Northern Wild Sheep and Goat Council

PROCEEDINGS OF THE 22nd BIENNIAL SYMPOSIUM

NOVEMBER 3-5, 2020
VIRTUAL MEETING, ALBERTA, CANADA

Symposium Chair: Beth MacCallum
Symposium Coordinating Committee Members: Anne Hubbs, Mike Jokinen, Jon Jorgenson, Margo Pybus, Kathreen Ruckstuhl, Kirby Smith
Sponsorship Conference Program Development: Kathreen Ruckstuhl
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Chair of Business Meeting: Kevin Hurley
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Proceedings Editors: Kathreen Ruckstuhl (coordinator), Marco Festa-Bianchet, Anne Hubbs, Jon Jorgenson, Margo Pybus, and Kirby Smith
Technical Support: Alberta Environment and Parks
Proceedings Assembly: Jon Jorgenson and Alice Paquet

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Northern Wild Sheep and Goat Council

The 2020 Proceedings of the Biennial Symposium of the Northern Wild Sheep and Goat Council are dedicated to:

Valerius Geist

Northern Wild Sheep and Goat Council

We would like to thank our many sponsors for their generous contributions and support. Their willingness to stick with us in the face of the challenges with the Covid pandemic that required the holding of the first virtual symposium in the history of the Northern Wild Sheep and Goat Council is greatly appreciated. We in turn can show our appreciation through our patronage and thanks.

Northern Wild Sheep and Goat Council

NORTHERN WILD SHEEP AND GOAT COUNCIL SYMPOSIA

Date	Symposium	Location	Symposium Coordinator/Chair	Proceedings Editor(s)	NWSGC Executive Director
May 26-28, 1970	NWSC 1	Williams Lake, BC	Harold Mitchell		
April 14-15, 1971	NAWSC 1	Fort Collins, CO	Eugene Decker/Wayne Sandfort	Eugene Decker	
April 11-13, 1972	NWSC 2	Hinton, AB	E.G. Scheffler		
April 23-25, 1974	NWSC 3	Great Falls, MT	Kerry Constan/James Mitchell		
Feb. 10-12, 1976	NWSC 4	Jackson, WY	E. Tom Thorne		
April 2-4, 1978	NWSGC 1	Penticton, BC	Daryll Hebert/M. Nation	Daryll Hebert/M. Nation	
April 23-25, 1980	NWSGC 2	Salmon, ID	Bill Hickey		
March 17-19, 1982	NWSGC 3	Fort Collins, CO	Gene Schoonveld	James Bailey/Gene Schooneveld	
Apr. 30-May 3, 1984	NWSGC 4	Whitehorse, YK	Manfred Hoefs	Manfred Hoefs	Wayne Heimer
April 14-17, 1986	NWSGC 5	Missoula, MT	Jerry Brown	Gayle Joslin	Wayne Heimer
April 11-15, 1988	NWSGC 6	Banff, AB	Bill Wishart	Bill Samuel	Wayne Heimer
May 14-18, 1990	NWSGC 7	Clarkston, WA	Lloyd Oldenburg	James Bailey	Wayne Heimer
Apr. 27-May 1, 1992	NWSGC 8	Cody, WY	Kevin Hurley	John Emmerich/Bill Hepworth	Wayne Heimer
May 2-6, 1994	NWSGC 9	Cranbrook, BC	Anna Fontana	Margo Pybus/Bill Wishart	Kevin Hurley
Apr. 30-May 3, 1996	NWSGC 10	Silverthorne, CO	Dale Reed	Kevin Hurley/Dale Reed/Nancy Wild (compilers)	Kevin Hurley
April 16-20, 1998	NWSGC 11	Whitefish, MT	John McCarthy	John McCarthy/Richard Harris/Fay Moore (compilers)	Kevin Hurley
May 31-June 4, 2000	NWSGC 12	Whitehorse, YK	Jean Carey	Jean Carey	Kevin Hurley
April 23-27, 2002	NWSGC 13	Rapid City, SD	Ted Benzon	Gary Brundige	Kevin Hurley
May 15-22, 2004	NWSGC 14	Coastal Alaska	Wayne Heimer	Wayne Heimer/Dale Toweill/Kevin Hurley	Kevin Hurley
April 2-6, 2006	NWSGC 15	Kananaskis, AB	Jon Jorgenson	Margo Pybus/Bill Wishart	Kevin Hurley
Apr. 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/Steve Wilson/Mari Wood	Steve Wilson/Mari Wood	Kevin Hurley
June 2-5, 2014	NWSGC 19	Fort Collins, CO	Janet George	Bruce Watkins, Ricki Watkins	Kevin Hurley
May 9-12, 2016	NWSGC 20	Moscow, ID Pullman, WA	Hollie Miyasaki,/Rich Harris/David Smith	Rich Harris	Kevin Hurley
May 21-24, 2018	NWSGC 21	Whitefish, MT	Brent Lonner/Bruce Sterling/Caryn Dearing	Justin Gude	Kevin Hurley
November 3-5, 2020	NWSGC 22	Alberta (virtual)	Beth MacCallum	Kathreen Ruckstuhl	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 22nd Biennial Symposium of the Northern Wild Sheep and Goat Council, held November 3-5, 2020. While plans had been made to hold this NWSGC Symposium in April 2020 in Canmore, Alberta, the COVID-19 pandemic along with travel restrictions resulted in not only a ~7-month delay, but we were forced into holding a virtual symposium.

