Two bighorn licks and 3 mountain goat licks were monitored for 2 seasons, while the other 2 bighorn and 3 mountain goat licks were monitored for 1 season (including the shared lick).

When conducting field assessments at alpine mineral licks, animals were often present during the months of July and August. Goats used mineral licks at all hours of the day and bighorn tended to target morning and afternoon periods, thus there was no favorable time when disturbance of the animals could be avoided.

Alpine licks were usually located in rocky areas having little to no vegetation nearby; therefore, an organic layer was essentially absent and the disturbed area lacked hedging, typical of forest mineral licks (Jokinen et al. 2015). Alpine licks in our study region tended toward 3 distinct varieties. We termed the 3 lick types as unstable steep slope, timber flat surface, and rock face (Fig. 2–4).

Unstable, steep-slope licks (Fig. 2) were located on rocky slopes, having granule to boulder sized fragments, no vegetation, and contained deep cavities dug by bighorns or goats to access clay substrate. The surface of these licks eroded and changed in appearance each year with spring run-off. Timber flat surface licks were located at a lower elevation, at the forest edge, and somewhat removed from alpine ungulate escape terrain. Vegetation and forest flanked these licks; however, an organic layer was present but thin at the disturbance. Because these licks were located at the fringe of alpine ungulate habitat, they were often shared with forest ungulates, resulting in more frequent carnivore detections (Fig. 3). We documented instances where carnivores caused bighorn sheep and mountain goats to flee; however, confrontations were only observed at timber flat surface licks. Rock face licks were located along cliff faces, well within escape terrain and were obscure, as the rocky terrain seldom offered clues of animal use (Fig. 4). Essentially, animals frequenting a cliff area helped identify the location of a rock lick.

Alpine mineral licks were at elevations averaging 1,918 m (SE = 38.90) and 128 m^2 (SE = 13.26) in size (Table 1). Elevation at bighorn sheep licks averaged 1,874 m; elevation at mountain goat licks averaged

Figure 4. Site 78 is an example of a rock face lick used by mountain goats in southwest Alberta.

1,954 m. Hedging was insignificant at the majority of alpine licks in this study, as the substrate was primarily rock and there was little to no organic layer. Hedging occurs when trampling of hooves abruptly carve at the organic layer bordering a lick. Evidence for rubs was sporadic due to the lack of vegetation at most of the alpine licks; however, bighorn rams often rubbed their horns on Krumholtz conifers. Most of the alpine licks held moisture throughout the season and it appeared to be the seeping water at rock face licks that functioned as the mineral channel.

Game trails leading away from the alpine licks were extremely apparent in the direction of the escape terrain and remained recognizable until they reached solid rock faces. Rock face licks often lacked evidence of game trails

Table 1. Description of alpine ungulate mineral licks assessed in southwest Alberta, 2011−2013.

Site	Elev (m)	Hedging[c]	Digs[d]	Beds[e]	Rubs[f]	Browse[g]	Lick Type	Lick Soil	Soil Type	Lick Area (m^2)
1[a]	1,647	Yes	No	No	No	Yes	Dry	Dry	Sand/ Cobble	108.6
9	1,683	No	Yes	Yes	No	No	Unstable Steep Slope	Moist	Clay	450.0
12	1,893	No	No	Yes	No	Yes	Timber Flat Surface	Moist	Sandy Loam	100.0
13	2,260	No	Yes	Yes	No	No	Unstable Steep Slope	Moist	Boulder/ Gravel/Clay	225.0
60[b]	1,943	No	No	Yes	No	Yes	Timber Flat Surface	Moist	Silt/Loam	80.0
78	1,720	No	No	Yes	No	No	Rock Face	Moist	Rock	12.0
81[b]	2,205	Yes	No	Yes	No	Yes	Timber Flat Surface	Moist	Sandy Loam	11.0
83	1,959	No	Yes	Yes	No	No	Unstable Steep Slope	Moist	Boulder/ Gravel/Clay	144.0
84	1,950	No	No	Yes	No	No	Rock Face	Moist	Rock	25.0

[a] This site holds water early in the season but dries up after snowmelt, not a typical seeping lick
[b] This site hosts both alpine and forest species
[c] Hedging: an abrupt edge created by trampling of hooves on an organic layer
[d] Dig: cavities or excavations created by ungulates
[e] Beds: sign of bedding depressions
[f] Rubs: sign of horn or antler rubbing
[g] Browse: sign of whether vegetation immediately surrounding lick is browsed

because they were located on solid rock faces. The immediate area surrounding an alpine lick can provide evidence needed to determine the species using it. During the peak season of lick use, alpine licks almost always had a distinct barn-like odor, and fresh urine, scat, and tracks were observed. Clumps of molted hair on the ground or snared along vegetation of game trails were also found. Bedding areas were typically observed at alpine licks.

We monitored a bighorn lick (site 1) that likely resulted from several years of cattle mineral block placement at its location. Cattle graze within the forest reserve in our study area and the lessee had placed a mineral block at this lick location in 2012. Bighorn sheep and cattle were observed visiting the site at the same time in 2012. Although mineral blocks were not placed at site 1 each year, the minerals likely leach to the surface making them available to animals when water pools in the area during spring melt and precipitation. Bighorn visitations were comparable during year 1 of monitoring site 1, when no mineral block was available; however, domestic cattle occurrences increased substantially from year 1 to year 2 (the year a mineral block was on site).

Bighorn sheep mineral licks tend to contain higher concentrations of soil elements when compared to mountain goat mineral licks (Fig. 5). The mineral lick having both bighorn and goats visiting had the highest concentrations of calcium and magnesium. In general, soil elemental values were relatively similar between lick types, with exception of calcium and sodium levels observed at rock face licks (Fig. 6). Calcium and sodium

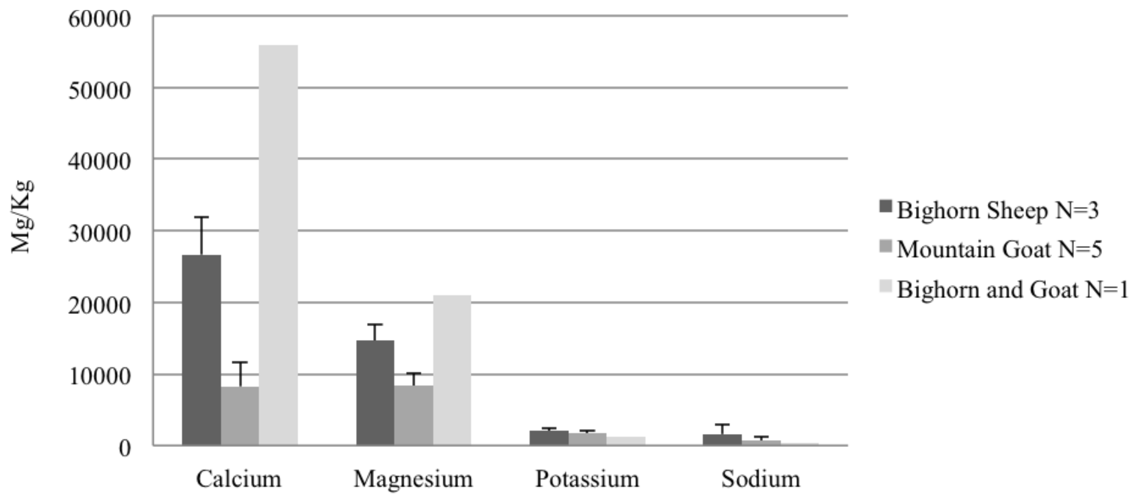

Figure 5. Mean (+SE) concentration of soil elements at bighorn sheep and mountain goat mineral licks in southwest Alberta, 2013.

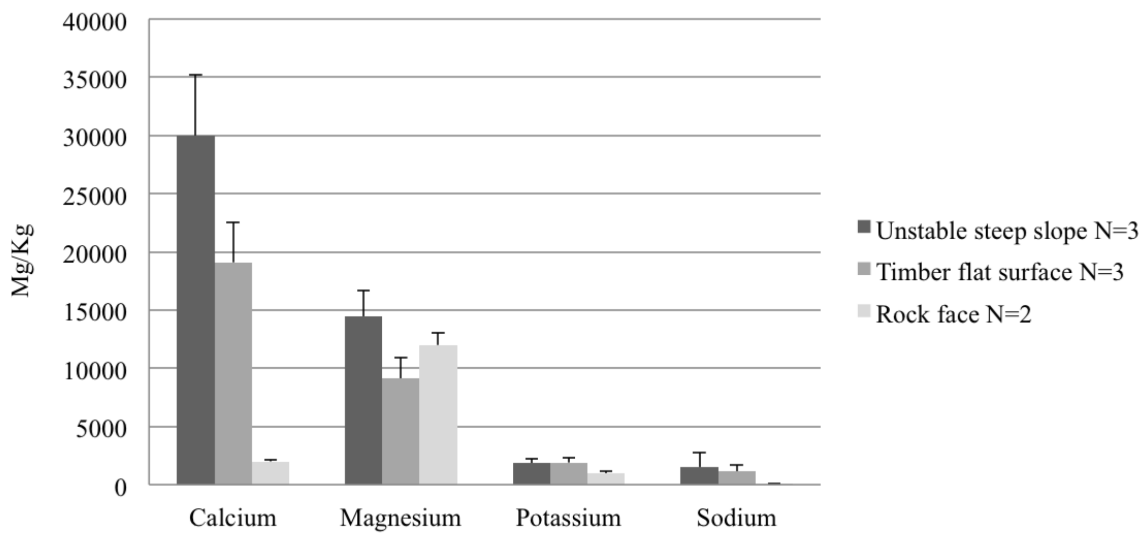

Figure 6. Mean (+SE) concentration of soil elements among 3 mountain ungulate lick types in southwest Alberta, 2013.

values were less at rock face licks (2,000 and 84 mg/kg, respectively) when compared to unstable steep slope (30,000 and 1,520 mg/kg, respectively) and timber flat surface licks (19,100 and 1,125 mg/kg, respectively).

Timing of use

Annual initiation. — Mountain ungulate use of alpine licks began once the snowpack receded from surrounding terrain and likely coincided with animals shifting from winter to summer range. The earliest use of a mountain goat lick was 15 May. The earliest recorded use of a bighorn sheep lick was 1 April, though use may have actually been initiated prior to this as the site was snow-free when we started camera monitoring at this site (Table 2). Mineral licks that were visited regularly by bighorn sheep were snow-free up to 2 months prior to those mineral licks that were primarily visited by mountain goats, making them available earlier in the season compared to mountain goat licks. Bighorn sheep mineral licks tend to be situated on exposed slopes that are largely snow-free by late April and, as a result, are utilized by bighorns prior to lambing. The peak lambing

Table 2. Mineral lick snow-free date, date of first visit by bighorn sheep adults lambs and mountain goat adults and kids in southwest Alberta, 2011–2013.

	Snow-free date			Bighorn sheep first visit			Lamb first visit		
Site	2011	2012	2013	2011	2012	2013	2011	2012	2013
1	30 March[a]	04 April[a]	--	01 April	06 April	--	22 June	16 June	--
9	--	26 April[a]	05 May	--	27 April	04 April	--	01 June	29 May
78	--	early May	--	--	02 June	--	--	05 Oct.	--
81	--	--	18 June[a]	--	--	18 June[a]	--	--	27 June
83	--	--	16 May[a]	--	--	19 May	--	--	06 June

	Snow-free date			Mountain Goat first visit			Kid first visit		
Site	2011	2012	2013	2011	2012	2013	2011	2012	2013
12	16 July	06 July	--	21 June[b]	22 May	--	04 July	29 June	--
13	mid-June	16 June	--	20 June[b]	15 May	--	20 June[b]	10 June	--
60	08 July	13 July	--	21 June	12 June	--	28 June	15 June	--
78	--	early May	--	--	30 May	--	--	30 June	--
83	--	--	16 May[a]	--	--	17 May	--	--	10 June
84	--	--	22 June[a]	--	--	28 June	--	--	30 June

[a] camera set on this date and lick was snow-free by this time
[b] camera set on this date and still snow covered
-- not surveyed this year

period in southern Alberta occurs during the first 2 weeks of June (Jokinen et al. 2008).

Persistent and peak use. — We found there to be 2 distinct timeframes associated with persistent use at alpine mineral licks. On average, licks at lower elevations having less snowfall, and greater exposure to winds and sunlight experienced habitual visitation by early May (i.e., bighorn licks) (Table 3A1). In contrast, those licks at high elevation and typically sheltered and having high wind-deposited snow were used consistently by early July, immediately after snows dissolved from the lick (i.e., mountain goat licks) (Table 3B1). Sites 78 and 83 were an exception to this, as they were snow-free earlier than most mountain goat licks and goats appeared to visit these 2 sites by late May or early June. Although visits started as early as May, and despite being snow-free by early May (Table 2), constant use at site 78 did not occur until July.

Bighorn sheep licks had the highest number of visits during the months of May and June (Table 3A2), while visits to mountain goat licks did not begin until the latter part of June (Table 3B2). Site 83 (monitored in 2013) was one exception to this 2-month range in the onset of mineral lick use by bighorn sheep and mountain goats. Site 83 was the only site where both bighorn sheep and mountain goats visited regularly despite the environment being more typical of bighorn sheep licks (i.e., exposed to wind, sun, less snowfall overall). Mountain goat use at site 83 was initiated in May, peaked during June and July, and tended to slow during the month of August. Peak use at bighorn sheep and mountain goat mineral licks in the study area occurred during late June and July, respectively. Mountain goats visited mineral licks on a daily basis during the months of July and August.

Table 3A1. Mean (+SE) number of days during the months of May through October when bighorn sheep visited an alpine lick in southwest Alberta, 2011−2013. Only 1 bighorn sheep lick was monitored in 2011. One lick was not monitored May 2013.

Year	# of sites	May	June	July	Aug	Sept	Oct
2011	1	18	14	16	8	4	3
2012	2	20	20	16	19	16	7
		(8)	(10)	(9)	(5)	(3)	(3)
2013	3	19	20	21	19	13	13
		(10)	(5)	(5)	(4)	(4)	(4)

Table 3A2. Mean (+SE) number of mineral lick visitations by bighorn sheep in southwest Alberta during the months of May through October, 2011−2013. A visitation was determined when time between visits was greater than 30 minutes. Only one bighorn lick was monitored in 2011. One lick was not monitored May, 2013.

Year	# of sites	May	June	July	Aug	Sept	Oct
2011	1	36	32	30	9	4	3
2012	2	88	100	78	71	41	10
		(67)	(87)	(67)	(39)	(16)	(1)
2013	3	82	81	65	53	32	34
		(61)	(25)	(20)	(12)	(7)	(16)

Time of day and duration of use. — Bighorn sheep utilized mineral licks less at night than in the morning and afternoon (Fig. 7). At some bighorn licks, night visitation was almost non-existent, whereas goats were visiting some licks in equal amounts throughout the day. The average visit duration was variable by time of day (Fig. 8) but both bighorn and mountain goats remained at mineral licks for longer periods during daylight hours. Day bedding areas were usually located upslope from a lick or individuals bedded at the lick itself during visitations. Bighorn sheep visited mineral licks an average of 3 times (SE = 0.54) during a single day, while mountain goats visited at a slightly higher frequency, averaging 5 visitations (SE = 0.58) per day.

The maximum group size observed at a lick for both bighorn sheep and mountain goats was 24 individuals. Bighorn sheep and mountain goats both visited in large group sizes and seldom visited a mineral lick alone (Fig. 9). On average, bighorn sheep visited in larger group sizes when compared to goats, with exception of the nighttime period.

In general, we avoid flying mountain goat aerial surveys during the afternoon, as goats tend to take cover when temperatures are highest. Despite this, mountain goats visited licks on a daily basis during the warmest months and visitations were slightly higher

Table 3B1. Mean (+SE) number of days during the months of May through October where mountain goat visited an alpine lick in southwest Alberta, 2011−2013. Two sites were not monitored May, 2011. A camera malfunctioned at 1 site July−August, 2012. During 2013, 1 site was not monitored in May and its camera was removed mid-September.

Year	# of sites	May	June	July	Aug	Sept	Oct
2011	3	0	8	30	27	8	8
			(2)	(1)	(2)	(1)	(6)
2012	4	3	11	29	21	18	4
		(2)	(2)	(2)	(5)	(4)	(1)
2013	2	9	13	24	10	0	3
			(11)	(4)	(1)		

Table 3B2. Mean (+SE) number of mineral lick visitations by mountain goats in southwest Alberta during the months of May through October, 2011−2013. A visitation was determined when time between visits was greater than 30 minutes. Two sites were not monitored May 2011. A camera malfunctioned at 1 site July−August 2012. During 2013, 1 site was not monitored in May and its camera was removed mid-September.

Year	# of sites	May	June	July	Aug	Sept	Oct
2011	3	0	43	211	174	27	23
			(29)	(38)	(54)	(9)	(19)
2012	4	3	61	119	104	86	9
		(3)	(28)	(17)	(43)	(30)	(4)
2013	2	24	74	105	22	0	18
			(71)	(55)	(3)		

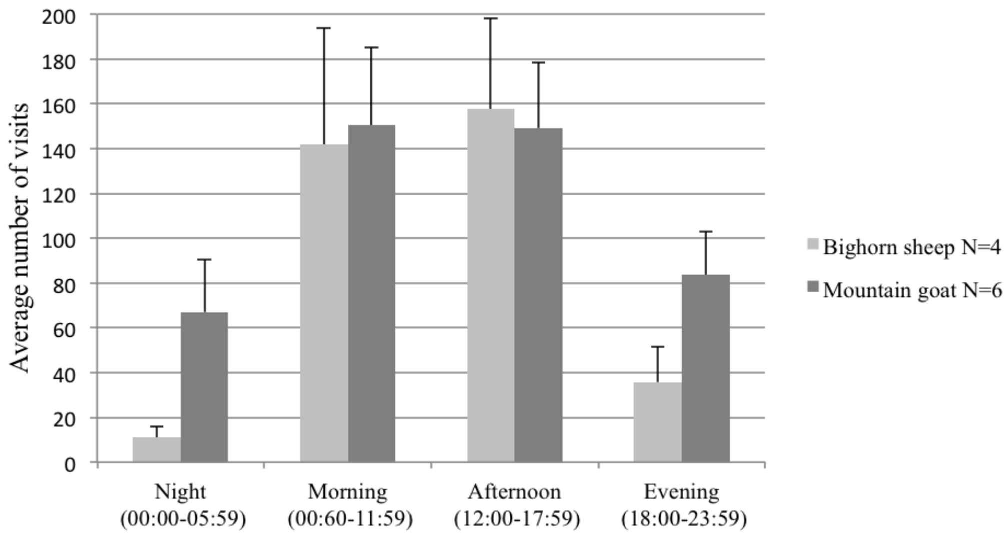

Figure 7. Seasonal mean (+SE) number of bighorn sheep and mountain goat visitations (by time of day) at alpine mineral licks in southwest Alberta, 2011–2013. A visitation was determined when time between visits was greater than 30 minutes.

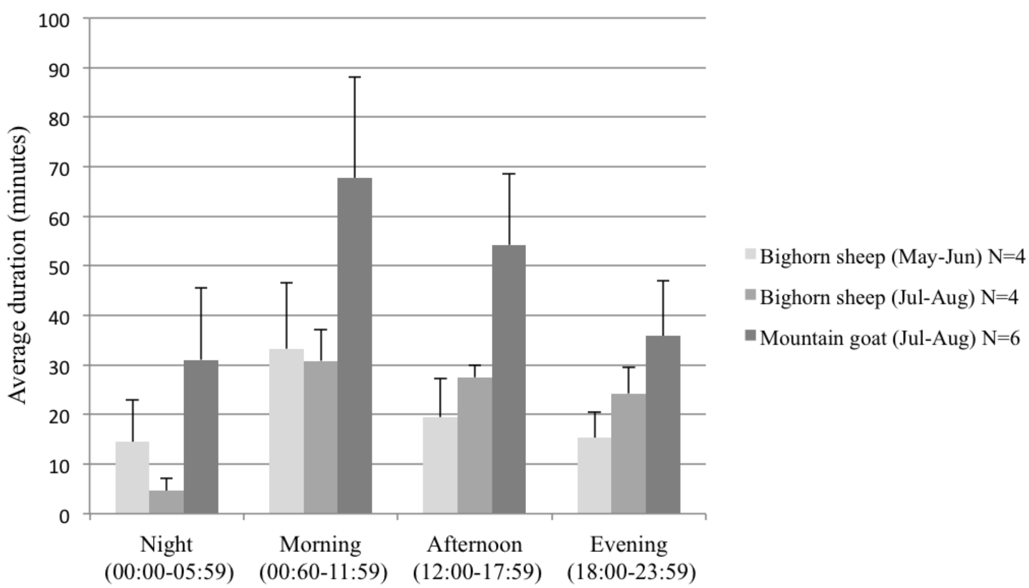

Figure 8. Mean (+SE) duration of mineral lick visits (by time of day) by bighorn sheep (May–Jun/Jul–Aug) and mountain goats (Jul–Aug) during peak season, in southwest Alberta, 2011–2013. A visitation was determined when time between visits was greater than 30 minutes.

during the afternoon period at some licks. We observed instances where afternoon sun was shadowed by the mountain, creating tolerable afternoon temperatures at the mineral lick, even during the warmest times of the day.

Spatial fidelity of mountain goats in relation to alpine mineral licks

We assessed mountain goat aerial survey counts that were within a 3-km and 5-km radius around each monitored mineral lick, but we concede that we likely did not capture every mountain goat mineral lick available within these survey regions, particularly WMU 400. Only 1 of the 6 mountain goat mineral licks that we monitored was located within this

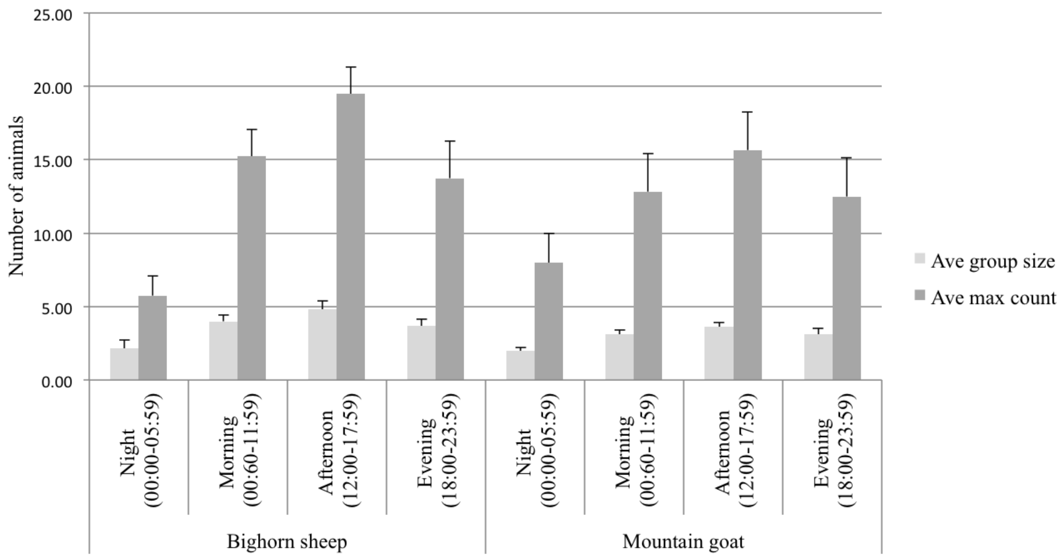

Figure 9. Mean (+SE) group size and maximum count of bighorn sheep and mountain goats at mineral licks by time of day in southwest Alberta, 2011−2013. Our maximum counts represent a minimum group size.

unit. According to summer goat aerial survey counts in WMU 400, an average of 22% of the mountain goat population is observed within 3 km of site 12 (Table 4A).