Heart-felt thanks are extended to the sponsors of, and all those participating in, this highly successful 22nd biennial symposium. Thanks to all of the session presenters for assembling and sharing relevant new science on wild sheep and goat ecology and management.

Special thanks to Chair Beth MacCallum for leading a dedicated Alberta organizing committee; under very difficult circumstances, Alberta delivered a first-class symposium.

Thanks go to all the committee members who adapted so readily to the fluidly changing timelines caused by Covid-19. Mike Jokinen, Alberta Conservation Association, set up the registration process and oversaw all the refunds when the April date was cancelled; he then started the process again to accept registrations for the November virtual Symposium. The committee made frequent use of the conference call number provided by Anne Hubbs, Alberta Environment and Parks. Anne was instrumental in bringing on Alberta Environment and Parks' IT Team to help run the virtual Symposium and maintaining this vital communication. Rob Harris, Director of Engagement and Education and Jenna Curtis, Engagement and Education Specialist, held training sessions in the use of Zoom for participants and monitored the entire event to ensure technical difficulties were handled smoothly and the program was delivered.

Thanks to Kirby Smith for keeping track of the fund-raising donations and arranging the field trip, BBQ venue and entertainment. When the decision was made to cancel the in-person event the Mount View BBQ and Brewster Bus Lines returned our deposits with no questions. After long negotiations with the Canmore Coast Hotel, Jon Jorgenson finally secured a written agreement to honour our deposit for future bookings, to be used by the NWS&GC or another organization. Thanks to Ken Nowicki for helping with the negotiations. Thanks to Kathreen Ruckstuhl for developing the program, inviting special speakers, and tirelessly updating the draft agenda as the program developed. Kirby Smith's virtual entertainment session was a highlight of the Symposium bringing together musicians from Alaska, Alberta, and Wyoming. Thanks to Jon Jorgenson for arranging for the banking services, tracking expenses, and producing the Proceedings. All committee members were dedicated and a pleasure to work with.

We would like to thank the Alberta Fish and Game Association whose funding went to the printing of these Proceedings.

Northern Wild Sheep and Goat Council

These Proceedings were edited by Kathreen Ruckstuhl. Peer-reviewers included Marco Festa-Bianchet, Anne Hubbs, Jon Jorgenson, Margo Pybus and Kirby Smith. 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
December 9, 2021