Three mountain goat mineral licks (i.e., sites 78, 83 and, 84) were monitored within Waterton Lakes National Park. Two of these were rock face licks and likely serve small, localized herds. On average, 64% of the mountain goat population in Waterton Park is observed within 5 km of these 3 mineral licks (Table 4B).

In WMU 402, 47% of the goats in that population are located within 3 km of sites 13 and 60 (Table 4C). Similar to Waterton Park, greater than half of the goat population in WMU 402 (58%) was observed within 5 km of a mineral lick, on average. Site 13 is located approximately 4 km from the BC boundary although we feel that the majority of the goats occupying this area remain on the Alberta side of the divide. Site 60 is located 1 km from the BC boundary and we are certain that goats in this area commonly use both sides of the Continental Divide.

Spatial fidelity and movement of bighorn sheep in relation to alpine mineral licks

In the Yarrow-Castle region (southern half of WMU 400), a GPS-collared bighorn sheep ewe maintained a distance of 3 km or less from site 9 from April-July 2004 (Fig. 10). This ewe's home range was approximately 25 km^2, condensing to a spring and summer range of 8 km^2, focusing around the mineral lick zone. The ewe did visit the lick during September; however, she began to extend her movements outside the 3-km range during this time (Fig. 11).

Two additional GPS-collared bighorn sheep ewes migrated to the mineral lick from a separate mountain complex in the study area during 2003 and 2004 (Jokinen et al. 2008). These ewes traveled 17 km to reach the lick from their respective range. One of those individuals migrated 2 consecutive years during the same timeframe, utilizing the same stopover in both instances (Fig. 12). Both ewes traveled to the mineral lick on separate occasions; however, both utilized the stopover before spending time inside the 3-km mineral lick zone (Fig. 13). In addition to GPS collared individuals, 7 very high frequency collared bighorns (and several unmarked bighorns) were observed utilizing the mineral lick during the study (Jokinen et

Table 4A. Mountain goat aerial survey counts associated with mineral lick 12 in Wildlife Management Unit 400 of southwest Alberta, 2004–2011.

Year	Date surveyed	Total goat count (entire WMU)	% <3km of lick (site 12)	% 3-5km of lick (site 12)	% 0-5km of lick (site 12)
2004	13 July	207	25	0	25
2005	07 July	248	21	11	32
2007	29 June	193	22	17	39
2008	03 July	218	13	16	29
2011	28 July	146	30	3	33
Mean		202	22	9	32

Table 4B. Mountain goat aerial survey counts associated with mineral licks 78, 83, and 84 in Waterton Lakes National Park, Alberta, 2004–2011.

Year	Date surveyed	Total goat count (in WLNP)	% <3km of lick (sites 78, 83, 84)	% 3-5km of lick (sites 78, 83, 84)	% 0-5km of lick (sites 78, 83, 84)
2004	14 July	80	35	23	58
2005	04 July	93	42	11	53
2007	26 June	74	51	26	77
2008	01 June	106	48	24	72
2011	25 July	126	38	20	58
Mean		96	43	21	64

Table 4C. Mountain goat aerial survey counts associated with mineral licks 13 and 60 in Wildlife Management Unit (WMU) 402 of southwest Alberta, 2006–2013.

Year	Date surveyed	Total goat count (entire WMU)	% <3km of lick (sites 13 and 60)	% 3-5km of lick (sites 13 and 60)	% 0-5km of lick (sites 13 and 60)
2006	Not available	142	42	8	50
2009	12 July	186	57	3	60
2010	26 June	148	36	28	64
2013	19 July	173	51	5	56
Mean		162	47	11	58

al. 2008) and in subsequent years following the study.

We observed similar migratory behavior in the Waterton bighorn sheep population. For example, a 9-year-old GPS-collared ram traveled approximately 10 km from his typical range to end his northbound journey at site 83 (Fig. 14). Not only did bighorn sheep rams make extensive movements for short visits to the mineral lick but they also spent considerable amounts of time in the mineral lick zone, utilizing the lick over several days (Fig. 15). Ram 06−08 spent 6 days in the mineral lick zone and appears to have visited the lick on 2 occasions. This ram's greatest step-lengths were made while traveling to and from the mineral lick and it appears that he visited the lick a second time before leaving the area. Bighorn ewes also made dedicated movements to the mineral lick zone (Fig. 16). Ewe 06−03 traveled approximately 18 km during one day to spend the next 5 days in and around the mineral lick zone of site 83.

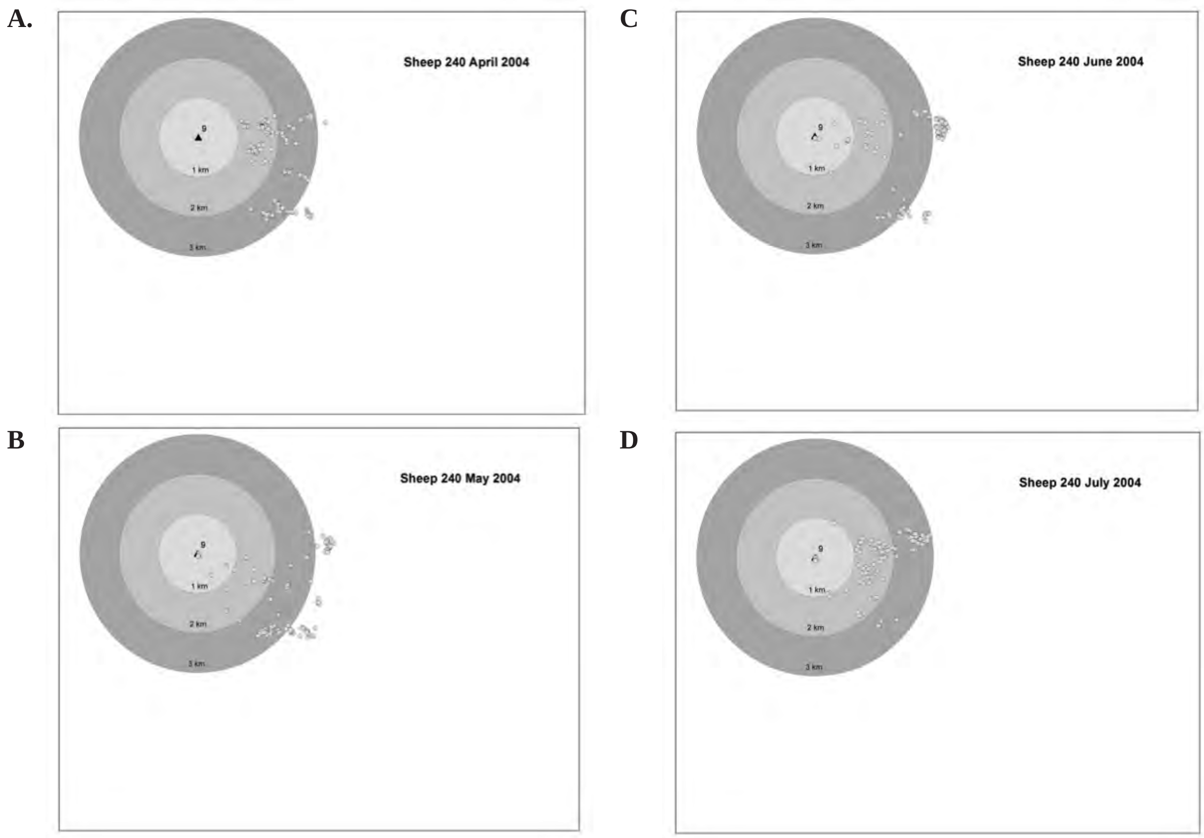

Figure 10. Bighorn sheep ewe (240) monthly movements in relation to lick 9 during April (A), May (B), June (C) and July (D) 2004 in the Yarrow-Castle region of southwest Alberta.

DISCUSSION

For several decades, wildlife managers have realized that natural mineral licks are a special habitat feature on the landscape. This study is among the first to monitor bighorn sheep and mountain goat mineral lick use where observation is uninterrupted over time (i.e., using trail cameras), having the ability to capture every visit by any animal in a population. Most studies have relied on visual observation and GPS collar data from select individuals. Our trail camera monitoring provides an improved understanding of when mountain ungulate populations use mineral licks. For a habitat feature to be recognized as requiring special attention, collecting data such as we have on bighorn sheep and mountain goat mineral licks, is an essential first step to making informed decisions when land use considerations arise.

Based on our observations, alpine ungulate mineral licks are not as common on the landscape as forest mineral licks. Bighorn sheep and mountain goats visit mineral licks in sizable numbers and they are habitually visiting on a daily basis and multiple times throughout the day. Therefore, each bighorn and mountain goat lick on the landscape should inevitably hold high value as a significant habitat feature encompassed by critical summer range.

Mineral lick site characteristics

Bighorns generated the greatest number of camera triggers at site 1 and we consider site 1 to be an important bighorn sheep mineral lick even though it may originate from a man-made source. Bighorn sheep notoriously frequent artificial mineral sources and, in our region, we have observed bighorn sheep licking vehicles, roadsides, railways, oil and gas structures and

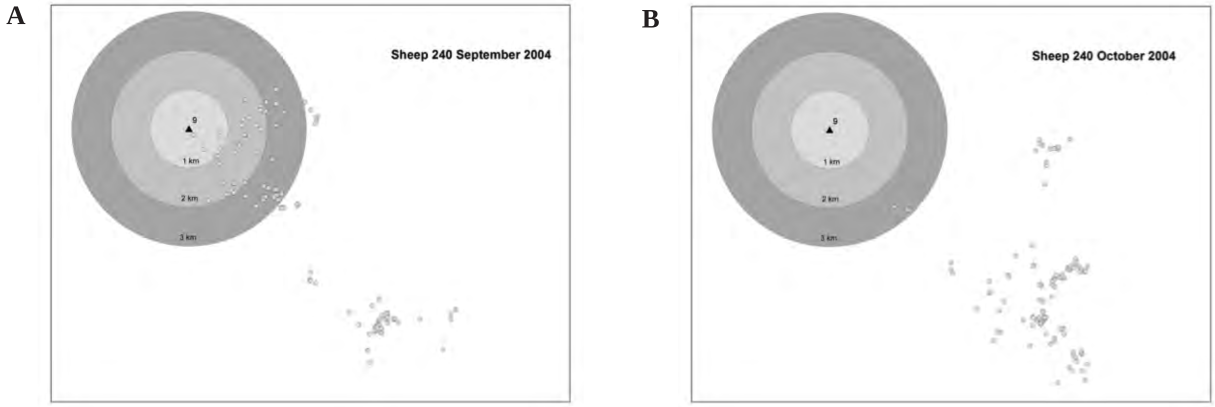

Figure 11. Bighorn ewe (240) monthly movements in relation to lick 9 during September (A) and October (B) 2004 in the Yarrow-Castle region of southwest Alberta.

areas where humans have urinated. Some National Parks in the United States have urged visitors not to urinate along hiking trails because goats have become aggressive towards humans in those areas where they have become habituated to urine salt deposits (U.S. Forest Service 2014).

Alpine ungulates in our region may encounter artificial mineral sources along the Continental Divide because it is legal to place mineral blocks out as an attractant for wild species in British Columbia. This practice is illegal in Alberta. We observed mineral blocks along mountain ridges on the BC side of the divide. Ungulates can establish an attraction to these areas years after the mineral block has been depleted since the minerals seep into the substrate below and leach back to the surface over time. Mincher et al. (2008) bring up the important point that the introduction of man-made mineral blocks to bighorn sheep can interfere with natural mineral lick use, which can limit bighorn intake of minor elements that are only available from a natural mineral source.

Mountain goat licks in our study had roughly half the amount of calcium and sodium concentrations as bighorn sheep licks. Calcium and sodium levels were lower at rock face licks compared to other licks; however, rock face lick values were generated from water samples rather than soil samples. Our alpine ungulate mineral lick elemental analyses resulted in higher concentrations than those reported by Ayotte (2004) in BC, in which the highest reported calcium (15,419 mg/kg) concentration was half that of our average for bighorn licks, though it was similar in concentration to our mountain goat licks. The highest concentrations of magnesium (3,225 mg/kg), sodium (118 mg/kg) and potassium (418 mg/kg) reported by Ayotte (2004) at his sheep and mountain goat licks were all less than our concentrations. Magnesium concentrations in our region are more than double than those reported by Ayotte (2004).

Rock face licks may serve as a concentrated source of magnesium for goats as other elements at rock face licks were extremely low in concentration. It appears that the seep (drinking) at rock face licks provide ungulates with mineral elements. Ayotte et al. (2006) mention that inflow waters at wet licks are particularly high in magnesium. Magnesium may be sought after by ungulates when high levels of dietary potassium (a result of consuming lush spring vegetation) inhibit nutrient absorption (Jones and Hanson 1985, Heimer 1988, Ayotte et al. 2006).

Site 78 was 1 of 2 rock face licks that we suspect served a local population of goats. This lick was snow-free by early May as it was located on a relatively steep, south-facing

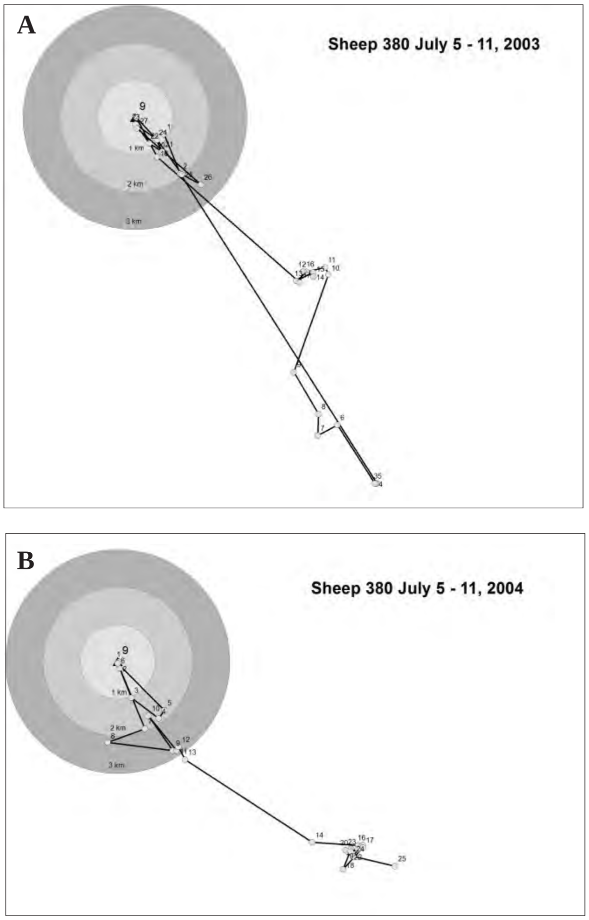

Figure 12. Bighorn ewe (380) movement and stopover in relation to lick 9 during July 2003 (A) and July 2004 (B) in the Yarrow-Castle region of southwest Alberta.

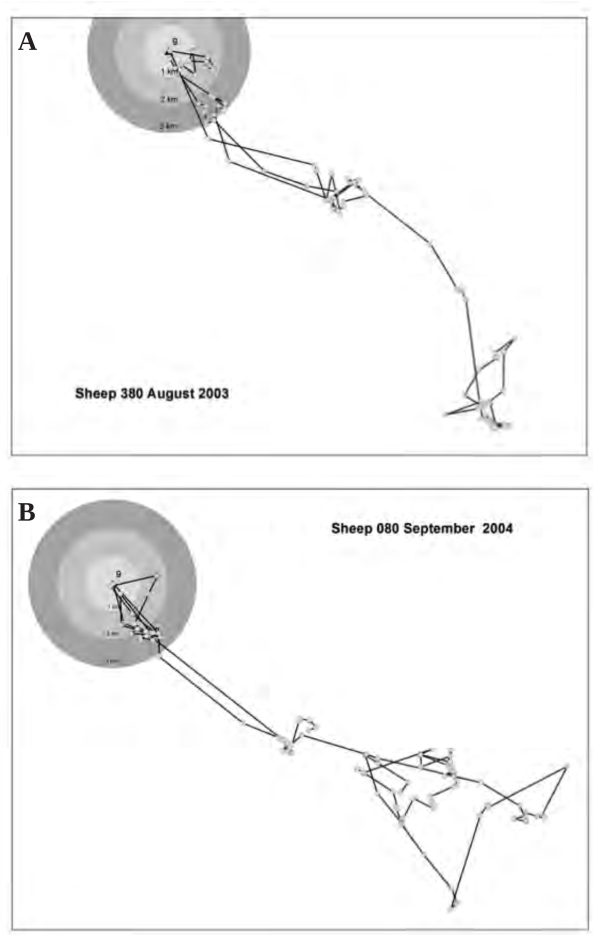

Figure 13. Bighorn movements and stopovers in relation to lick 9 by ewe #380 (A) August 2003 and ewe #080 (B) September 2004 in the Yarrow-Castle region of southwest Alberta.

rocky bluff. However, mountain goats did not visit site 78 with regularity until July, visiting daily in July and August. This delay could be related to seasonal migration or it may be magnesium driven during the onset of lactation or change in emerging vegetation.

Researchers in BC found mountain goats accessing minerals by digging cavities under trees where the subsoil was completely dry (Poole et al. 2010); however, we are unaware of any tree licks occurring in our region.

Timing of use

Nearly all alpine ungulates fed for an extended period during each mineral lick visit. Bighorn sheep and mountain goats are herd species; therefore, the number of animals in a herd influences the duration of a particular visit (i.e., the larger the herd, the greater potential for an extended visit time, as some animals bed while others feed at the lick).

In this study, animals repeatedly visited alpine ungulate mineral licks, usually immediately after snow receded during early spring and summer. This suggests that snow cover and thawing temperatures dictated animal arrival at the majority of the mineral licks in our region. As snow recedes, available forage begins to green-up and animals migrate onto their summer range. On average, bighorn sheep mineral licks were snow-free 2 months prior to mineral licks that were visited by

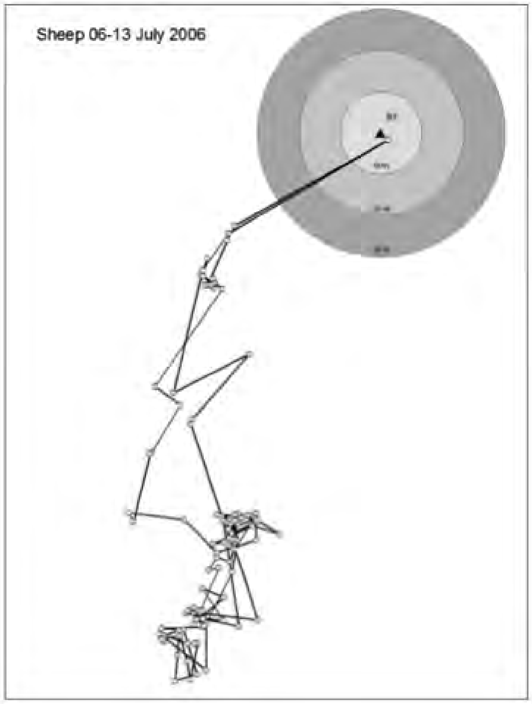

Figure 14. Bighorn ram (06–13) movement in relation to lick 83 during the month of July 2006 in Waterton Lakes National Park.

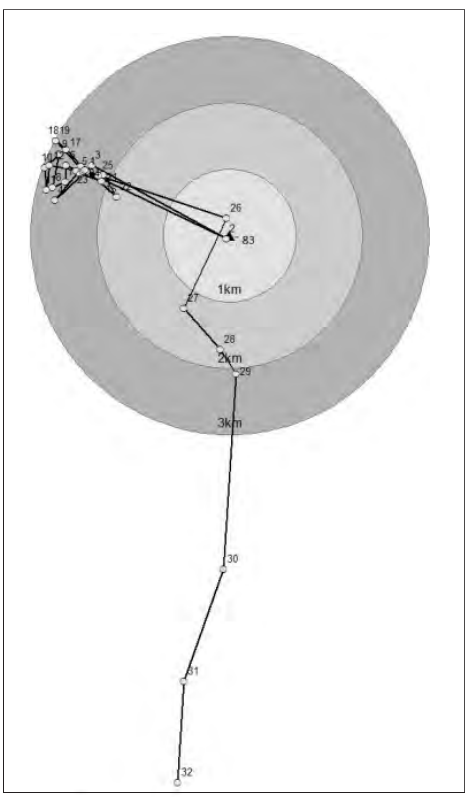

Figure 15. Bighorn ram (06–08) movement in relation to lick 83 over a 1-week period during June 2006 in Waterton Lakes National Park.

mountain goats, therefore bighorn licks tended to be used sooner. However, mountain goats utilized site 83 in a similar pattern to what we observed with bighorn sheep but this area did green-up sooner than most other mountain goat licks because of its location (i.e., front-range, having less snowfall, exposed to sun and wind). This lick had twice the calcium concentration of other bighorn and goat mineral licks and was composed of a clay substrate. Kreulen (1985) and Ayotte et al. (2006) discuss how carbonates and clay minerals help stabilize the rumen with early season foraging.

Our region holds a variety of habitat types and many front-range mountainous areas, which support bighorn sheep but do not provide mountain goats with appropriate habitat conditions. We have not observed mountain goats in the mineral lick zone of any bighorn licks in our region, with the exception of site 83 that is used by both species. It is interesting to note however, that we have observed bighorn sheep in the mineral lick zone of 2 mountain goat licks, but bighorn were never detected at the licks over a 2-year period. Alpine ungulates may be initially driven to mineral licks by dietary and lactation demands (Hebert and Cowan 1971, Ayotte et al. 2008) but access (i.e, snowmelt) may delay mineral lick use for some populations. We observed mountain goats accessing minerals during snow melt directly downslope of site 12 weeks prior to the lick being snow-free (water seeping overtop the lick area and flowing downslope). However, once the lick was partially free of snow, the goats shifted their visitations to the mineral lick.

Rea et al. (2013) observed a unique instance in which moose were using mineral licks during winter months. Due to heavy snow cover and freezing temperatures in our study area, we presumed bighorn sheep and mountain goats are unable to access mineral licks during winter. Installing cameras prior to initial visits proved to be a challenge, as safety and logistical issues (e.g., avalanche

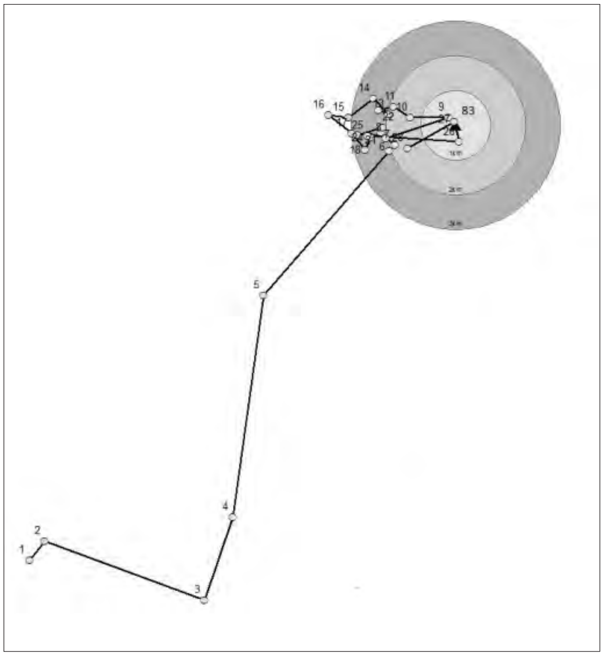

Figure 16. Bighorn ewe (06–03) movement in relation to lick 83 over a 1-week period during July 2006 in Waterton Lakes National Park.

conditions, access, etc.) influenced our ability to access licks in late winter or early spring. Therefore, because of a limited sample of licks at which we could collect data for initial use in multiple years, we were unable to effectively test our prediction that initial use would vary among years.

Our data suggested that, overall, bighorn sheep preferred to visit mineral licks during morning (0600-1200 hours) and afternoon (1200-1800 hours); they visited in groups, averaging 4–5 individuals; they remained at mineral licks for 15–30 minutes on average (often bedding nearby); and visited an average of 3 times per day. Their use was constant during the months of May through July with peak use occurring in June and use continuing to the end of August and moderately into October.

Overall, our data provide evidence that mountain goats travel to and from mineral licks at all times of the day and night, their use is constant, and visits are longer than 45 minutes on average. Mid- to late July was the peak period for mountain goats and lick use was constant to the end of August and continued well into September at some sites. Group size varied from 1 individual up to 24; goats often bedded nearby, visiting an average of 5 times throughout the day; and visitations virtually occurred daily during July and August.

At the intensity that mineral licks are being used by bighorn sheep and mountain goats, the mineral lick itself is not only critical, but the lick's proximity to surrounding topographic cover (for bedding, security, rearing), food and water resources is fundamental.

Spatial fidelity and movement

The draw of a mineral lick to a bighorn sheep or mountain goat population influences how individuals delineate their summer range. The immediate landscape surrounding a mineral lick will be used by those ungulates utilizing lick areas for foraging and cover on summer range (Simmons 1982, Singer and Doherty 1985). In northern BC, Stone's sheep (*Ovis dalli stonei*) and mountain goats were documented as traveling a minimum of 3 km from their foraging habitat to lick areas (Ayotte et al. 2008); while along the Rocky Mountains of BC, some individual goats were observed visiting multiple licks during a season, traveling up to 17 km to visit licks (Poole et al. 2010). In addition, Poole et al. (2010) found that during 2 consecutive years, collared mountain goats inhabited the slopes neighboring a mineral lick during the summer season. In Washington State, mountain goats traveled up to 29 km along mountain ridges to visit mineral licks. The author identified goats having 4 movement patterns associated with lick use (Rice 2010). Rice (2010) found some goats to be migrants, traveling far distances but remaining in the vicinity of the lick for a month on average, while other goats included the lick as a component of their usual range.

Both bighorn sheep and mountain goats in our study appear to draw on an area of about 3 km (i.e., mineral lick zone) from a mineral lick for other habitat needs during the summer months or while they are visiting a mineral lick. The degree to which bighorn and mountain goats use each mineral lick likely depends on whether other habitat needs are located nearby. Simmons (1982) and Singer and Doherty (1985) found mineral licks influenced the shape of wild sheep and mountain goat summer range and movements. A GPS-collared bighorn sheep ewe (240) in the Yarrow-Castle region maintained a spring and summer range (April through July) of 8 km^2 revolving around site 9. The ability to relate mountain goat aerial survey observations and bighorn sheep collar data in relation to alpine mineral licks provided an example of how these alpine ungulates utilize the range surrounding a mineral lick. Maintaining connectivity between mountain passes, ridges, and stopovers traditionally used to access lick regions and mountain ranges adjacent to licks should be considered in land-use planning. This should be of particular interest along the Continental Divide where these alpine ungulate populations occupy both Alberta and BC. Investigating mountain goat distribution and range use along the Continental Divide could provide both jurisdictions with a unified management strategy.

MANAGMENT IMPLICATIONS

To ensure the long-term integrity and productivity of Alberta's ungulate populations, industrial and recreational guidelines must provide adequate protection to mineral licks, based on research findings that are specific to licks and the species that rely on them. We present information on the timing of use of mineral licks and spatial movement around mineral licks, further supporting the idea that mineral licks should evolve into a special management classification, rather than simply a general categorization in industrial operating ground rules.

The Alberta Fish and Wildlife Division (2001) suggest that industrial activity, whether ground or air based, should occur between 1 July and 22 August in sheep and goat zones. This timeframe has been suggested to avoid birthing time periods and hunting seasons, but it does not consider the animal's dependency on mineral licks throughout the periods of nearly constant summer use that we identified in our study. The timeframe recommended for industrial activity could impact an alpine ungulate population utilizing a mineral lick and surrounding summer range. Human disturbances displace mountain ungulates (Schoenecker and Krausman 2002, Keller and Bender 2007, St-Louis et al. 2012, Côté et al. 2013). Disturbances may be intermittent on the landscape but the cumulative effects of disturbances can have serious consequences to a population (Schoenecker and Krausman 2002). When industrial activity is conducted during summer months in bighorn sheep and mountain goat range, managers should consider mineral licks and industrial activity should be directed accordingly using mineral lick specific restrictions.

Alberta's timber harvest guidelines list mineral licks under the "other species/sensitive site" section of the document. In this section, mineral licks are universally managed with amphibian sites, bat hibernacula, nesting areas, and wolverine dens, all receiving a forested buffer distance of 100 m (AESRD 2012). Corbould et al. (2010) investigated the effects of forest disturbance on low-elevation mountain goat lick use and found that forest removal treatments (conducted during the winter) along trails leading to mineral licks did not have a behavioral effect on goats. Although, lick and trail use by goats declined post timber harvest (at both treatment and control licks), while carnivore detections increased. Their treatments included a buffer of 150 m on either side of the trail leading to the lick and then clearcutting the buffer a few years afterwards. Authors postulated that forest removal might have an indirect effect, increasing mortality risk (Corbould et al. 2010). In our study region, the principal threat from timber harvest to bighorn sheep and mountain goats is the access it creates, especially to off-highway vehicles. St-Louis et al. (2012) found goats to be highly disturbed when off-highway vehicles approached directly and at high speeds. Based on our data, a buffer distance of 100 m is inadequate in most instances.

Bighorn sheep and mountain goat mineral licks are often located at the fringe of what is typical of their range because licks are often low-lying. Therefore, it is important for managers to understand where alpine ungulate mineral licks are located, as they are seldom high on the mountain and there may be instances where mountain ungulates are overlooked where in fact they could be directly impacted by human influences. Creating a universal buffer distance for bighorn and mountain goat mineral licks is a complex undertaking but our observational data provide awareness to the issue. Marking and tracking movements of individuals in a population would provide a better sense of effective buffer distances at alpine ungulate mineral licks. Furthermore, each alpine mineral lick is unique to the setting in which it is located and industrial or recreational regulation may require site-specific forethought. Consequently, it is critical that all alpine ungulate mineral licks in a region are pinpointed and that the location and mineral lick zone receive special consideration when land use planning.

Guidelines have been established for when industrial activity occurs in bighorn sheep and mountain goat range (AESRD 2012). A 2-km buffer from position of known animals is the suggested distance if helicopter activity should occur in bighorn and mountain goat terrain (Côté 1996; Hurley 2004). If mineral licks were to be integrated into this 2-km rule for aerial based activity, an additional 3-km mineral lick zone buffer could be considered. Based on the evidence that bighorn sheep and mountain goats in our study area concentrate use around mineral licks (i.e., based on trail camera, aerial survey and, animal collar data), adding 3-km to the 2-km rule would allow the majority of the population utilizing the mineral lick and surrounding mountain range to go relatively undisturbed. It also ensures that travel corridors regularly used by the animals between the lick and the nearby mountain range are undisturbed by rotary wing aircraft.

A timing restriction on industrial and or recreational disturbance in relation to alpine mineral licks or critical summer range would be most effective. A seasonal timing restriction that is designed to avoid activity near mineral licks during the peak months of May through August would be an appropriate standard. This incorporates the snow-free period, the lambing or kidding season, as well as the peak use period by bighorn sheep and mountain goats at mineral licks. Bighorn sheep and mountain goat mineral lick use somewhat decreases by September but does not cease; therefore, industrial activity in close proximity to mineral licks during the months of September and October should be conducted with this understanding. Preserving corridors between summer range and mineral licks from short and long-term disturbance is paramount. Managers need to consider the consequences of newly constructed roadways or off-highway vehicle trails when in close proximity to bighorn sheep and mountain goat summer range. Keller and Bender (2007) reported how road and human disturbance negatively affected bighorn use of a mineral lick, while St-Louis et al. (2012) found that off-highway vehicles can cause high levels of disturbance in mountain goats while on summer range. Special management considerations (closures, regulations, or gates) may be necessary for those bighorn and goat summer range areas already affected by disturbance.

Future research on the role of mineral licks and alpine ungulate populations should focus on seasonal range use and identifying traditional travel routes associated with them. Collaring a proportion of the mountain goat population would provide necessary range use information and those marked individuals would be identifiable at mineral lick sites. This research would be of particular value along the Continental Divide, where evaluating the potential impacts of recreational and industrial development on goat seasonal ranges, mineral licks and corridors would benefit the conservation and management of mountain goats across both provinces.

Alpine ungulate licks are intermittent on the landscape and alpine species are conditioned to exploiting these areas, including the summer range and corridors associated with them. These areas hold biological significance and this is why mineral licks require a conscientious approach to ensure their preservation for wildlife.

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Estimating Bighorn Sheep Abundance Using Noninvasive Sampling at a Mineral Lick within a National Park Wilderness Area

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ABSTRACT Conservation of species requires accurate population estimates. We used genetic markers from feces to determine bighorn sheep (*Ovis canadensis*) abundance for a herd that was hypothesized to be declining and in need of population status monitoring. We sampled from a small but accessible portion of the population's range where animals naturally congregate at a natural mineral lick to test whether we could accurately estimate population size by sampling from an area where animals concentrate. We used mark-recapture analysis to derive population estimates, and compared estimates from this smaller spatial sampling to sampling of the entire bighorn sheep range. We found that estimates were somewhat comparable; in 2009, the mineral lick sample and entire range sample differed by 20 individuals, and in 2010 they differed by only 1 individual. However, we captured 13 individuals in the entire range sample that were not captured at the mineral lick, and thus broke a model assumption that all individuals had an equal opportunity of being captured. This eliminated the possibility of inferring a total population estimate from just animals visiting the mineral lick, but because estimates were relatively similar, monitoring at the mineral lick can provide a useful index for management and conservation. We compared our results to a radio collar study conducted in 2003-2004 and confirmed that the population remained stable since 2004. Our population estimates were 78 (CI= 62−114) in 2009 and 95 (CI= 77−131) in 2010. Between 7 and 11 sampling dates were needed to achieve a CV of 20% for population estimates, assuming a capture probability of between 0.09 and 0.13. We relied on citizen science volunteers to maximize data collection and reduce costs; 71% of all fecal samples were collected by volunteers, compared to 29% collected by paid staff. We conclude our technique provides a useful tool to mangers for monitoring, and could be tested and applied in similar populations where animals congregate with high fidelity at a mineral lick or other area.

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KEY WORDS bighorn sheep, citizen science, feces, genetic tagging, mark-recapture, microsatellites, mineral lick, noninvasive population estimate, *Ovis canadensis*.

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Sighting Probability and Survival in Two Colorado Bighorn Sheep Herds

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ABSTRACT The management of many bighorn sheep (*Ovis canadensis*) herds in Colorado is based primarily on the results of annual surveys that provide data on minimum population sizes and demographic rates. Very little information is available on bighorn sighting probability during these surveys, which prevents the derivation of population estimates with known levels of precision. To refine the management of the Georgetown and Pikes Peak bighorn herds and to inform the management of other herds, we initiated population estimation and demographic studies on both of these herds. From 2005-2009, we captured and radio-collared 73 bighorn sheep from the Georgetown herd (49 ewes, 24 rams) and 54 bighorn sheep from the Pikes Peak herd (32 ewes, 18 rams). During the summers of 2006-2009 in the Georgetown herd and 2007-2009 in the Pikes Peak herd, we conducted mark-resight studies to estimate adult ewe and ram population size and sighting probability. We also estimated annual survival rates for ewes and rams in each herd. We then incorporated these data into population models for each herd. The July adult population estimates ranged from 342 (SE = 42) to 445 (SE = 50) for Georgetown and from 92 (SE = 5) to 142 (SE = 7) for Pikes Peak. The mean proportion of the modeled population observed during surveys was 0.35 in the Georgetown herd and 0.48 in the Pikes Peak herd. In the Georgetown herd, the mean annual survival rate excluding harvest was 0.91 (range 0.85-0.97) for adult ewes and 0.92 (range 0.85-1.0) for adult rams. For Pikes Peak, the mean annual survival was 0.90 (range 0.88-0.92) for adult ewes and 0.90 (range 0.81-1.0) for adult rams. The leading cause of adult mortality was vehicle collisions in the Georgetown herd and mountain lion (*Puma concolor*) predation in the Pikes Peak herd.

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KEY WORDS bighorn sheep, Bowden's Estimator, Colorado, Georgetown, mark-resight, *Ovis canadensis*, Pikes Peak, population estimation, sighting probability, survival.

The management of many bighorn sheep (*Ovis canadensis*) herds in Colorado is based primarily on the results of ground or helicopter surveys (George et al. 2009). More than 25 years of ground survey results in the Georgetown and Pikes Peak herds have provided valuable information on sex and age ratios, minimum population size, and minimum

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distributions (Huwer 2010, 2015, Stiver 2011). These surveys do not provide information on bighorn sighting probability, which prevents the derivation of population estimates with estimates of precision (Anderson 2001, Pierce et al. 2012). To refine management of the Georgetown and Pikes Peak herds and to inform the management of other herds, we used mark-resight methods to estimate the population size and demographic parameters of both herds. The objectives of these studies were to 1) estimate the size of the populations with statistical confidence; 2) determine adult ewe and ram sighting probability during surveys; 3) estimate survival rates for adult ewes and rams; 4) develop a population model for each herd; and 5) determine the proportion of the modeled populations observed during surveys of each herd.

STUDY AREA

The Georgetown bighorn sheep herd occupied 330 km^2 west of Denver, Colorado (Fig. 1). During the summer, the bighorn sheep are found throughout this overall range. Elevation ranged from 1,700 m to 4,000 m. The climate varied greatly from east to west depending on elevation. The eastern, low-elevation portion had comparatively warm summers and mild winters. The western, high-elevation portion was much colder with snow covering timbered areas and north-facing slopes from November through May.

Vegetation was diverse depending on elevation and climate. Foothills shrubs dominated to approximately 2,300 m. Mountain riparian communities were found along streams, wetlands, and irrigation ditches between 1,700 m and 3,400 m. Ponderosa pine (*Pinus ponderosa*) dominated communities were found up to 2,500 m with Douglas fir (*Pseudotsuga menziesii*) covering many north-facing slopes in the foothills. Subalpine forests occurred from 2,500 m to timberline at approximately 3,500 m. Within the subalpine forest zone, lodgepole pine (*Pinus contorta*) intermixed with aspen (*Populus tremuloides*) dominated sites up to 3,200 m. Engelmann spruce (*Picea engelmannii*) and subalpine fir (*Abies lasiocarpa*) forests interspersed with meadows were dominant to timberline. Stands of limber (*Pinus flexilis*) and bristlecone pine (*Pinus aristata*) also occurred at higher elevations. Alpine tundra, alpine willows (*Salix* spp.), and rock dominated above timberline.

The Georgetown herd is a native population. It was supplemented with 47 bighorn sheep from the Tarryall herd of Colorado in the 1940s. Numbers fluctuated from less than 50 before supplementation to nearly 500 in 2001. During this study, 300-400 bighorn sheep occupied the area making

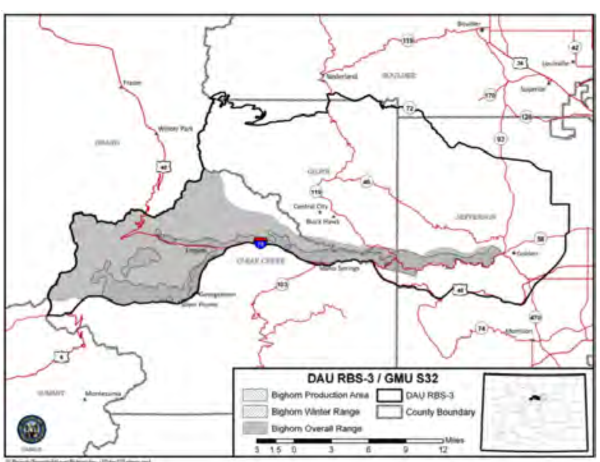


Figure 1: Location of the Georgetown bighorn sheep herd.

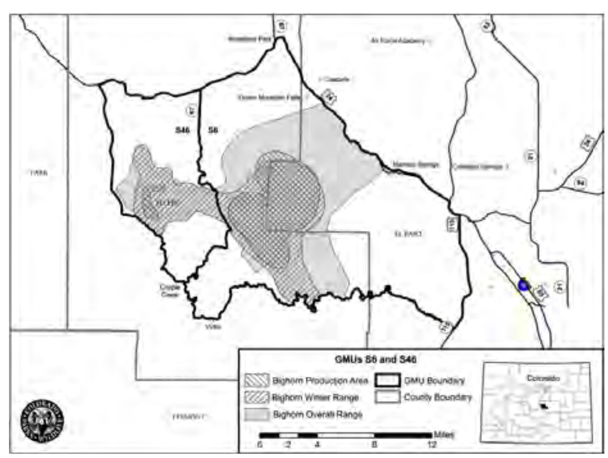


Figure 2. Location of the Pikes Peak bighorn sheep herd.

it one of the largest bighorn sheep populations in Colorado. Potential predators of this herd include mountain lions (*Puma concolor*), coyotes (*Canis latrans*), bobcats (*Lynx rufus*), domestic dogs (*Canis lupus familiaris*), golden eagles (*Aquila chrysaetos*), and black bears (*Ursus americanus*). Several major highways and heavily used roads, including Interstate 70, US Highways 6 and 40, State Highway 119, and the Central City Parkway, run through the range of the Georgetown herd. Many of these roads bisect traditional movement corridors. The Georgetown herd was contained within Data Analysis Unit RBS-3 and Game Management Unit (GMU) S32 (Huwer 2010).

The Pikes Peak bighorn sheep occupied 250 km^2 west of Colorado Springs, Colorado (Fig. 2). During the summer, the bighorn sheep occupied 109 km^2 of summer range, which was comprised primarily of alpine areas where visibility is high. Elevation ranged from 2,500 m to 4,300 m. Climate conditions varied depending on elevation. The highest mean snowfall occurred in March and April but snow was possible at higher elevations throughout the year. Weather in the Pikes Peak herd was characteristic of high elevation peaks throughout Colorado. During the summer, conditions were relatively mild during the morning hours but thunderstorms often formed during the afternoon. Snow and freezing temperatures were possible throughout the year. During the winter and spring, strong winds (>100 knots) were common at the summit.

Vegetation was diverse depending on elevation and climate. Above timberline (> 3,500 m), the vegetation communities were typical of alpine bedrock, scree, and tundra. However, some meadow complexes occurred within the alpine in the Pikes Peak herd. Subalpine communities were composed of Engelmann spruce and subalpine fir, bristlecone, and lodgepole pine; aspen forests occurred between 3,200 m and 3,500 m. Below 3,200 m, much of the area was dominated by ponderosa pine and aspen forests, though some areas contained wet meadow complexes.

The Pikes Peak herd is a native population that has never been supplemented. Numbers have fluctuated from less than 40 in the 1950s to an estimate of 425 in the 1990s. It was thought to be one of the largest bighorn sheep herds in Colorado at the start of this study. Potential predators of this herd include mountain lions, coyotes, bobcats, golden eagles, and black bears. No major highways pass through the range of the Pikes Peak herd. The Pikes Peak herd is contained within Data Analysis Unit RBS-8, GMU S6 (Pikes Peak) and GMU S46 (Dome Rock, Stiver 2011).

METHODS

From 2005 to 2009, we deployed radio collars on 73 bighorn sheep (49 ewes, 24 rams) in the Georgetown herd with adherence to the Colorado Bighorn Sheep Capture and Translocation Guidelines (George et al. 2008). We captured these bighorn on winter range throughout the study area via drop netting (11 ewes, 4 rams), chemical immobilization (28 ewes and 8 rams), and helicopter net-gunning (10 ewes, 12 rams). We used 3 types of radio collars: 1) Lotek LMRT-4 (very high frequency (VHF) collars; 46 ewes and 23 rams); 2) Lotek Global Positioning System (GPS) 3300SL (store-on-board GPS collars; 2 ewe and 2 ram); 3) and Northstar Globalstar D-cell (GPS collars with satellite upload; 9 ewes). We recaptured 9 of the bighorn sheep originally given VHF collars to replace the collars with Lotek GPS collars (1 ewe and 1 ram) and Globalstar collars (7 ewes). In the Pikes Peak herd, we deployed radio collars on 50 bighorn sheep (32 ewes, 18 rams). We captured these bighorn on winter range throughout the study area via drop netting (6 ewes, 5 rams), chemical immobilization (13 ewes and 9 rams), clover trapping (7 ewes), and helicopter net-gunning (5 ewes, 5 rams). All Pikes Peak bighorn sheep were collared with VHF Lotek LMRT-4 radio collars. We affixed unique alphanumeric marks to the collars in both study areas to enable individual identification, as required by mark-resight methodology (Bowden and Kufeld 1995, Thompson et al. 1998, Pierce et al. 2012).

In the Georgetown herd, each July from 2006-2009, we conducted 5-7 one-day resight surveys. Each survey consisted of 11-16 ground-based routes conducted simultaneously either on foot or from trucks or off-highway vehicles. The total combined length of all the routes was 298 km. These routes were designed to provide maximum coverage of the range of the herd and to minimize double counting of bighorn. Routes had been modified and refined during the previous 18 years of July surveys of the area. To determine the proportion of the summer bighorn habitat visible from the resight survey routes of each study area, we used a Geographic Information System (GIS) to conduct a viewshed analysis (ArcMap 10.1, Environmental Systems Research Institute, Inc., Redlands, CA). We derived the viewshed from the 30 m digital elevation model with the Viewshed and Raster Calculator tools in the Spatial Analyst extension.

Observers on each route began at approximately sunrise and continued until completed (3-12 hours later depending on the route). Along each route, 1-6 observers (including CPW staff and volunteers) used binoculars and spotting scopes to find groups of bighorn sheep. The observers recorded the following for each group of bighorn: 1) number of bighorn, 2) classification of each bighorn (i.e., full-curl ram, 7/8-curl ram, 3/4-curl ram, 5/8-curl ram, 1/2-curl ram, ewe, yearling ram, yearling ewe, lamb, or unclassified), 3) number of marked ewes, 4) number of marked rams, 5) mark identifications, 6) behavior, and 7) location. We removed duplicate sightings made during each one-day survey. Using the same methods for the Pikes Peak herd, we conducted surveys consisting of 9-11 routes from 2007-2009. Each survey was repeated 7 times in 2007 and 6 times in 2008-2009 in July and August. The total combined length of routes was 62 km. For the Georgetown herd, additional resight data were collected via opportunistic sightings and extra routes conducted between complete surveys. Prior to the resight surveys each year, we confirmed that all marked bighorn were within the study areas and alive via ground and aerial radio-telemetry.

Following McClintock and White (2007), we used Bowden's estimator (Bowden and Kufeld 1995) implemented in NOREMARK software (White 1996) to generate a mark-resight estimate with standard errors and 95% confidence interval for each bighorn sheep population. This method assumes that: 1) the sample of marked individuals is drawn from a closed population; 2) each individual has an equal chance of being marked; 3) marked and unmarked individuals are identified and counted correctly; and 4) marking does not increase the probability that an individual is sighted. Additionally, this method allows for mortality during the sighting period. This estimator was appropriate for our sample because it accounted for 1) variation in individual sighting probabilities and 2) resighting of individuals known to be marked but who cannot be identified. Besides mark-resight population estimates, statistical analyses were preformed in R version 3.0.2 (R Core Team 2013) with package nlme (Pinheiro et al. 2014).

One assumption of Bowden's estimator is that the each animal has an equal chance of being selected for marking and that the marked animals are independent. This assumption can be approximated if the selection of animals to be marked is different than the selection of those resighted (White and Shenk 2001). This was achieved in this study by marking animals on winter range and resighting them on summer range. In the Georgetown herd, ground surveys were also conducted during December of each year. Each single-day survey consisted of 5-6 simultaneous routes repeated up to 4 times. We did not use these surveys to produce a December population estimate because the assumptions of Bowden's estimator were likely violated. We did use these surveys to calculate demographic rates and to evaluate differences between July and December surveys.

We calculated the annual individual sighting probability of each marked bighorn by dividing the number of surveys during which an individual was observed by the number of surveys completed each year. We used repeated measures ANOVA to evaluate the interaction between sex and annual sighting probabilities. The mean individual sighting probability does not incorporate collars that are observed but not individually identified. To incorporate these unidentified collars, we calculated the proportion of marked ewes and rams observed on each survey by dividing the number of marks observed by the number of marks in the population. We also compared the number of ewes, rams, and total bighorn observed during each survey to the modeled numbers in the population.

We monitored the radio-collars via ground and aerial radio-telemetry throughout the year. All collars were equipped with mortality sensors except the Globalstar collars; we determined the mortality status of the bighorn wearing these collars by monitoring daily satellite uploaded locations. We located mortalities as soon as possible and, when possible, determined the cause of death. For each herd, we calculated annual survival rates for adult ewes and adult rams from December 2005 to December 2009 using a Kaplan-Meier staggered entry design. Harvest mortality was incorporated separately from natural mortality in the population models described below. Therefore, harvest mortalities were censored when calculating survival rates. This also allows for the comparison of survival rates in Georgetown and Pikes Peak herds to other herds with different harvest pressures.

We developed a population model for each herd to estimate the July and December populations from 1991 to present for Georgetown and from 1988 to present for Pikes Peak (White and Lubow 2002). These optimized fit models incorporated all available Bowden's ewe and ram population estimates; observed December age ratios; observed December sex ratios; observed adult ewe and ram survival rates; and removals via hunter harvest, translocations, and vehicle collisions. Akaike Information Criterion model selection was not performed due to insufficient data.

These studies followed guidelines and protocols approved through the Colorado Parks and Wildlife Animal Care and Use Committee (10-2006, 04-2007 and 07-2006).

RESULTS

Surveys and Sighting Probability

Based on the viewshed analysis, 87% (288 km^2) and 79% (86 km^2) of the area classified as summer bighorn sheep range of the Georgetown and Pikes Peak herds, respectively, were visible from the resight survey routes.

From 2006-2009, we successfully completed 22 resight surveys in the month of July for the Georgetown herd. Two marked ewes were out of the study area in July 2006 and were, therefore, censored from the analysis. One survey in 2006 was not completed due to restricted visibility and one survey in 2007 was excluded from survey averages due to the small number of bighorn observed. From 2007 to 2009, 19 surveys were successfully completed of the Pikes Peak herd.

Within each herd and year, the individual surveys varied widely in the number of bighorn observed; observed sex and age ratios; the individual sighting probabilities of marked bighorn; and the proportion of marked animals observed on surveys. The individual sighting probability of collared animals and the proportion of collared animals observed on surveys were consistently higher in the Pikes Peak herd than in the Georgetown herd (Table 1).

Population Estimates

For both herds, we found an interaction between sex and annual sighting probabilities (repeated measures ANOVA: Pikes Peak T_{52} = 3.944, P = 0.0004; Georgetown T_{128} = 2.152, P = 0.03), so we generated separate estimates for rams and ewes in each herd. The Bowden population estimates in the Georgetown herd ranged from 150 (SE = 19) to 229 (SE = 32) for ewes and from 157 (SE = 37) to 216 (SE = 38) for rams. Based on these estimates a mean of 18% of the ewe population and 9% of the ram population was marked during the resight surveys (Table 2). In the Pikes Peak herd, the Bowden population estimates ranged from 60 (SE = 3) to 92 (SE = 5) for ewes and from 32 (SE = 4) to 50 (SE = 4) for rams. Based on these estimates, a mean of 31% of the ewe population and 28% of the ram population was marked during the resight surveys (Table 3). The 95 percent confidence interval lengths were smaller for the Pikes Peak herd estimates than for those of the Georgetown herd.

Survival

In the Georgetown herd, mean annual survival excluding harvest was 0.91 for adult ewes and 0.92 for adult rams (Table 4). For the Pikes Peak herd, the mean annual survival was 0.90 for adult ewes and 0.90 for adult rams. From December 2005 to April 2011, 37 marked

Table 1. Identification rates and sighting probability (mean and range) of ewe and ram collars during resight surveys in the Georgetown and Pikes Peak bighorn sheep herds, Colorado, 2006-2009.

	Bighorn Sheep Herd						
	Georgetown Herd				Pikes Peak Herd		
	2006	2007	2008	2009	2007	2008	2009
Ewe							
Collars deployed in study area	33	33	33	34	19	22	27
Identified collar observations	61	33	42	38	52	60	93
Unidentified collar observations	4	15	12	15	19	12	6
Mean sighting probability	0.31	0.17	0.25	0.22	0.31	0.45	0.57
Range sighting probabilities	0.00-0.67	0.00-0.67	0.00-0.80	0.00-0.60	0.14-0.57	0.00-0.83	0.00-0.83
Mean proportion of collars observed	0.33	0.24	0.33	0.31	0.36	0.55	0.61
Range proportion of collars observed	0.12-0.45	0.12-0.36	0.15-0.58	0.18-0.47	0.16-0.74	0.41-0.73	0.33-0.81
Ram							
Collars deployed in study area	14	18	16	15	7	11	14
Identified collar observations	26	18	9	7	33	40	29
Unidentified collar observations	2	11	7	8	4	3	3
Mean sighting probability	0.31	0.17	0.11	0.09	0.51	0.61	0.35
Range sighting probability	0.00-0.83	0.00-0.50	0.00-0.40	0.00-0.40	0.29-0.71	0.17-0.83	0.17-0.83
Mean proportion of collars observed	0.35	0.27	0.20	0.20	0.59	0.64	0.38
Range proportion of collars observed	0.14-0.57	0.00-0.50	0.00-0.38	0.13-0.37	0.14-1.00	0.27-1.00	0.21-0.57

Table 2. July population estimates with 95% confidence intervals (95% CI) and percent confidence interval lengths (% CIL) and the proportion of the ewe and ram population that were marked each year in the Georgetown bighorn sheep herd, Colorado, USA, 2006-2009.

Year	Ewe	95% CI	% CIL	Ram	95% CI	% CIL	Prop Ewes marked	Prop Rams marked
2006	174	147-207	34	194	144-261	60	0.19	0.07
2007	229	175-300	55	216	154-303	69	0.14	0.08
2008	185	150-229	43	157	101-245	92	0.18	0.10
2009	150	118-192	49	171	112-264	89	0.23	0.09

Table 3. July population estimates with 95% confidence intervals (95% CI) and percent confidence interval lengths (% CIL) and the proportion of the ewe and ram population that were marked each year in the Pikes Peak bighorn sheep herd, Colorado, USA, 2006-2009.

Year	Ewe	95% CI	% CIL	Ram	95% CI	% CIL	Prop Ewes marked	Prop Rams marked
2007	92	83-103	22	50	43-59	32	0.21	0.14
2008	85	71-104	39	42	34-51	40	0.26	0.26
2009	60	54-67	22	32	25-41	50	0.45	0.44

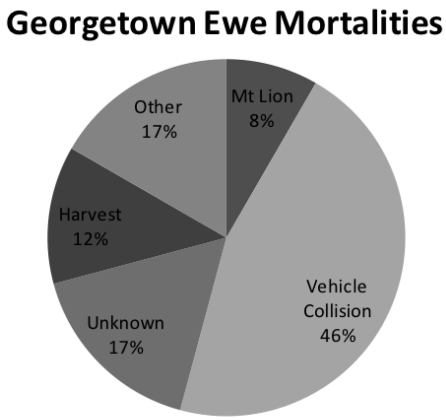
bighorn sheep (24 ewes, 13 rams) from the Georgetown herd died. The largest source of mortality for ewes was vehicle collisions (11) followed by hunter harvest (3). Other known causes of mortality in the Georgetown herd included mountain lion (2), fence entanglements (1), natural causes (1), liver tumors (1), and hardware disease (1, Fig. 3). For rams, the largest source of mortality was hunter harvest (6) followed by vehicle collisions (3). Other known causes of mortality in the Georgetown herd included mountain lion (1) and wounding loss (1, Fig. 3). From December 2006-April 2011, 19 marked bighorn sheep (10 ewes, 9 rams) from the Pikes Peak herd died. The largest known source of mortality for ewes was mountain lions (3) followed by falls (2, Fig. 4). The largest sources of mortality for rams were hunter harvest (3) and mountain lions (3) followed by falls (2, Fig. 4).

Population Models

From 2006-2009, in the Georgetown herd, the mean proportion of the modeled ewe and ram population observed during a survey was 0.34 and 0.32, respectively (Fig. 5, Fig. 6). In the Pikes Peak herd, the mean proportion of the modeled population observed during a survey

Table 4. Annual (Dec to Dec) survival rates with 95% confidence intervals of adult ewes and adult rams in the Georgetown and Pikes Peak bighorn sheep herds, Colorado, USA, Dec 2006-Dec 2009. Harvested animals were censored.

	Ewe Survival		Ram Survival	
Year	Georgetown	Pikes Peak	Georgetown	Pikes Peak
2005-2006	0.97 (0.92-1.00)		0.94 (0.81-1.00)	
2006-2007	0.85 (0.73-0.96)	0.89 (0.77-0.99)	1.00 (1.00-1.00)	0.88 (0.67-1.00)
2007-2008	0.87 (0.76-0.98)	0.91 (0.85-1.00)	0.89 (0.74-1.00)	0.81 (0.59-1.00)
2008-2009	0.94 (0.85-1.00)	0.89 (0.85-1.00)	0.85 (0.65-1.00)	1.00 (1.00-1.00)
Average	0.91	0.90	0.92	0.90



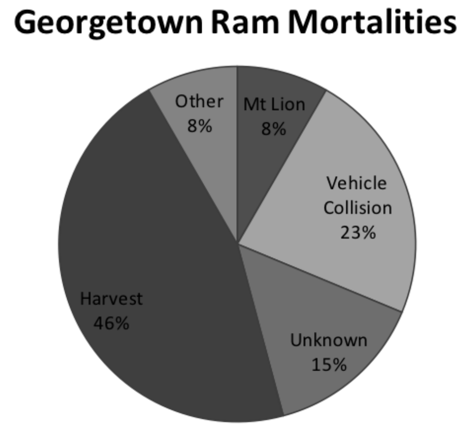
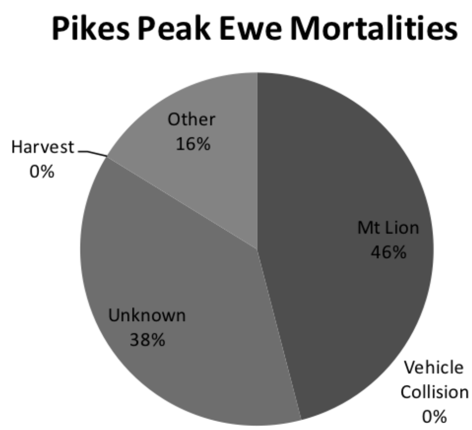


Figure 3. Causes of mortality for the 24 collared ewes and 13 collared rams that died from the Georgetown bighorn sheep herd, Colorado, USA, Dec 2005 - April 2011.



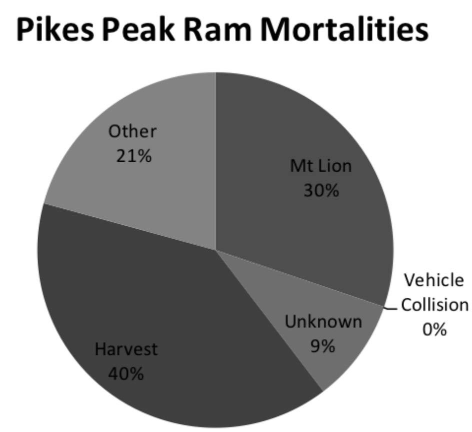


Figure 4. Causes of mortality for the 10 collared ewes and 9 collared rams that died from the Pikes Peak bighorn sheep herd, Colorado, USA, Dec 2006 - April 2011.

from 2007-2009 was 0.52 for ewes and 0.53 for rams (Fig. 7, Fig. 8).

From 1992 to 2010, in the Georgetown herd, a higher proportion of the total modeled population was observed during December surveys (mean = 0.50) than during July surveys (mean = 0.35, Fig. 9). The mean proportion of the modeled population observed during surveys in the Pikes Peak herd was 0.48.

DISCUSSION

We found high variability in mean individual sighting probability between the surveys conducted in the Georgetown and Pikes Peak herds, as well as between years and individual surveys within each area. Although the proportion of the summer bighorn habitat visible from the resight survey routes was higher in the Georgetown study area than in the Pikes Peak study area, the mean sighting probability was consistently higher for the Pikes Peak herd than the Georgetown herd. This was due to several factors. The Pikes Peak herd occupies a smaller area that is primarily alpine where visibility is high. In addition to the alpine, the Georgetown herd occupies forested areas with reduced visibility. Also, survey routes on Pikes Peak were shorter and more easily accessible than Georgetown routes, providing observers with more time each day to survey visible bighorn habitat.

Within each year, sighting probability likely

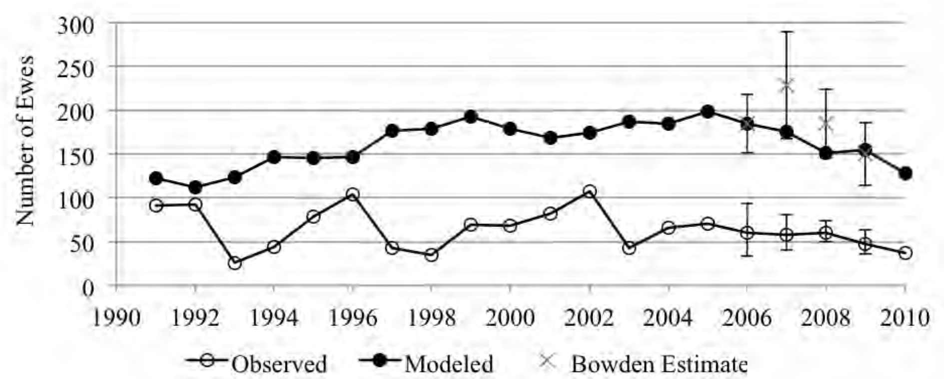


Figure 5. Number of ewes observed during the July survey of the Georgetown bighorn sheep herd, Colorado, 1991-2010; the modeled ewe population for the same time period and the Bowden population estimate with 95% confidence intervals from the mark-resight study 2006-2009. For years in which multiple surveys were conducted, the mean and range of the number of bighorn observed over all the surveys is shown.

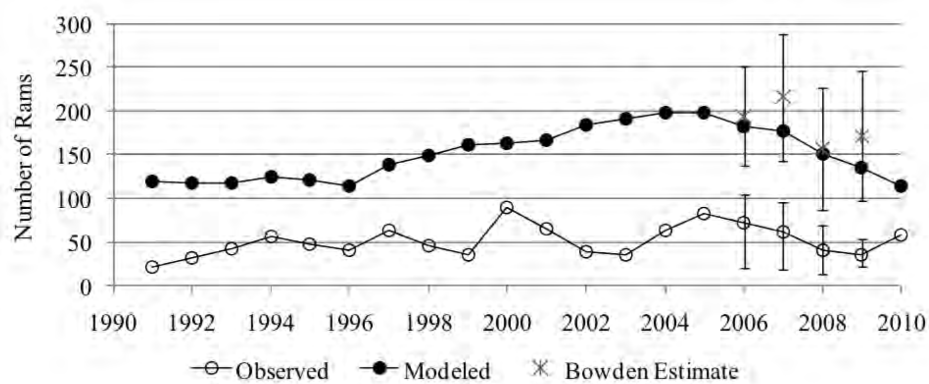


Figure 6. Number of bighhorn sheep rams observed during the July survey of the Georgetown bighorn sheep herd, Colorado, 1991-2010; the modeled ewe population for the same time period and the Bowden population estimate with 95% confidence intervals from the mark-resight study 2006-2009. For years in which multiple surveys were conducted, the mean and range of the number of bighorn observed over all the surveys is shown.

varied from survey to survey due to factors, such as bighorn distribution and activity, weather conditions, group size, and, possibly, observer bias (Bodie et al. 1995; Conroy et al. 2014). Mean sighting probabilities increased annually for Pikes Peak ewes but the same trend did not occur for Georgetown ewes. Many of the same observers were used over the course of the Pikes Peak study and likely became better at finding bighorns, especially ewes, over time. In contrast, observers in the Georgetown study tended to be either novel each year or experienced with the area and less likely to improve during the years of the study. For Pikes Peak rams, mean sighting probabilities increased between 2007 and 2008 but fell in 2009. For Georgetown rams, mean sighting probabilities declined over the course of the study.

Several previous studies have reported bighorn sighting probabilities (Table 5). McClintock and White (2007) reported ewe sighting probability on summer ground-based resight surveys in Rocky Mountain National Park of 0.39 and 0.33 for 2 years. This result falls between the sighting probabilities of the Pikes Peak and Georgetown herds. Their study area was a mix of alpine and timbered areas

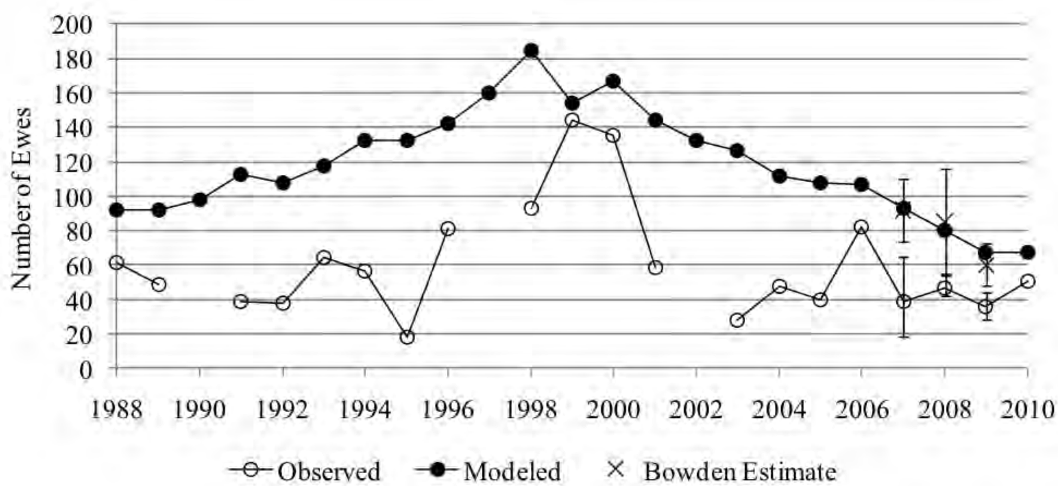


Figure 7. Number of ewes observed during the July survey of the Pikes Peak bighorn sheep herd, Colorado, 1991-2010; the modeled ewe population for the same time period and the Bowden population estimate with 95% confidence intervals from the mark-resight study 2007-2009. For years in which multiple surveys were conducted, the mean and range of the number of bighorn observed over all the surveys is shown.

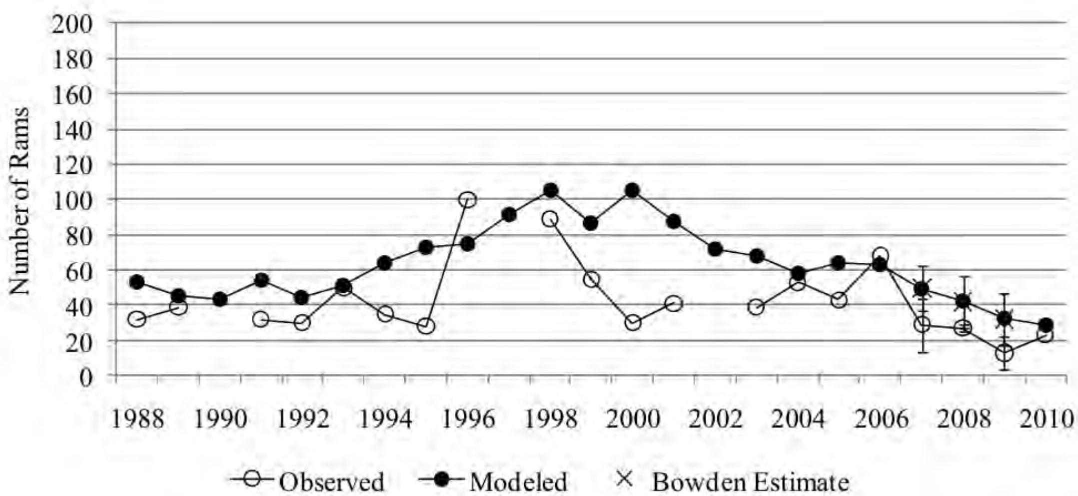


Figure 8. Number of rams observed during the July survey of the Pikes Peak bighorn sheep herd, Colorado, 1991-2010; the modeled ewe population for the same time period and the Bowden population estimate with 95% confidence intervals from the mark-resight study 2007-2009. For years in which multiple surveys were conducted, the mean and range of the number of bighorn observed over all the surveys is shown.

similar to the habitats used by the Georgetown herd excluding the lower elevations. Direct comparisons of sighting probabilities from the other studies are difficult due to differences in seasonality, resight methods, terrain and vegetation; however, comparisons relative to several factors are possible. Conroy et al. (2014) found that, during aerial surveys, the probability of detecting desert bighorn sheep groups increased as group size increased. Bodie et al. (1995) found that group size was not related to sightability during helicopter surveys. George et al. (1996) reported higher ewe sighting probability during helicopter surveys of an alpine herd (Kenosha herd - 0.95) compared to an adjacent herd occupying a timbered habitat (Tarryall herd - 0.61). George et al. (1996) also found higher variability in bighorn sighting probability in timbered habitats than in alpine habitats. Both of these

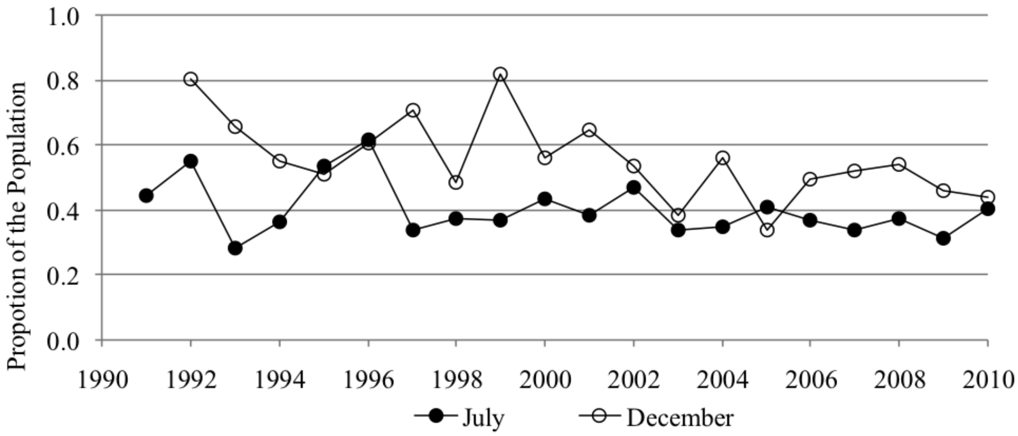


Figure 9. Proportion of modeled total population observed during the July and December surveys in the Georgetown bighorn sheep herd, Colorado, 1991-2010.

findings are consistent with our study in which the sighting probability of both ewes and rams was higher in the Pikes Peak herd than in the Georgetown herd and variability in sighting probability was higher in the Georgetown herd than in the Pikes Peak herd. George et al. (1996) reported ewe sighting probability higher than ram sighting probability in late winter helicopter surveys of alpine habitat. Bodie et al. (1995), on the other hand, reported ram sightability as higher than that of ewes in summer helicopter surveys in canyon habitat. In the current study, ewe sighting probability was higher than that of rams in the Georgetown herd; the opposite was true in the Pikes Peak herd.

Mark-resight methods proved effective for estimating the bighorn population in both herds. These estimates were more precise for the Pikes Peak herd, in which a greater proportion of the

Table 5. Mean bighorn sheep sighting probabilities reported in previous studies.

Class	Sighting probability	State	Population	Habitat	Resight method	Season	Citation
Ewe	0.61	CO	Tarryall Mt	Timbered	Helicopter	Winter	George et al. 1996
Ewe	0.95	CO	Kenosha	Alpine	Helicopter	Winter	George et al. 1996
Ewe	0.39, 0.33[a]	CO	Rocky Mountain National Park	Alpine/timbered	Ground	Summer	McClintock and White 2007
Ewe	0.24[b]	CO	Georgetown	Alpine/timbered /canyon	Ground	Summer	This Study
Ewe	0.44[c]	CO	Pikes Peak	Alpine	Ground	Summer	This Study
Ewe	0.57	ID	Little Jacks Creek	Canyon	Helicopter	Summer	Bodie et al. 1995
Ewe	0.58	CO	Trickle Mt		Helicopter	Winter	Neal et al. 1993
Ram	0.50	CO	Kenosha	Alpine	Helicopter	Winter	George et al. 1996
Ram	0.17[d]	CO	Georgetown	Alpine/timbered/ canyon	Ground	Summer	This study
Ram	0.49[e]	CO	Pikes Peak	Alpine	Ground	Summer	This study

[a]2003 and 2004 reported separately
[b,c,d,e]Many marks were not uniquely identified. The mean proportion of collars observed was [b] 0.30, [c] 0.51, [d] 0.25, [e] 0.54

herd was marked and observed during surveys compared to the Georgetown herd. Within each herd and year, demographic ratios varied widely between individual surveys (Table 6). The variability in demographic ratios can be attributed to the heterogeneity in the groups observed and missed on individual surveys. Sexual segregation during the summer counts added to variability in the sex ratio.

In the Georgetown herd, we were able to compare the proportion of the herd observed during July surveys to that of December surveys. Even though 2-3 times more routes were completed on each of the surveys in July than surveys in December, the proportion of the herd observed was higher in December. This was due to the fact that in December bighorn are concentrated on winter range that is easily accessible to survey and that ewes and rams were engaged in rutting behavior, which makes them more active and visible.

Adult survival did not appear to be limiting population growth in either herd. In the Georgetown herd, mortality resulting from collisions with vehicles was estimated at 8% of the population per year during the study (Huwer 2010, 2015). This mortality was dispersed along the interstate and major highways that pass through the range of the herd with speed limits up to 65 miles per hour. The Georgetown bighorn were vulnerable to being struck by vehicles when crossing, feeding adjacent to and licking salt from these roadways. Vehicle-caused mortalities have been recorded in every month of the year; however, most mortality occurred in April, followed by November. None of the collared bighorn in the Pikes Peak herd died as a result of being struck by a vehicle.

Even though the leading causes of adult mortality were very different between the herds, the non-harvest adult ewe and ram survival rates were similar. This raises the question of whether mortalities resulting from mountain lion predation and vehicle collisions were largely compensatory in these specific herds during the respective studies. Both the Pikes Peak and Georgetown herds were declining from peak population numbers and experiencing low lamb recruitment during these studies, possibly indicating some level of density dependent response, such as disease, may have been operating. Bronchopneumonia was known to be prevalent in both herds (Huwer 2010, 2015, Stiver 2011). In the Sheep River bighorn herd in Alberta, Ross et al.

Table 6. Means and ranges of adult ewes and adult rams, lamb:ewe, and ram:ewe observed during resight surveys in the Georgetown and Pikes Peak bighorn sheep herds, Colorado, 2006-2009.

	Bighorn Sheep Herd						
	Georgetown Herd				**Pikes Peak Herd**		
	2006	2007	2008	2009	2007	2008	2009
Number of surveys	6	6	5	5	7	6	6
Routes per survey	11-14	13-16	13-15	13-15	9	10-11	11
Mean observed lamb:ewe	0.27	0.43	0.36	0.40	0.50	0.45	0.24
Range of observed lamb:ewe	0.15-0.55	0.18-0.54	0.16-0.54	0.24-0.47	0.33-0.82	0.24-0.64	0.04-0.42
Mean observed ram:ewe	1.19	1.05	0.66	0.83	0.79	0.60	0.36
Range of observed ram:ewe	0.48-2.09	0.22-2.23	0.23-1.38	0.40-1.33	0.52-1.32	0.45-0.65	0.13-0.79
Mean no. of ewes observed	60	58	60	47	39	47	36
Range no. of ewes observed	33-93	40-81	50-74	36-63	19-65	42-55	28-44
Mean no. of rams observed	71	61	40	36	29	27	29
Range no. of rams observed	21-105	18-96	14-69	22-53	17-44	24-29	4-22

(1997) found that more than 30% of lion-killed bighorn sheep appeared to have disabilities prior to death. In northern Colorado, mule deer (*Odocoileus hemionus*) infected with chronic wasting disease were more likely to be killed by vehicle collisions or mountain lions than uninfected deer (Krumm et al. 2005, 2010). Bighorn with bronchopneumonia in the Pikes Peak and Georgetown herds may have been more susceptible to vehicle collisions and mountain lion predation than healthy bighorn due to reduced levels of alertness. In addition, most of the major roadways within the range of the Georgetown herd run along creeks through the low elevations of the range. Bighorn with compromised respiratory health may have been likely to spend more time in valley bottoms than on steep slopes and high elevation portions of their home range, bringing them into close proximity to major roadways. Indeed, in cases of bronchopneumonia die-offs, carcasses are frequently found along creeks in canyons and at the base of escape terrain.

MANAGEMENT IMPLICATIONS

For many bighorn populations, no studies have been conducted to estimate the population sizes with known levels of precision. Managers, in these cases, often apply an upward adjustment to minimum count data to estimate population size. The size of the upward adjustment required depends on survey methods and characteristics of the herd and its habitat. The Georgetown and Pikes Peak herds occupy areas characteristic of other bighorn habitat in Colorado. Our studies provide sighting probabilities, proportions of collars observed and proportions of modeled populations observed during ground based surveys for 2 herds that differ in size, habitat use, and survey coverage. These results can be used to inform the size of the upward adjustments applied to minimum counts obtained through ground counts in other herds.

During both the summer and fall surveys, the proportion of the herd, the sex ratio, and the age ratio observed on a specific day are variable, depending on environmental conditions and bighorn distribution on the day of the survey. For many herds in Colorado, only 1 survey is conducted per year and annual variation in the results is high. In these herds, more reliable data can be collected and conducting multiple surveys per season can reduce annual variability.

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Additions to Dall's Sheep Working Hypotheses

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ABSTRACT In 1999, the Second North American Wild Sheep Conference focused on producing working management hypotheses for Rocky Mountain bighorns (Ovis canadensis), California bighorns (Ovis canadensis californiana), desert bighorns (Ovis canadensis nelsoni), and a generalized thinhorn sheep. Additionally, these hypotheses predicted the probable responses of sheep to anticipated challenges. The idea was to help planners or new managers grasp the rudiments of wild sheep management. As conceived, the working management hypotheses were to be predictive statements that integrated available biological knowledge with management experience and summaries of the known aspects of wild sheep species biology. These summaries focused on distribution, abundance, and population strategy; predation and harvest management; disease; parasites; and disturbance. Integral to the usefulness of these documents as working management hypotheses was the idea that they would be updated as new knowledge and experience increased over time. Developments in Dall's sheep (Ovis dalli) management in Alaska since 1999 invite a contemporary reevaluation of the Dall's sheep working management hypotheses there. Knowledge of the existing elements is examined and updated. Additionally, the importance of putative genetic impacts of harvest management and human involvement in management allocation in Alaska is specifically discussed.

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KEY WORDS Alaska, bighorn sheep, Dall's sheep, genetics, harvest management, *Ovis dalli, Ovis canadensis,* thinhorn sheep.

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Montana's New State-wide Bighorn Sheep Research Initiative

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ABSTRACT Bighorn sheep (*Ovis canadensis*) conservation in Montana is challenging. A majority of Montana's populations are patchily distributed and relatively small, with many populations static or periodically experiencing dramatic declines despite the abundance of seemingly adequate habitat. Managers are routinely making decisions on bighorn sheep population augmentation and restoration, harvest, habitat management, disease prevention and response, and other conservation actions without adequate knowledge of the drivers of demographic processes that inform management of many of Montana's more successfully restored ungulate species. A research program has been designed and funded on the premise that broadly applicable insights for management and conservation are best obtained by addressing the same questions in multiple populations representing the range of ecological settings realized by the species of interest. The research program will involve field studies of 7 bighorn sheep herds in Montana, with data on each herd collected over a 5-year period. Herds were selected to capture a wide range of variability in disease outbreak history, habitat types, and herd attributes in an effort to maximize our ability to partition and quantify the potential relative effects of these factors on lamb and adult survival, recruitment, and population dynamics.

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KEY WORDS bighorn sheep, disease, health, Montana, *Ovis canadensis*, pathogens, population dynamics, recruitment, survival, telemetry.

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Pregnancy Rates in Dall's Sheep in the Chugach Mountains, Alaska

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ABSTRACT Dall's sheep (*Ovis dalli*) populations in the Chugach Mountains in south central Alaska have declined between 30-50% over the past 20 years. In an effort to obtain demographic data on these populations and to inform biologists as to the causes of the declines, 30-40 ewe Dall's sheep were captured annually in Alaska's Chugach Mountain from 2009 to 2013. Pregnancy rates in ewes were measured via serum levels of pregnancy-specific protein B. This appears to be an effective method of assessing pregnancy rates in wild sheep because most (>90%) ewes that showed a positive pregnancy test were later observed with lambs. Population pregnancy rates in ewes 3 years old and older were variable but lower than expected and generally lower than comparative data obtained from other thinhorn sheep populations. Rates ranged from a low of 21% in winter 2011–2012 to a high of 94% in winter 2012–2013. Age at first reproduction and individual reproductive histories, in conjunction with qualitative measures of body condition conducted at capture, suggest that some females are nutritionally stressed. This may be delaying age at first reproduction or causing ewes to experience a reproductive pause that could allow them to build nutritional reserves between pregnancies.

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KEY WORDS Alaska, Dall's sheep, *Ovis dalli,* pregnancy, protein B, nutritional restriction.

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Disease and Predation: Sorting Out Causes of a Bighorn Sheep Decline

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ABSTRACT From 2010 to 2012, we captured and radio-collared 74 neonate bighorn sheep (*Ovis canadensis)* in Black Hills, SD, to estimate 52-week survival and document cause-specific mortality. We estimated survival using known fate analysis in Program MARK. Model {S1wk, 2-8wks, >8wks} had the lowest Akaike's Information Criterion corrected for small sample size value, indicating that a 3-stage age interval (1 week, 2-8 weeks, and >8 weeks) best explained survival. Weekly survival estimates for 1 week, 2-8 weeks, and >8 weeks were 0.81 (95% Confidence Interval (CI) = 0.70-0.88), 0.86 (95% CI = 0.81-0.90), and 0.94 (95% CI = 0.91-0.96), respectively. Overall probability of surviving 52 weeks was 0.02 (95% CI = 0.01-0.07), with pneumonia (36%) as the leading cause of mortality followed by predation (30%). We found that pneumonia and predation were temporally heterogeneous; lambs were the most susceptible to predation during the first 2-3 weeks of life, but at the greatest risk of pneumonia during weeks 4-8. Mortality from predation may have been partly compensatory to pneumonia and its effects were less pronounced as alternative prey became available. Given the high rates of pneumonia-caused mortality observed, management activities should be geared toward eliminating contact between diseased and healthy populations.

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KEY WORDS bighorn sheep, cougar, disease, neonate, *Ovis canadensis*, pneumonia, predation, *Puma concolor*, South Dakota, vaginal implant transmitter.

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Capture and Survival of Neonatal Bighorn Sheep Lambs in a Colorado Herd using Vaginal Implant Transmitters

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ABSTRACT We captured, radio-collared, performed ultrasounds on and inserted vaginal implant transmitters (VITs) into 15 pregnant ewes from a Rocky Mountain bighorn sheep (*Ovis canadensis)* herd in Colorado that was experiencing poor lamb recruitment. Previous sampling from this herd demonstrated presence of respiratory pathogens, including *Mycoplasma ovipneumonia*e (by polymerase chain reaction, culture, and serology) and leukotoxigenic *Pasteurellaceae*, including a *Bibersteinia trehalosi* strain previously associated with bighorn pneumonia in Colorado herds. Use of the VITs allowed us to detect, capture and radio collar 15 neonate lambs within 48 hours of parturition and monitor their survival daily throughout their first months of life. Fourteen of the 15 VITs were successful (VITs shed during parturition); one VIT was shed in early April and was not located at a birth site. We were able to collar a neonate lamb from each of the 14 successful VITs and collared a fifteenth lamb opportunistically from a non-transmitted ewe. Recovered carcasses were submitted for necropsy and laboratory assessment. Of the lambs captured, all 15 were dead by 130 days of age: 10 died of apparent pneumonia (all within 8–10 weeks of age), 1 died from trauma after being kicked or trampled, 1 was killed by a mountain lion, and 3 died of starvation likely caused by abandonment after capture. VITs may be a viable option for capturing neonate lambs in herds where VITs can be monitored daily during the lambing season and where the terrain allows for safe access to lambing sites. However, we recommend exercising care in lamb handling and monitoring to minimize abandonment and we urge caution in ascribing starvation-related deaths within the first week after lamb capture to anything other than capture-related loss.

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KEY WORDS, bighorn sheep, Colorado, *Mycoplasma ovipneumoniae,* neonatal survival, *Ovis canadensis, Pasteurellaceae*, recruitment, respiratory disease, vaginal implant transmitters.

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Rates and Causes of Mortality of Dall's Sheep in Alaska: A Comparison Among Mountain Ranges

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ABSTRACT Annual survival and causes of mortality of Dall's sheep (*Ovis dalli*) lambs and ewes were estimated in Alaska's Chugach Mountains (CHU; 2010-2014), central Alaska Range (CAR; 1999-2005), and eastern Brooks Range (EBR; 2009-2012). Survival of ewes ranged from 0.88 in the CHU to 0.91 in the EBR. Lamb survival was lowest in the CHU (mean = 0.27) and highest in the EBR (mean = 0.48). Wolves (*Canis lupus*) were the most common cause of ewe mortality in the CAR and EBR (80% and 83% of deaths, respectively). In contrast, 85% of CHU ewes died of accidents, disease, or other non-predation causes. Predation was the leading cause of lamb deaths in the CAR and EBR (95% and 75% of deaths, respectively) but predators only killed 46% of CHU lambs. Golden eagles (*Aquila chrysaetos*) were important predators of lambs in all 3 areas. Wolverine (*Gulo gulo*) predation was common in the CHU and EBR but less important in the CAR. Coyote (*Canis latrans*) predation was a significant cause of mortality only in the CAR, whereas predation by black bears (*Ursus americanus*) and grizzly bears (*U. arctos*) was common only in the CHU. Differences among areas in predator communities, particularly the abundance of coyotes, could explain many of the differences we observed, though differences between the CHU and CAR are more likely due to weather and topography. These results suggest that the relative importance of predation, particularly that of specific predators, to sheep population dynamics differs among areas within Alaska. Thus, managers should obtain information specific to a particular area before adopting predator management plans intended to benefit sheep.

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KEY WORDS Alaska, *Aquila chrysaetos*, *Canis lupus*, Dall's sheep, golden eagle, lamb, mortality, *Ovis dalli*, predation, survival, wolf.

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Determining Cause-specific Mortality, Disease Prevalence and Survival Rates of Bighorn Sheep Inhabiting the Elk Mountain Region of South Dakota and Wyoming

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ABSTRACT Between March 2012 and July 2014, we investigated cause-specific mortality, survival rates, and disease prevalence in the bighorn sheep (*Ovis canadensis*) herd occupying Elk Mountain, located in the Black Hills of South Dakota and Wyoming. We captured adult bighorn sheep (n = 38) via drop net and helicopter net-gunning and fitted them with Very High Frequency or Global Positioning System collars. Pregnant ewes (n = 43) were fitted with vaginal implant transmitters. Nasal swabs, blood and fecal samples were collected for disease testing. Lambs (n = 32) were captured by hand and fitted with expandable VHF collars. Predation accounted for 42.9% (n = 3) of adult and 43.8% (n = 8) of lamb mortalities. Unknown causes claimed 57.1% (n = 4) of adult mortalities; unknown and other causes claimed 56.3% (n = 9) of lamb mortalities. *Mannheimia haemolytica* was documented in 52.6% (n = 20) of adults and 9.4% (n = 3) of lambs; *M. glucosida* was found in 6.3% (n = 2) of lambs, while *Bibersteinia trehalosi* was documented in 100% (n = 38) of adults and 15.6% (n = 5) of lambs. Overall, annual adult survival was 88.0%, 2013 lamb survival was 25.6% and 2014 lamb survival was 37.5%. The population is considered healthy relative to pneumonia and this, coupled with minor predation loss, shows population growth.

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KEY WORDS bighorn sheep, Black Hills, cause-specific mortality, *Ovis canadensis*, pneumonia, South Dakota, survival, Wyoming.

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Long-distance Movement of the Granby Ram Through Colorado and Wyoming

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ABSTRACT On 7 July 2009, Colorado Division of Parks and Wildlife staff captured and placed a Global Positioning System collar with satellite upload capability on a 5-year-old bighorn sheep (*Ovis canadensis*) ram near Granby, Colorado. This lone ram, known as the Granby ram, had been observed in the area 19 km from the nearest bighorn herd for the previous 7 months. Our goal was to monitor his movements, determine if he was likely to contact any domestic sheep, and to prevent him from contacting other bighorns if necessary. The ram remained within 10 km of the capture site for 3 months. Then, from 19 October 2009 to 11 January 2010, he traveled approximately 650 km through Colorado and Wyoming, passing through the home ranges of 5 bighorn herds. On 11 January 2010, due to concerns over pathogens the ram may have been carrying, the Wyoming Game and Fish Department killed him to prevent him from contacting Wyoming's bighorn herds. In this article, we describe the movements of the Granby ram in relation to modeled habitat and bighorn herd home ranges and characterize the attributes of his locations during his movement from Granby, Colorado to the Laramie Mountains of Wyoming.

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KEY WORDS bighorn sheep, Colorado, long-distance movement, *Ovis canadensis*, telemetry, Wyoming.

Long-distance movements of bighorn sheep (*Ovis canadensis*) outside of their home ranges have been reported in previous studies. O'Brien (2014) reported bighorns travelling 50 km from their core home ranges in Idaho, with 10% of the rams traveling at least 21 km outside of their core home ranges. Festa-Bianchet (1986) reported ram movements of 48 km in Alberta, Canada. DeCesare and Pletscher (2006) reported movements of 19– 33 km by 4 of 5 radio-collared males in Montana. In Colorado, an ear-tagged ram from the Dome Rock herd appeared in Waterton Canyon 50 km away and stayed for several years. In the early 1990s, a ram that had been ear-tagged as a lamb in Georgetown was harvested by a hunter in the Kenosha Mountains 35 km away. Another ear-tagged ram moved from Waterton Canyon to Green Mountain 25 km away and remained in the area for months (J. George, personal communication). In addition to these rams, there are numerous examples of bighorn sheep being observed far outside bighorn herd home ranges apparently on long-distance movements.

On 7 July 2009, Colorado Division of Parks and Wildlife (CPW) staff placed a Global Positioning System (GPS) radio collar on one such bighorn ram, which has come to be known as the Granby ram. This 5-year-old ram had

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been observed alone near Granby, Colorado, approximately 19 km from the nearest bighorn herd for the previous 7 months. Our goal was to monitor his movements, determine if he was likely to contact any domestic sheep, and prevent him from contacting other bighorns if necessary. From 19 October 2009 to 11 January 2010, he traveled approximately 650 km through Colorado and Wyoming. Here, we describe his movements in relation to modeled habitat and bighorn herd home ranges and characterize the attributes of his locations during his movement from Granby, Colorado, to the Laramie Mountains of Wyoming.

STUDY AREA

The capture location was in north central Colorado along the Fraser River between the towns of Granby and Tabernash in Grand County. This area is approximately 90 km northwest of Denver and is an island of habitat suitable for bighorn sheep. The locations used by the Granby ram while in this area ranged from 2,480 m to 2,840 m in elevation and were dominated by lodgepole pine (*Pinus contorta*). The nearest area of significant bighorn habitat is 11 km to the west. The nearest bighorn herds are the St. Vrain herd with a population in 2010 of approximately 50 bighorn 19 km to the northeast, and the Georgetown herd with a population in 2010 of approximately 300 bighorn 20 km to the south.

The removal location was in the Laramie Mountains of Wyoming in Converse County. This location is within the range of the Laramie Peak herd, which is 150 km north of Laramie, Wyoming. The area is predominately big sagebrush (*Artemisia tridentate*) shrubland. The Granby ram's locations ranged in elevation from 1,990 m to 2,400 m.

METHODS

On 7 July 2009, CPW staff captured the 5-year-old Granby ram via chemical immobilization. CPW staff fitted him with a Northstar Globalstar D-cell collar. This was a GPS collar with satellite upload capabilities that was programmed to record 6 locations each day at 0500 hours, 0800 hours, 1100 hours, 1400 hours, 1700 hours, and 2000 hours mountain standard time and to upload the 2000 hour location each day. They collected disease samples at the time of capture. We then monitored his movements via satellite uploads as he moved through Colorado and Wyoming. CPW staff informed the Wyoming Game and Fish Department (WGF) when he crossed into Wyoming. On 11 January 2010, he was lethally removed by the WGF to prevent him from contacting local bighorn and possibly transmitting pathogens he may have been carrying. The WGF performed a necropsy on the ram. We downloaded the stored data points from the collar.

The Payette National Forest developed a number of models to assess the viability of bighorn populations on the Forest as part of the Payette National Forest Land and Resource Management Plan (US Department of Agriculture, Forest Service 2010). One of these models was the Summer Source Habitat Model, which uses topography and vegetation to identify suitable bighorn habitat. CPW refined the US Forest Service (USFS) Summer Source Habitat Model for use in Colorado based on radio telemetry data from Colorado, as follows: 1) the minimum slope of escape terrain was reduced from 31° to 27°; 2) allowable canopy cover was increased from 30% to 70%; 3) low-intensity developed land was included; 4) mesic-wet spruce fir forest was removed; 5) pinyon pine (*Pinus edulis*)-juniper (*Juniperus* spp.) and Gambel oak (*Quercus gambelii*) with ≤ 40% was included; and 6) all alpine was included (Eichhoff et al. 2012). Wyoming has not yet refined the USFS Summer Source Habitat Model based on telemetry data from Wyoming. To evaluate the Granby ram's habitat use, we intersected his telemetry locations with slope and aspect

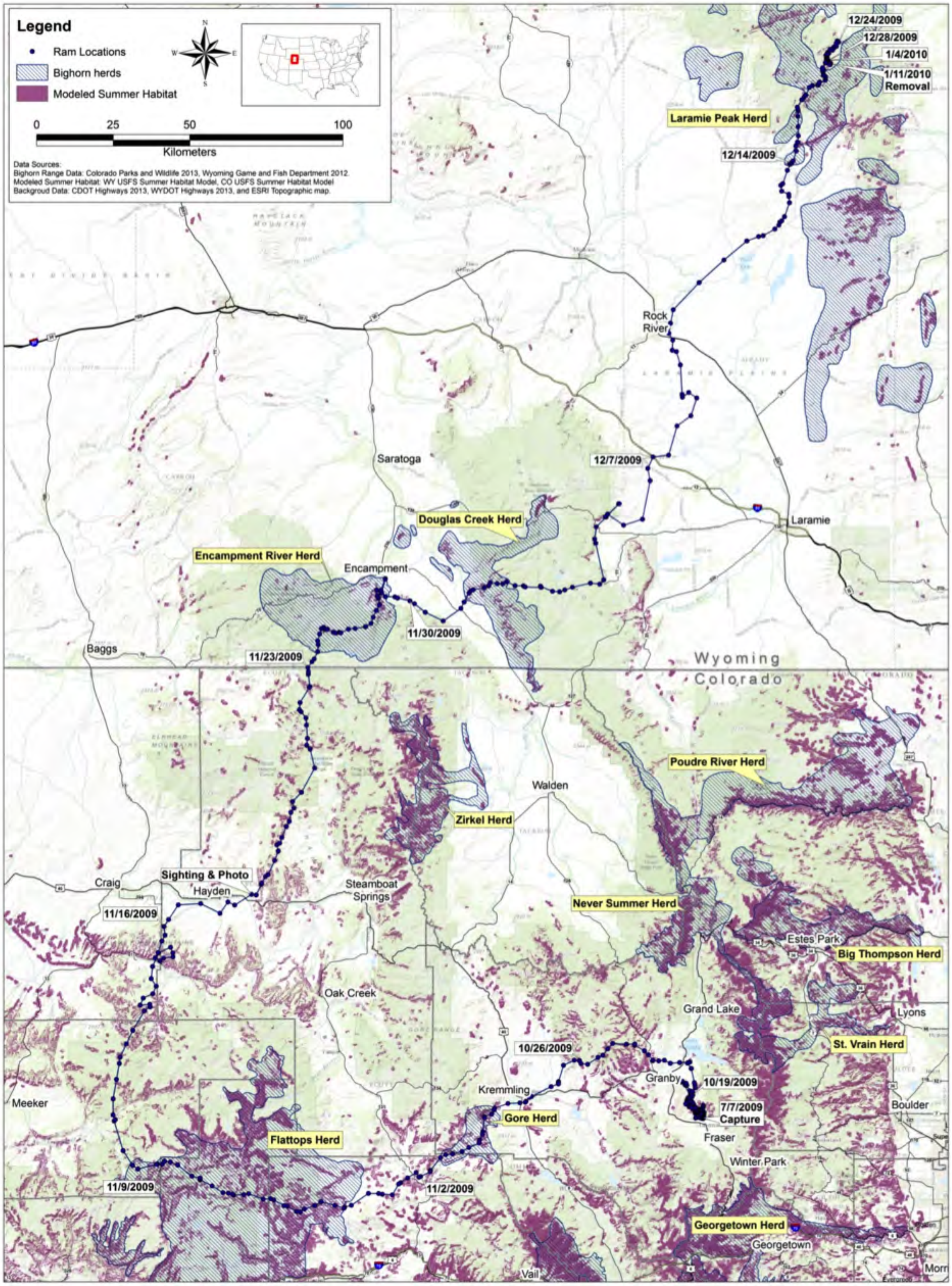

Figure 1. Locations of the Granby ram in relation to bighorn sheep herds and modeled bighorn habitat as he moved through Colorado and Wyoming, USA, 7 July 2009 to 11 Jan 2010.

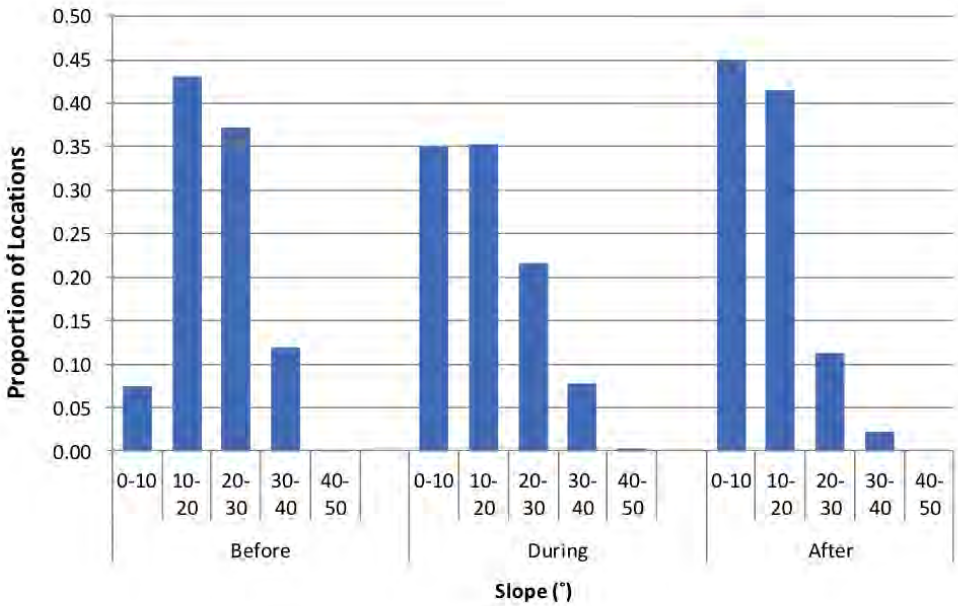

Figure 2. Slope of the locations of the Granby ram before (7 July 2009 to 18 Oct 2009; n = 577), during (19 Oct 2009 to 28 Dec 2009; n = 391) and after (29 Dec 2009 to 11 Jan 2010; n = 88) his movement from Granby, Colorado, to the Laramie Mountains, Wyoming.

derived from a 30-m DEM, LANDFIRE vegetation and canopy cover, and either the USFS Summer Source Habitat Model for the Wyoming locations or the Colorado Summer Source Habitat Model for the locations in Colorado.

The Granby ram’s locations occurred during summer, fall, and winter. We have chosen to compare all of the locations to the summer habitat model because this is the most inclusive model. Winter models are a restricted case of the summer models in which certain aspects, elevations, and areas of persistent snow are excluded. Even fewer of the Granby ram’s locations would have been within the winter model.

The attributes of the locations before, during, and after the movement from Granby, Colorado, to the Laramie Mountains, Wyoming, differ and are reported separately. These differences may have been due to habitat availability in the areas used or due to the fact that the locations before the movement occurred primarily in the summer; those during the movement occurred primarily in the fall and those after the movement occurred in the winter.

RESULTS

The radio collar worn by the Granby ram recorded 1,059 locations between 7 July 2009 and 11 January 2010; an average of 5.6 locations per day (Fig. 1). The longest time between recorded locations was 15 hours. The Granby ram remained within 10 km of the capture site for 3 months after capture. Between 19 October 2009 and 28 December 2009, he traveled more than 650 km through Colorado and Wyoming. He reached the furthest extent of movement in the Laramie Mountains of Wyoming on 24 December 2009. He then traveled back along his trail for 4 days and 6 km. He remained within 1.2 km of this location until 11 January 2010 when he was lethally removed by WGF to prevent him from contacting bighorns and transmitting any pathogens he was carrying.

He passed through the ranges of 2 bighorn herds in Colorado (the Gore and Flattops herds) and 3 bighorn herds in Wyoming (the Encampment River, Douglas Creek,

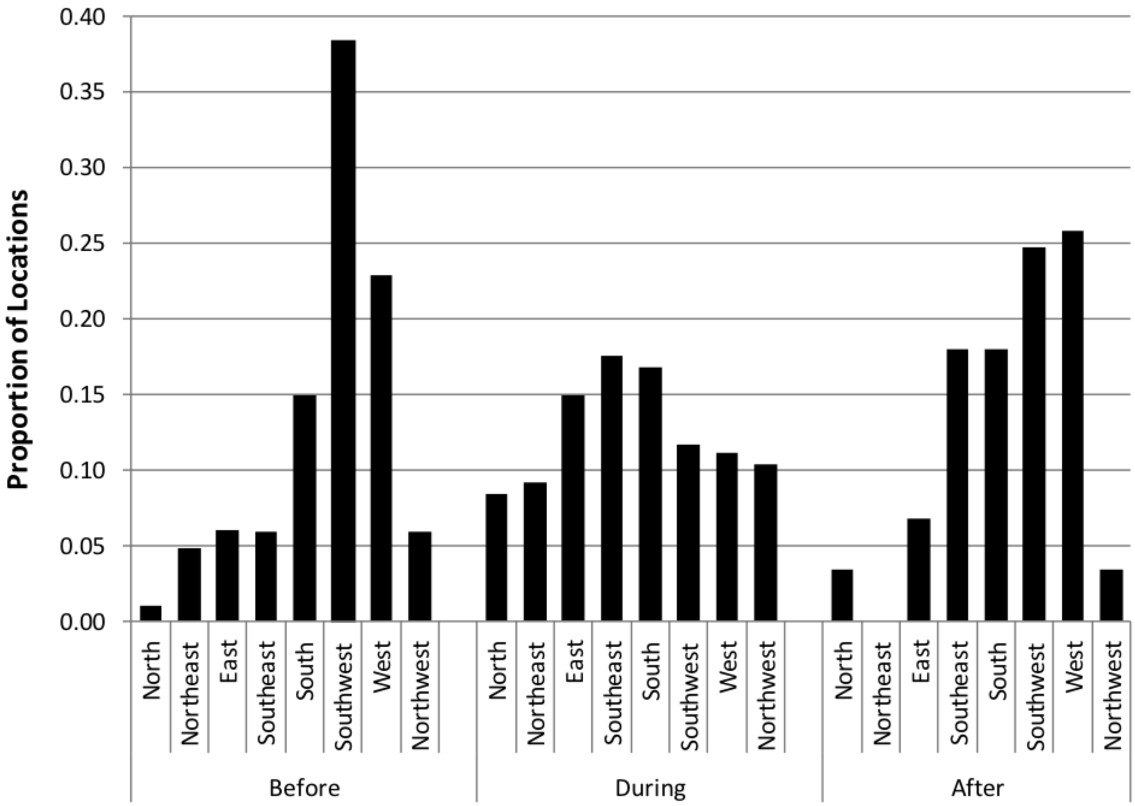

Figure 3. Aspects of Granby ram locations before (7 July 2009 to 18 Oct 2009; n = 577), during (19 Oct 2009 to 28 Dec 2009; n = 391) and after (29 Dec 2009 to 11 Jan 2010; n = 88) his movement from Granby, Colorado, to the Laramie Mountains, Wyoming.

and Laramie Peak herds). He also passed through numerous sheep grazing allotments in Colorado and Wyoming. He was observed and reported only 2 times during his travels. One of these reports initially claimed that he was travelling with other sheep but that proved to be unsubstantiated. One of the observers took a photograph of him near Hayden, Colorado.

Sixty-five percent of the locations in Colorado were within the Colorado Summer Source Habitat Model (Eichhoff et al. 2012). Four percent of the locations in Wyoming were within the USFS Summer Source Habitat Model (US Department of Agriculture, Forest Service 2010).

Ninety percent of all locations were on slopes of 0-30˚, with the highest proportion of locations on slopes of 10-20˚ (Fig. 2). The proportion of locations on slopes of 30-50˚ was higher before the movement than during or after.

Fifty-four percent of all locations had southerly aspects. During the movement, the locations were more evenly dispersed among all aspects, whereas southerly aspects were more prominent before and after the movement (Fig. 3).

Locations prior to the movement were predominately tree-dominated, whereas those following the movement were predominately shrub-dominated. During the movement, tree-dominated and shrub-dominated locations were similarly represented (Fig. 4). Of the tree-dominated locations, the 40-50% tree-cover class was the most common prior to the movement, whereas during the movement, the 50-60% tree-cover class was the most common. After the movement, only 2 locations

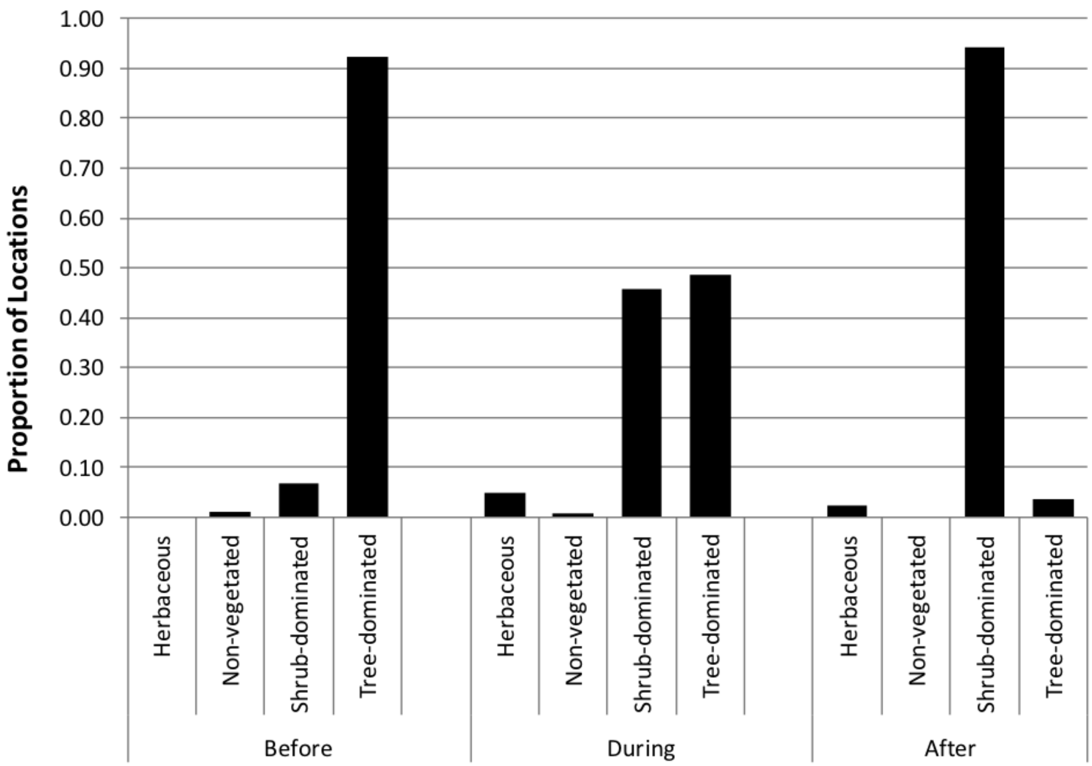

Figure 4. Vegetation cover classes of the locations of the Granby ram before (7 July 2009 to 18 Oct 2009; n = 577), during (19 Oct 2009 to 28 Dec 2009; n = 391) and after (29 Dec 2009 to 11 Jan 2010; n = 88) his movement from Granby, Colorado, to the Laramie Mountains, Wyoming.

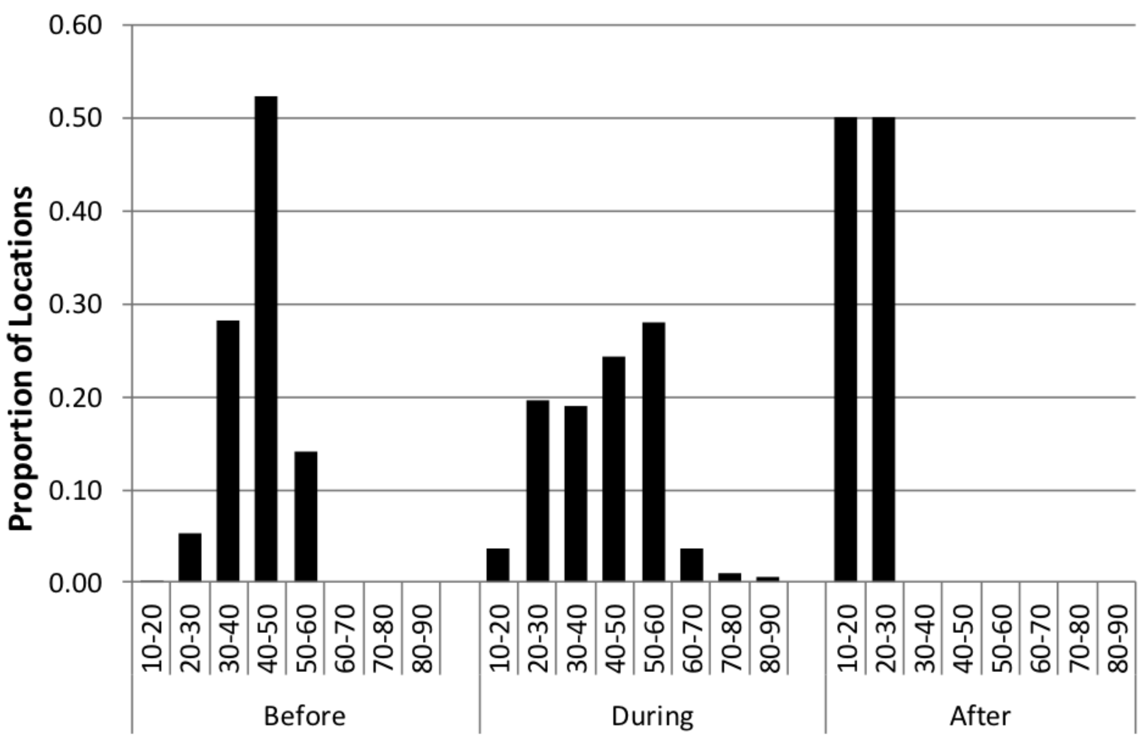

Figure 5. Percentage of tree-cover in tree-dominated locations of the Granby ram before (7 July 2009 to 18 Oct 2009; n = 533), during (19 Oct 2009 to 28 Dec 2009; n = 118) and after (19 Dec 2009 to 11 Jan 2010; n = 2) his movement from Granby, Colorado, to the Laramie Mountains, Wyoming.

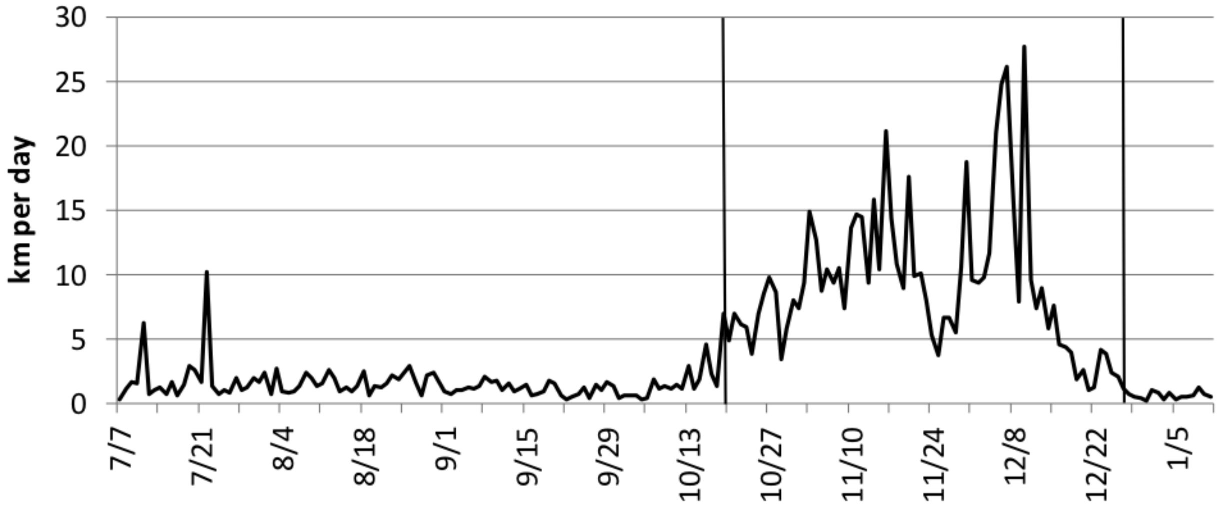

Figure 6. Speed of travel of the Granby ram before (7 July 2009 to 18 Oct 2009), during (19 Oct 2009 to 28 Dec 2009) and after (29 Dec 2009 to 11 Jan 2010) his movement from Granby, Colorado, to the Laramie Mountains, Wyoming.

were tree-dominated (10-30% tree cover) (Fig. 5).

Before, during, and after his movement from Granby, Colorado, to the Laramie Mountains of Wyoming, he traveled an average of 1.8, 11.3, and 0.7 km per day, respectively (Fig. 6). Before his movement, he only traveled more than 3 km per day on 3 occasions (10, 6, and 5 km/day). During his movement, he only moved slower than this on 8 days after he reached the Laramie Peak herd. He traveled more than 20 km/day on 5 occasions, with a maximum of 27.7 km/day. The longest distances moved per day occurred during movement across large expanses of non-habitat between the Douglas Creek and Laramie Peak herds of Wyoming. After his movement, he never moved more than 1.3 km/day.

At the time of capture, the Granby ram was in good body condition and no mycoplasma, parainfluenza, or hemolytic pasteurella strains were detected in the biological samples (CPW, unpublished data). At the time of removal, he was still in good body condition (WGF, unpublished data). The WGF were unable to determine what bacterial strains he was carrying at the time of death due to contamination of the nasal and lung passageways with ingesta resulting from gunshot wounds of the thoracic cavity (WGF, unpublished data).

DISCUSSION

Prior to being collared, the Granby ram was observed several times over a 7-month period alone and in an area not used by other bighorns. This area is between 2 herds: 1) the Georgetown herd 20 km to the south; and 2) the St. Vrain herd 19 km to the north. After being collared, he remained in the area alone for another 3 months before he initiated his movement to Wyoming. The timing of this movement is consistent with that of rutting behavior in nearby herds. It is common for rams of this age class to travel seeking mating opportunities during the rut. However, we do not know of any previously documented movements of this magnitude.

O'Brien (2014) concluded that the frequency of bighorn movements outside of their core herd home ranges and the distances traveled were underestimated in his study. This was due to non-detection of animals that moved away from frequently used areas and the intervals between detections, during which the location of the animals is unknown. This was true for studies involving collared animals monitored by aerial and ground-based surveys. In the case of the Granby ram, it was very unlikely that we would have known about his movements had he not been wearing a radio collar with satellite upload capabilities.

In a study of the Georgetown herd, the most probable herd of origin for the Granby ram, from 2006-2011, 9 to 18 rams were collared each year (Huwer 2015). The very high frequency (VHF) collars were located via ground and aerial telemetry an average of 1.5 times per month (range = 1.0-2.4) and the 3 GPS collars recorded 6 locations per day. None of these rams were found to have moved outside of their home range. In the same study, 17 to 35 ewes were collared each year. The VHF collars were located via ground and aerial telemetry an average of 2.3 times per month (range = 0.9-3.7) and the 11 GPS collars recorded 6 to 8 locations per day. Four different ewes were found to have moved outside their home range on 1 occasion for distances of 14 km, 10 km, 10 km, and 1.6 km. Each of these returned to their home range within a few months (CPW, unpublished data).

During his movement, the Granby ram frequently used areas that were more forested, less steeply sloped, and further from escape terrain than called for by the USFS Summer Source Habitat Model. He also covered large distances through areas considered unsuitable habitat for bighorn sheep. This is consistent with O'Brien (2014) who reported that foraying bighorn were twice as likely to be seen outside of habitat and more than 15 times more likely to be found in non-habitat than animals within the core herd home range. He concluded that, "foraying animals were clearly more willing to spend time in nonpreferred habitat types, allowing them to traverse it on their way to unconnected habitat patches."

MANAGEMENT IMPLICATIONS

Disease outbreaks are considered the primary factor limiting bighorn populations. Management of disease in bighorn sheep centers on reducing the probability of contact between domestic and bighorn sheep. Bighorn sheep that make long-distance movements risk contacting domestic sheep and transmitting diseases from domestic sheep to other bighorn sheep with which they come into contact. Therefore, much work has gone into establishing expectations of barriers to movement of bighorn sheep and domestic sheep to predict the probability of contact between bighorn sheep and domestic sheep.

The movement of the Granby ram represents a rare event with a high risk of creating contact between domestic sheep and bighorn sheep. Management options to prevent the spread of disease through these types of movements is limited as is the ability to predict them. To better predict and manage the risks of bighorn sheep movements outside of their home ranges, more information is needed on their frequency and extent. This information could be gathered through the increased use of radio collars with satellite upload capability in studies involving collared animals, as well as increased efforts to document the movements of solitary bighorn sheep and those encountered outside of known bighorn sheep home ranges.

ACKNOWLEDGMENTS

We thank L. Wolfe, D. Walsh, K. Oldham, and J. Yost for help with capture and tracking. We also thank J. George for her support and advice. The manuscript was improved by comments from an anonymous reviewer and the editor. Colorado Auction and Raffle Fund provided funding for this project.

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Identification of an Abbreviated Migration Behavior in Bighorn Sheep after Migration Loss

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ABSTRACT Many ungulate populations have lost or are at risk of losing their traditional migrations. The Teton bighorn sheep (*Ovis canadensis*) population in northwest Wyoming is one such example. It lost access to its historical winter range over 60 years ago and now resides year-round on its high elevation summer range, wintering exclusively on windswept ridges above 3,000 m. We sought to investigate how this population has persisted after migration loss by evaluating seasonal movements. We outfitted 28 ewes with Global Positioning System collars from 2008 to 2010. We analyzed seasonal movements in conjunction with vegetation phenology using the Normalized Difference Vegetation Index. We found that bighorn sheep undergo distinct elevation movements within their one seasonal range. They begin spring in the high peaks and then descend approximately 500 m to 10 km to seek out vegetation emergence at mid-elevations. This movement allows them to access forage approximately 30 days before it becomes available on their high-elevation summer and winter ranges. We termed this behavior "abbreviated migration" because it partially connects individuals with their historical migration, while remaining confined to one seasonal range. This abbreviated migration behavior may be critical for bighorn sheep persistence after migration loss.

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KEY WORDS abbreviated migration, bighorn sheep, habitat, NDVI, migration loss, *Ovis canadensis,* Wyoming.

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Evaluating Habitat Use of an Alaskan Dall's Sheep Population via Camera Traps

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ABSTRACT The study of Dall's sheep (*Ovis dalli*) is often constrained by the variable terrain, extreme climate, and, at times, cryptic nature of the species. Infrequently, camera traps have been employed to estimate population size and presence of mountain ungulates, but little or no use has been directed toward Dall's sheep. Camera traps are an increasingly utilized tool for the management and study of numerous taxa of wildlife. This study utilizes camera traps to determine the occupancy of Dall's sheep within the U.S. Army's Donnelly and Black Rapids Training Areas in Fort Wainwright, Alaska. A system of camera traps, installed via a spatially balanced design, is assessing the seasonality and habitat use of sheep in these military training areas from August 2013 to August 2016. Each camera is programmed to capture a time-lapse image every 30 minutes or when triggered by a movement or infrared signal. Preliminary results have shown that 68% of the cameras operated throughout the year, 26% were disrupted or destroyed by wildlife, and 6% stopped operating. Approximately 20,000 images of sheep and other mammal species were captured by time-lapse and movement triggers. These data will allow for occupancy modeling of sheep habitat use and, potentially, to the habitat use of the overall mammalian community. Final results will determine recommendations to the U.S. Army as to the most appropriate time to conduct military exercises in the training areas as they pertain to sheep presence.

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KEY WORDS Alaska, camera trap, Dall's sheep, habitat use, military lands, occupancy modeling, *Ovis dalli.*

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Multi-elements, Radionuclides and Persistent Organics in Tissues of Mountain Goats in Northwest Territories

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ABSTRACT There has been limited study on mountain goats (*Oreamnos americanus*) inhabiting the Mackenzie Mountains of the Northwest Territories (NT), Canada. As part of a larger study on sympatric ungulates of the area, we collected kidney, liver, and muscle samples from adult male mountain goats to document concentrations of heavy metals and other elements, persistent organic pollutants (POPs), and radionuclides, as well as stable isotope signatures. Most elemental concentrations were higher in kidney; only aluminum, magnesium, potassium and antimony were higher in muscle tissue. Cadmium had the highest kidney:muscle (251) ratio; mean concentration in kidney was 28.3 mg/kg (dry weight). Mean total mercury in kidney was 0.3 mg/kg (dry weight). ^{137}Cs and ^{40}K levels were relatively consistent, with means of 6.46 and 108 Bq/kg, respectively. ^{134}Cs presence in only the 2011 samples is a clear marker of deposition from the 2011 Fukushima nuclear accident in Japan. POPs were present at sub-ng/g (wet weight, ww) concentrations in liver similar to measurements in other ungulates in the NT. Chlorobenzenes (0.49 ± 0.12 ng/g ww), toxaphene (0.40 ± 0.32 ng/g ww), and DDT-related compounds (0.29 ± 0.21 ng/g ww) were the major POPs detected. Mean stable isotope signatures for δ^{13}C (-24.8‰) and δ^{15}N (1.53‰) reflect the generalist diet composition. Based upon the low reported concentrations of trace elements and radionuclides, no concerns about consumption of mountain goats were identified in an assessment of the data by health authorities.

Biennial Symposium of the Northern Wild Sheep and Goat Council 19:98-107; 2014

KEY WORDS cadmium, kidney, *Oreamnos americanus,* Mackenzie Mountains, mercury, muscle, Northwest Territories, persistent organic pollutants, radiocesium, radionuclide, stable isotope.

In the Northwest Territories (NT), Canada, mountain goats (*Oreamnos americanus*) are distributed in the southern portion of the 130,000-km^2 Mackenzie Mountains, which are located along the Yukon-NT border generally south of 63°00’ N latitude (Fig. 1). Studies of mountain goats in the NT have been extremely limited (Veitch et al. 2002). More recently, aerial surveys have been conducted in different parts of the range to estimate population size; the current best estimate of the population is 1,200-1,500 animals (N. Larter, Government of the Northwest Territories, unpublished report). Because of the inaccessibility of the area,

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harvest is limited and is almost exclusively by non-resident trophy hunters. From 1967-2013, non-residents harvested 313 goats; there is no annual quota (N. Larter, unpublished data).

The concentration of Cd in organs of moose inhabiting the study area is high (Gamberg et al. 2005, Larter 2009) and has previously resulted in consumption advisories by Health Canada (Larter and Kandola 2010). These consumption advisories are based on maintaining the concentrations of Cd in the human diet below levels at which histological effects may develop in the human kidney. The World Health Organization has recommended a provisional tolerable monthly intake of 25 µg Cd/kg body weight or 1,500 µg/month for a 60 kg person (Joint FAO/WHO Expert Committee on Food Additives 2010), while the European Food Safety Authority has recommended a weekly intake of 2.5 µg Cd/kg body weight (European Food Safety Authority 2012). These recommendations are based on an assessment of the total intake of Cd from all sources and improved understanding of the possible adverse effects in the human kidney. Histological samples of moose (*Alces alces*) kidneys from the Mackenzie Mountains showed cellular changes that could be attributed to Cd exposure (N. Larter, unpublished data). To our knowledge, mountain goats have not previously been analyzed for persistent organic pollutants (POPs). Concentrations of POPs in other northern ungulates, such as caribou (*Rangifer tarandus*) and moose, are generally very low (Muir et al. 2013). Kelly and Gobas (2001) reported total polychlorinated biphenyls (ΣPCBs) of about 0.4 ng/g (wet weight (ww)) in female caribou liver from the Bathurst Inlet area of Nunavut. ΣPCBs averaged 0.86 ± 0.78 ng/g (ww) in liver of moose in the southwestern NT (N. Larter et al. unpublished data). Mountain goat meat from harvested animals is provided to residents of local communities for consumption; however, the concentrations of contaminants in mountain goat in the study area are unknown. The objectives of this study were to 1) document the levels of various elements, POPs, and radionuclides in tissues of mountain goat; 2) compare the levels to those of sympatric wildlife; 3) assess the reported levels from a human consumption perspective; and 4) document stable isotope levels to provide some baseline information on the diet of mountain goats relative to other large mammals in the area.

STUDY AREA

The Mackenzie Mountains cover both the western NT and eastern Yukon Territory (YT) of northwestern Canada. The NT portion of the range covers approximately 130,000 km^2 between the Mackenzie River and the border with the YT (Fig. 1). The Mackenzies are a system of irregular mountain masses resulting primarily from deformation and uplift (Simmons 1968). Because they are comprised primarily of limestone, dolomite,

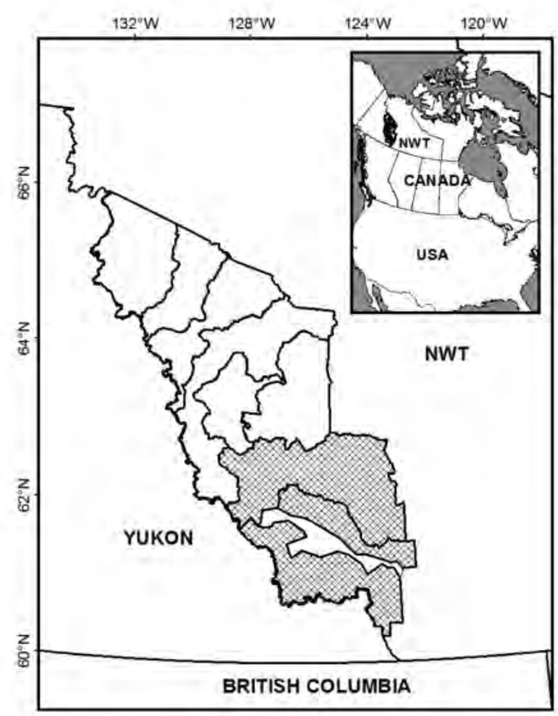

Figure 1. Location of the study area in the Mackenzie Mountains, Northwest Territories, Canada. Samples were collected in the hatched area.

and shale, they have been heavily eroded, producing unstable rubble slopes over large areas (Simmons 1982) and many spectacular canyons, ravines, and rock outcrops. Along the YT-NT border, some peaks reach 2,700 m and a few active glaciers occur (the Backbone Range), whereas along the eastern front range (the Canyon Range), the topography is generally more gentle (1,000-2,000 m). The average frost-free season lasts only 70-75 days and total annual precipitation is between 25 and 30 cm (Simmons 1968). Mountain goats occur almost exclusively below 63°00'N (Veitch et al. 2002), being most numerous in high relief terrain between 61°00' and 62°00'N. The other major large mammal species that occur across most of the mountain range include: Dall's sheep (*Ovis dalli*), northern mountain caribou, moose, grizzly bear (*Ursus arctos*), wolf (*Canis lupus*), and wolverine (*Gulo gulo*).

METHODS

We requested licensed outfitters to voluntarily submit a sample of muscle and liver tissue and a whole kidney from mountain goats harvested by their clients during the August and September hunting seasons in 2011, 2012, and 2013. All goats were harvested during the 3 August to 17 September time period annually. We provided outfitters with sampling kits and sampling instructions for the different tissues being collected. Data on sex, age (based upon counting horn annuli), and general location were also collected. Samples were kept cool or frozen at the main guide camps before being transported to the Fort Simpson regional office where we prepared and stored samples frozen prior to shipping to the various laboratories for analysis.

Following Larter (2009), a bilateral sample of kidney and a sample of muscle tissue (50 g ww) were analyzed for 33 elements by Inductively Coupled Plasma-Sector Field spectrometry (ICP-SFMS Instrumental) at the National Laboratory for Environmental Testing (NLET) at National Water Research Institute in Burlington, Ontario (National Laboratory for Environmental Testing 2003). Total mercury (NLET Method 02-2802) was analyzed by cold vapor atomic absorption spectrometry. The detection limit for most elements is 0.0001 mg/kg ww, but varied for other specific elements (Table 1). We reported data on a ww basis and converted it to a dry weight basis using tissue-specific moisture values. Accuracy and recovery rates were monitored using dogfish liver (DOLT-4), dogfish muscle (DORM-2), and lobster hepatopancreas (TORT-2) standards from the National Research Council of Canada. Using direct gamma spectrometry, Becquerel Laboratories (Mississauga, ON) analyzed gamma-emitting natural and anthropogenic radionuclides in muscle samples ($\geq$ 100 g ww). The radioactivity in samples was counted using a 50% relative efficiency hyper-pure germanium detector, with samples as fresh weight, for count times of 7-24 hours, and occasionally longer, to quantify the low levels of ^{134}Cs. We report concentrations backdated to the day of collection using standard decay constants for the individual nuclides. The methods quantified ^{134}Cs and ^{137}Cs, which were known to be released from the 2011 Fukushima nuclear accident in Japan, and ^{40}K, a radioactive isotope of potassium that is present in all biological material.

Liver samples were analyzed for PCBs, organochlorine pesticides (OCPs), and other chlorinated organics (OCOs), following US Environmental Protection Agency Method 1699 (US Environmental Protection Agency 2007) by ALS Global Laboratories (Burlington, ON). In brief, samples were thawed, thoroughly homogenized in a small stainless steel blender. Subsamples (3.5 g ww) were Soxhlet extracted with dichloromethane and lipid was removed by gel permeation chromatography. Percent lipid was determined gravimetrically on a subsample of the extract. Extracts were cleaned up on a silica gel column. Final extracts were analyzed

Table 1. Mean concentrations (mg/kg wet weight) of elements (with standard deviation and range) for muscle (n = 9) and kidney (n = 13) samples collected from mountain goats in the Mackenzie Mountains, Northwest Territories, Canada. Kidney:muscle concentration ratios calculated on a dry weight basis. Detection limits (DL) indicated for each element.

		Muscle			Kidney			
Element	**DL**	**Mean**	**SD**	**Range**	**Mean**	**SD**	**Range**	**Ratio**
Total Mercury	0.002	0.0048	0.0039	< DL-0.011	0.03	0.04	0.006-0.16	7.18
Antimony	0.001	0.03	0.05	0.003-0.165	0.01	0.01	< DL-0.05	0.26
Aluminum	0.02	7.19	13.5	0.11-41.4	0.28	0.28	0.05-1.15	0.04
Arsenic	0.002	0.03	0.029	0.005-0.08	0.022	0.02	< DL-0.07	0.82
Barium	0.001	0.69	1.14	0.02-3.44	0.39	0.28	0.14-1.14	0.56
Beryllium	0.0001	0.00039	0.001	< DL-0.002	< DL		< DL-0.0004	0.33
Bismuth	0.0001	0.00021	0.002	< DL-0.0006	< DL		< DL-0.0003	0.52
Cadmium	0.001	0.02	0.014	0.004-0.05	5.78	6.32	1.07-22	252
Calcium	0.001	118	125	22.8-359	76.8	14.5	59.5-116	0.65
Cobalt	0.001	0.02	0.03	0.002-0.10	0.04	0.02	0.02-0.08	2.44
Chromium	0.002	0.23	0.35	0.015-1.15	0.06	0.07	0.005-0.21	0.28
Cesium	0.001	0.23	0.16	0.08-0.57	0.20	0.18	0.02-0.59	0.87
Copper	0.001	1.54	0.66	0.67-3.03	2.76	0.39	2.27-3.4	1.79
Iron	0.001	41.29	29.2	17-116	44.0	18.8	22.9-81.3	1.07
Gallium	0.0001	0.0028	0.01	< DL-0.016	0.0002	0.0002	< DL-0.0007	0.08
Lanthanum	0.0002	0.02	0.02	0.0003-0.07	0.0013	0.0013	0.0003-0.0048	0.09
Lithium	0.02	0.03	0.04	0.01-0.12	0.08	0.06	0.01-0.19	3.01
Magnesium	0.0001	221	19.4	199-245	130	10.6	117-149	0.59
Manganese	0.0001	0.46	0.72	0.11-2.35	0.84	0.21	0.53-1.3	1.82
Molybdenum	0.0001	0.01	0.01	0.001-0.024	0.32	0.14	0.15-0.64	40.4
Nickel	0.01	0.06	0.08	0.009-0.27	0.05	0.03	0.01-0.10	0.85
Lead	0.001	0.11	0.27	0.003-0.84	0.03	0.02	0.005-0.08	0.25
Palladium	0.01	< DL		< DL	< DL		< DL	1.46
Platinum	0.001	< DL		< DL	< DL		< DL	1.46
Potassium	0.001	3456	461	2770-4310	2237	181	2060-2580	0.65
Rubidium	0.001	8.48	2.97	3.64-12.9	6.91	2.54	2.43-10.2	0.81
Selenium	0.001	0.30	0.23	0.02-0.64	1.16	0.58	0.43-2.24	3.87
Silver	0.0001	< DL		< DL-0.0003	0.0014	0.0014	0.0003-0.005	14.7
Tin	0.02	0.14	0.13	0.01-0.33	0.13	0.10	< DL-0.35	0.96
Strontium	0.001	0.16	0.24	0.018-0.751	0.09	0.03	0.03-0.13	0.59
Thallium	0.0001	0.0013	0.00	< DL-0.01	0.02	0.0242	0.0025-0.09	12.5
Uranium	0.0001	0.0012	0.00	< DL-0.01	0.0016	0.0019	0.0002-0.0064	1.29
Vanadium	0.001	0.04	0.08	0.001-0.25	0.0017	0.0009	< DL-0.003	0.05
Zinc	0.0001	39.8	13.5	27.8-72.5	24.8	6.02	19.3-39.9	0.62

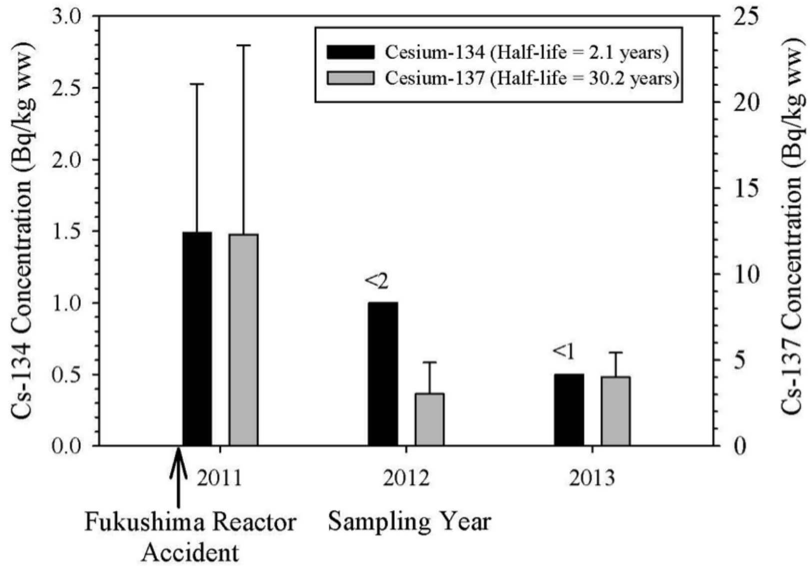

Figure 2. Mean (with error bars indicating SD) concentrations of ^{134}Cs and ^{137}Cs (Bq/kg wet weight) in muscle tissue of mountain goats collected in the Mackenzie Mountains, Northwest Territories, Canada, 2011-2013. "<" indicates below detection in all samples collected that year. The Fukushima nuclear accident occurred 6-7 months prior to sampling in 2011.

by GC-high resolution mass spectrometry. All 209 PCB congeners were determined (representing 162 gas chromatographic peaks due to coelutions). The dioxin-like PCBs (CB 81, 77, 126, 169) were included in the analysis. A total of 31 OCP related compounds (isomers and metabolites of DDT, chlordane, toxaphene, hexachlorocyclohexanes, and endosulfan, as well as mirex, dieldrin, aldrin, endrin, methoxychlor, dacthal, pentachloronitrobenzene, chlorpyrifos and dicofol) were determined. Nine OCOs (hexachlorobutadiene, tetra-, penta- and hexachlorobenzenes, pentachloroanisole, tetrachloroveratrole) were also determined.

Muscle samples (1.0-1.5 mg dry weight) were analyzed for ^{15}N and ^{13}C using a Micromass Optima (Waters, Milford, MA, USA) continuous-flow isotope-ratio mass spectrometer directly coupled to a Carlo Erba NA1500 elemental analyzer (Elemental Microanalysis, Okehampton, UK) at the Environmental Isotope Laboratory (Waterloo, ON). Samples were standardized against atmospheric nitrogen or Canyon Diablo PeeDee Belemnite (National Institute of Standards and Technology, Gaithersburg, MD, USA) using the equation ^{15}N or ^{13}C (‰) = $[(R_{sample}R_{reference})/(R_{reference})] \cdot 1{,}000$, where R^{15}N:^{14}N or ^{13}C:^{12}C. Replicate samples had a precision of 0.05‰ (Houde et al. 2008). Ratios of stable isotopes of carbon and nitrogen can be used to assess herbivore diets (Ben-David and Flaherty 2012).

We analyzed data using Systat 11.00.01. We made statistical comparisons on a dry weight basis, converted from ww basis using moisture content or using log transformed dry weight to maintain normality. We reported tissue elemental concentrations as arithmetic means. Sample sets with >50% samples below detection are summarized as < detection limit.

RESULTS

All samples came from males. We conducted multi-elemental analyses on kidneys (n = 13)

Table 2. Mean concentrations (ng/g ± SD) of persistent organic pollutants in liver samples (n = 3) collected from mountain goats in the Mackenzie Mountains, Northwest Territories, Canada. Concentrations on a wet weight (ww) and lipid weight (lw) basis. Mean % lipid = 0.72 ± 0.19.

Analyte	Abbreviation	wet weight	lipid weight
Hexachlorobutadiene	HCBD	0.05 ± 0.02	6.8 ± 1.5
Tetrachlorobenzenes[a]	ΣTeCBz	0.06 ± 0.03	8.8 ± 1.8
Pentachlorobenzene	PeCBz	0.05 ± 0.03	6.8 ± 2.4
Hexachlorobenzene	HxCBz	0.31 ± 0.07	44 ± 7.3
Polychlorinated biphenyls[b]	ΣPCBs	0.03 ± 0.02	4.9 ± 2.3
Dioxin-like PCBs[c]	DL-PCBs	< 0.010	< 1.09
Dichlorodiphenyltrichloroethane and metabolites[d]	ΣDDT	0.29 ± 0.21	41 ± 31
Hexachlorocyclohexanes[e]	ΣHCH	< 0.05	< 8.97
Chlordane related compounds[f]	ΣCHL	0.09 ± 0.08	13 ± 13
Endosulfans[g]	ΣEndo	< 0.12	< 29
Dieldrin, aldrin and endrin	Σdrins	< 0.10	< 15
Dicofol	dicofol	< 10	< 3500
Octachlorostyrene	OCS	0.03 ± 0.01	5.0 ± 2.5
Mirex	mirex	< 0.13	23 ± 3.5
Pentachloroanisole	PeCA	0.03 ± 0.04	4.1 ± 3.7
Pentachloronitrobenzene	PCNBz	0.02 ± 0.02	3.1 ± 2.7
Dacthal	Dacthal	< 0.019	< 3.3
Methoxychlor	Methoxychlor	< 0.16	< 55
Chlorpyrifos	Chlorpyrifos	< 0.11	< 25.8
Toxaphene[h]	Toxaphene	0.40 ± 0.32	54 ± 47

[a]Sum of 1234- and 1245-tetrachlorobenzene
[b]Sum of 209 PCB congeners represented by 162 gas chromatographic peaks
[c]Sum of PCBs 77, 81, 126 and 169
[d]Sum of 4,4'-DDE,- DDD, -DDT and 2,4-DDE, -DDD, DDT.
[e]Sum of alpha, beta and gamma isomers
[f]Sum of heptachlor, heptachlor epoxide B, oxychlordane, trans-chlordane, cis-chlordane, trans-nonachlor, cis-nonachlor
[g]Sum of alpha and beta-endosulfan and endosulfan sulphate
[h]Sum of toxaphene congeners (Parlar 26, 50 and 62)

from animals with the mean age of 6.5 years (range 3-11 years) and muscle tissue (n = 9) from animals with mean age 6.0 years (range 3-9 years). We conducted radionuclide analyses on muscle tissue (n = 12) from animals with mean age 6.1 years (range 2-9 years) and stable isotope analyses on muscle tissue (n = 9) from animals with mean age 6.0 years (range 3-9 years). We conducted the analyses for POPs on liver tissue (n = 3) with mean age 7.0 years (range 5-9 years).

Most element concentrations were higher in kidney than in muscle; only Al, Mg, K, and Sb had higher concentrations in muscle tissue. Cd had the highest kidney:muscle (251) ratio; the kidney:muscle ratio for total Hg was 7.2. Concentrations of Cd and Hg in goat kidneys ranged from 1.07-22.00 mg/kg ww (mean 28.3 mg/kg dry weight) and 0.006-0.160 mg/kg ww (mean 0.3 mg/kg dry weight), respectively (Table 1).

Mean ^{134}Cs concentrations decreased over time, being below detection limits in 2012 and 2013 (Fig. 2). In 2011, shortly after the Fukushima reactor accident, mean ^{134}Cs levels were 1.49 Bq/kg ww. ^{137}Cs remained relatively consistent in most samples with a mean value of 6.46 Bq/kg ww, though the 2 highest values were observed in the 2011 collection. Concentrations of ^{40}K were relatively constant (mean 108 Bq/kg ww).

Very low or non-detectable concentrations of the PCBs, OCPs, and OCOs were found in mountain goat liver (Table 2). The major OCP was toxaphene, consisting of the octachlorobornane (P26) and nonachlorobornane (P50), which averaged 0.40 ± 0.32 ng/g ww. Hexachlorobenzene was prominent in all 3 livers sampled (0.31 ± 0.02 ng/g ww). Combined with the tetra- and pentachlorobenzenes, the total chlorobenzenes (ΣCBz) were present at the highest concentration of all the POPs that were measured (ΣCBz = 0.49 ± 0.12 ww). DDT-related compounds, mainly 4,4’ – and 2,4’ – DDE, were found in all samples (0.29 ± 0.21 ng/g ww). All other POPs were present at < 0.01 ng/g ww. Consistently detected were chlordane-related compounds (ΣCHL = 0.09 ± 0.08 ng/g ww; consisting of oxychlordane and heptachlor epoxide), as well as pentachloroanisole (PeCA), hexachlorobutadiene (HCBD), and octachlorostyrene (Table 2). PCBs averaged 0.03 ± 0.02 ng/g ww, with trichlorobiphenyl congeners CB-18/30 and CB-20/28 predominating. Dioxin-like congeners were not detected (< 0.01 ng/g ww).

The mean stable isotope signatures for (n = 9) muscle samples was -24.8 ‰ for δ^{13}C and 1.53 ‰ for δ^{15}N.

DISCUSSION

Concentrations of elements in mountain goat were generally higher in kidney than muscle tissue and most elements did not show a positive correlation with age. Total Hg levels were more than 7 times higher in kidney than muscle but were relatively low and similar to those reported for co-habiting Dall’s sheep (N. Larter, unpublished data). Cd had the highest kidney:muscle ratio at 251, showing the ability of the metal to accumulate in the kidney. The Cd concentrations we report for mountain goat kidney ranged from 1.07-22.00 mg/kg ww and were substantially lower than the range of 8.9-624.0 mg/kg ww (n = 18) reported for co-habiting moose, which resulted in a human health advisory (Larter and Kandola 2010). Hg concentrations reported for moose kidneys ranged from 0.018-0.076 mg/kg ww and were similar to those we report for mountain goat (0.006-0.160 mg/kg ww). The low concentration of Cd we report in mountain goat kidneys were below levels reported to be associated with observed changes in other animal species (Aughey et al. 1984, Outridge et al. 1994, Beiglböck et al. 2002). An assessment of Cd and other metal data from a human health consumption perspective did not identify any concerns given the low levels.

^{134}Cs and ^{137}Cs were released during the Fukushima nuclear accident and deposited from the atmosphere roughly 1-2 weeks later in North America (Wetherbee et al. 2012). We report detectable concentrations of ^{134}Cs in the muscle tissue of mountain goats samples in the 2011 hunting season but not in subsequent years. ^{134}Cs has a rapid decay (half-life 2.1 years) and had fallen below detectable levels in mountain goats by 2012. ^{134}Cs was also detected in muscle from Dall’s sheep sampled in the 2011 hunting season but not in caribou or moose. Differences in dietary items could explain the differences in ^{134}Cs detection between animals as has been observed for Cd (Vandecasteele et al. 2002). Our stable isotope results were consistent with mountain goat and Dall’s sheep having a more generalist and diverse diet; they likely ingested specific food items that accumulated the nuclide. Although ^{137}Cs remained relatively consistent in muscle tissue over the 3-year sampling period, the 2 highest values were observed in the 2011 collection. The mean concentration of the naturally occurring ^{40}K (108 Bq/kg ww) we report was similar to the ~100 Bq/kg reported in other large mammals (Macdonald et al. 1996) and similar to that found in co-habiting Dall's sheep, northern mountain caribou, and moose (N. Larter, unpublished data). In general, the concentrations of concern for nuclides are based on levels that result in an incremental dose of 1 mSv/y above background for humans (Health Canada 2014) or 40 µGy/h for mammals (Anderson et al. 2009). The radionuclide concentrations we report were low and did not raise concerns for mountain goat health or from a consumption perspective.

Stable isotope signatures for $\delta^{13}C$ and $\delta^{15}N$ from muscle tissue reflect diet composition (Ben-David et al. 2001). Although food species vary seasonally, all goats were harvested in August and September of each year, reducing seasonality as a potential source of variation in the data. Mean $\delta^{13}C$ value (-24.8 ‰) for mountain goats were intermediate to higher values observed in sympatric northern mountain caribou and lower values observed in moose. Caribou and moose have more restrictive diets with high lichen (Gustine et al. 2012) and willow (*Salix* spp., Risenhoover 1989) dietary components, respectively. This isotopic pattern has been observed in ungulates in Alaska (Ben-David et al. 2001) and eastern Canada (Drucker et al. 2010). The stable isotope signatures we report were consistent with the interpretation that mountain goats are generalist feeders (Rideout 1978).

Concentrations of POPs in mountain goat liver were comparable to those in moose and caribou in the NT. Lipid weight concentrations (Table 2) are provided because most previous studies on terrestrial animals in the NT and Nunavut have reported POPs concentrations on this basis. The POPs consisted mainly of semi-volatile compounds such as HCBz, HCBD, PeCA, DDT, chlordane and trichlorobiphenyls – all of which are known to undergo global atmospheric transport and deposition. Similar to mountain goats, ΣCBz was the most prominent group between the OCPs and OCOs in moose liver from the southwestern NT with average concentrations of 0.16 ± 0.03 ng/g ww (N. Larter et al. unpublished data); ΣCBz was also predominant in caribou (Elkin and Bethke 1995, Kelly and Gobas 2001). However, mountain goats differed from moose and caribou in the proportions of other POPs. For example, HCH isomers were non-detectable (< 0.05 ng/g ww) in mountain goat but averaged 0.12 ± 0.02 ng/g in moose liver. A factor influencing the comparison among species that have been analyzed infrequently, as is the case for ungulates, is the year of collection. Samples reported by Kelly and Gobas (2001) and Elkin and Bethke (1995) were collected in the early 1990s and atmospheric concentrations of legacy POPs have been declining. Air measurements at Alert (Nunavut) have shown ΣHCH declined with a half-life of 3.9 years over the period 2002-2009 (Hung et al. 2013), thus HCH concentrations in diets of ungulates were likely higher in 1990s than in recent years. Seasonal variation in POPs has been documented in caribou (Kelly and Gobas 2001) and could affect comparisons between and within species. While the PCB, OCPs, and OCOs were present at sub-ng/g (ww) concentrations, other POPs, such as perfluorooctane sulfonate and related substances, as well as decabromo diphenyl ether, have been detected at somewhat higher concentrations in moose (N. Larter et al. unpublished data) and caribou liver (Müeller et al. 2011, Morris et al. unpublished data) and should be considered for future baseline monitoring in mountain goats.

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Quantifying Partial Migration in an Alpine Ungulate

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ABSTRACT As migratory species across a wide array of taxa face global declines, ecologists have shown a renewed interest in understanding the significance of movement behavior. Even so, the ecological significance of migration remains poorly understood. This lacuna is partly a function of past difficulty in rigorously defining migratory behavior. Consequently, attempts to account for migration have largely relied on untested assumptions about animal movement. For example, numerous studies assume that ungulate migratory behavior is fixed even though this assumption contradicts long-standing knowledge of broad behavioral variation in ungulate life history. We used non-linear modeling methods to quantify variation in migratory behavior across: 1) space, 2) time, and 3) individuals from 8 populations of Sierra Nevada bighorn sheep (*Ovis canadensis sierrae*), a partially migratory and federally endangered alpine ungulate. We found that although migratory distance varied by population, population and year were unable to explain variation in the timing and duration of migratory movements. Furthermore, we present strong evidence that individuals frequently change strategy among years. These results directly contradict the prevailing assumption in ungulate ecology that migratory behavior is fixed. To our knowledge this is the first study to quantify variation in migratory behavior in a caprid.

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KEY WORDS altitudinal migration, behavioral plasticity, bighorn sheep, California, *Ovis canadensis sierrae*, partial migration, Sierra Nevada.

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Comparison of Post-mortem Diagnostic Methods for Cases of Bighorn Sheep Lamb Pneumonia

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ABSTRACT During the spring of 2013, we examined post-mortem tissues from bighorn sheep (*Ovis canadensis*) lambs with pneumonia. Lambs originated from 2 herds in Colorado with a history of poor lamb recruitment. Four diagnostic methods were used to analyze post-mortem tissues: 1) bacterial culture; 2) polymerase chain reaction (PCR) assay using culture plate-wash DNA; 3) PCR assay using lung tissue DNA; and 4) histopathology. We detected both *Mycoplasma ovipneumoniae* and leukotoxigenic *Pasteurellaceae* in each lamb by at least one diagnostic method. PCR assays were the most sensitive method of detection with no significant difference between results from PCR assays using culture plate-washes and assays using lung tissue. Autolysis of tissues did not inhibit detection of organisms by PCR. Overall, our diagnostics provided a clear picture of bacterial pneumonia caused by a combination of *Mycoplasma* and *Pasteurellaceae* agents in both herds. However, we observed inconsistent results when diagnostics were applied to a single sample or single individual, highlighting the need for diagnostic investigations at the herd level whenever possible.

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KEY WORDS bighorn sheep, culture, histopathology, leukotoxin, *Mycoplasma ovipneumoniae*, *Ovis canadensis*, *Pasteurellaceae*, polymerase chain reaction.

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Identifying Pathways to Decline in the Junction-Churn Creek California Bighorn Sheep Population, British Columbia

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ABSTRACT California bighorn sheep (*Ovis canadensis californiana*) populations found along the Fraser River in south-central British Columbia provided source animals for transplants to 6 states between 1954 and 1990. These sheep populations suffered significant declines during the late 1990s and some have failed to recover. As a result, a recovery and management plan is being developed for the Churn Creek and Junction herds, where populations remain more than 80% below 1995 levels. Although the Junction population appears stable, migratory bands using the Churn Creek drainage appear close to extirpation. Preliminary work has involved developing a working hypothesis to identify potential pathways to decline and feasible management actions to address possible causes. Analyses of existing data suggest that predation is the most likely proximate cause preventing population recovery. This could be due to local habitat changes (e.g., forest ingrowth) and regional changes in the broader predator-prey system.

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KEY WORDS bighorn sheep, British Columbia, *Ovis canadensis californiana,* population declines, predation.

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No Evidence for Reduced Lungworm Loads or Improved Lamb Recruitment Following Experimental Anthelmintic Treatments in a Free-ranging Bighorn Sheep Herd

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ABSTRACT Beginning in the 1970s, free-ranging Rocky Mountain bighorn sheep (*Ovis canadensis*) in Colorado were treated with anthelmintics to reduce lungworm infections in pregnant ewes. The treatments were thought to reduce transmission of larval lungworm to fetuses in late pregnancy, which would result in higher early lamb survival. However, research has suggested that treatments did not improve lamb recruitment. Given the uncertainty of long-term lungworm treatments, we examined the efficacy of anthelmintics on 1) increasing lamb recruitment and 2) reducing larval lungworm loads in ewes. To investigate these questions, we captured, radio-collared and divided 24 ewes into a control and 2 treatment groups. We monitored these sheep over a 4-year period, repeating treatments once per winter. We quantified ewe larval lungworm loads from fecal samples and monitored lamb recruitment through lamb-ewe associations. We saw no difference in early lamb survival between the treatment and control groups. We also found that larval lungworm loads were equivalent or higher in treated sheep compared to control sheep after one year. Our results, combined with previous research, suggest that long-term lungworm treatments do not improve lamb recruitment or overall herd health in bighorn sheep.

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KEY WORDS anthelmintics, bighorn sheep, Colorado, lamb recruitment, lungworm, *Ovis canadensis*, *Protostrongylus.*

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Determining the Status and Trend for Desert Bighorn Sheep in the San Rafael Swell

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ABSTRACT The North San Rafael desert bighorn sheep population (*Ovis canadensis nelsoni)* has been steadily declining for several years. Average population growth has been λ = 0.89 since 2001. In January 2012, 30 ewes and 8 rams were tested for disease, fitted with Global Positioning System or Very High Frequency collars, and monitored for 2 years. Objectives were to 1) locate collared females weekly to document survival; 2) locate and necropsy dead bighorn sheep to determine causes of death and limiting factors; and 3) quantify production and survival of neonates. Initial observations show that lambing dates ranged from 31 April to 9 June, with a mean date of 23 May. The lamb to ewe ratio was 45:100 in November 2012 and 35:100 in November 2013. Twenty mortalities were documented: 10 associated with cougar predation, 2 bluetongue, 1 hunter harvest, 2 linked to reproductive complications (i.e., ruptured uterus, dystocia), 1 capture related mortality, and 4 unknown causes not related to predation. While bronchopneumonia was not identified as a primary cause of death in any mortality, it subsequently developed from secondary infections in 4 of the bighorns before they died. Results of disease testing show that *Mannheimia hemolytica* and *Mycoplasma ovipneumonia* are present in the population. The current population is about 130 animals and is holding relatively constant.

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KEY WORDS desert bighorn sheep, disease, limiting factors, *Ovis canadensis nelsoni*, San Rafael Swell, Utah.

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Managing the Risk of Disease Transmission from Domestic Sheep to Wild Sheep through the British Columbia Sheep Separation Program

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ABSTRACT The British Columbia Sheep Separation Program is an active working group that has members from the domestic sheep industry, wild sheep conservation groups, First Nations, and the provincial government. Our program focuses on education and outreach, coordinating the delivery of novel farm-specific mitigation projects and affecting policy change to limit or exclude domestic sheep farms from high-risk areas to protect wild sheep. With British Columbia's most recent pneumonia-related die-off likely unfolding in southern British Columbia, the program is acting on the increasing frustration and elevated profile of this issue to find effective long-term solutions.

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