TABLE OF CONTENTS

DISEASE PLENARY: IN A BLINK AT THE BRINK

DISEASE AND PARASITES

HABITAT AND CLIMATIC FACTORS

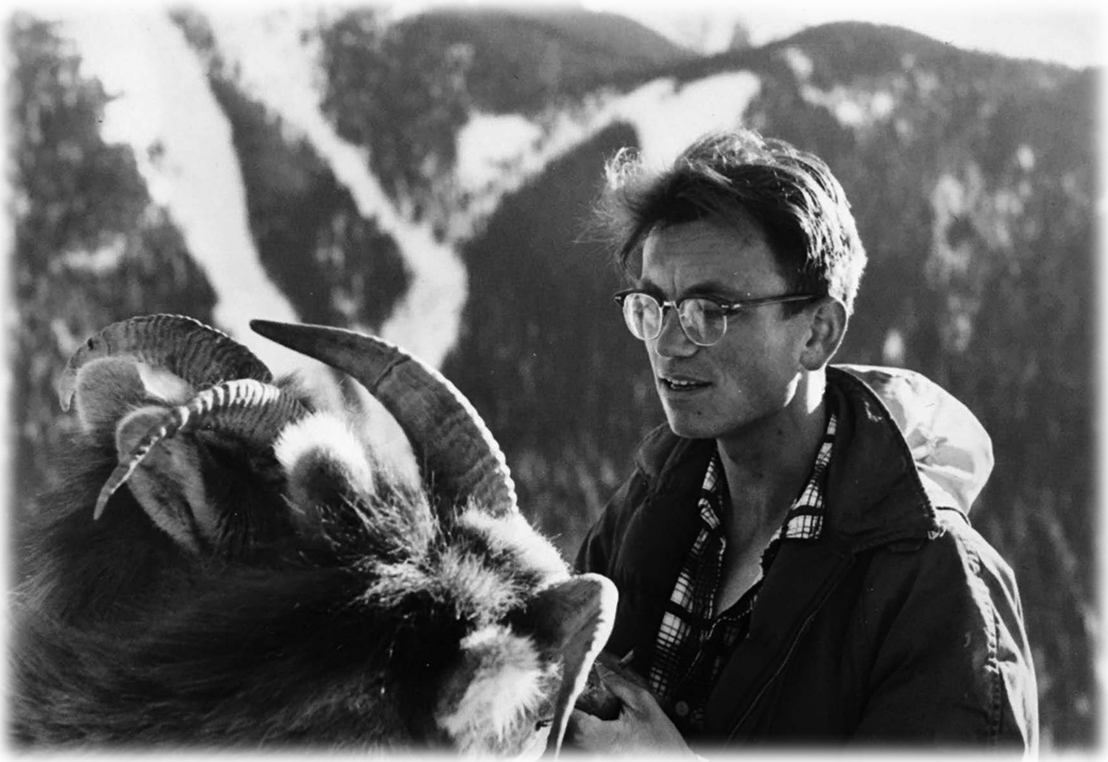
MANAGEMENT

POPULATION ECOLOGY

BEHAVIOUR AND ECOLOGY

Northern Wild Sheep and Goat Council

TRIBUTES TO DR. VALERIUS GEIST
(1938 – 2021)



Beth MacCallum
Chair, 22nd Symposium of the Northern Wild Sheep and Goat Council, Alberta, November 2020

As a student, I never missed a Valerius Geist lecture. The lecture may have started out as a discussion on biology of a specific ungulate, but it never stayed there and soon incorporated environmental, social, and cultural context. Val loved to share knowledge and engage with discussion, the more complex the better. We know Val as an icon in the world of bighorn sheep; even now, his 1971 book "*Mountain Sheep, A Study in Behaviour and Evolution*" is relevant. Val obtained a PhD in Zoology in 1966 from the University of British Columbia after studying Stone's sheep behaviour in the Cassiar Mountains of British Columbia. He then studied under Konrad Lorenz at the Max Planck Institute in Germany as a post-doctoral fellow. Subsequently, he moved to a position at the Faculty of Environmental Design, University of Calgary. This was the perfect place for Val to explore ideas and interact with faculty and students with a diverse set of skills and background – urbanists, architects, planners, economists, lawyers, and scientists. This integration was hard. Students had to participate in group projects with three of the four streams: environmental science, architecture, planning, and industrial design. Val was challenged and he thrived. Val was a very engaging person and always available to answer any question no matter how many times he must have heard each question before. Few people have the ability to move skillfully between art and science and in fact bring the two together. His keen eye for observation of the natural world was translated not only into science but interpreted through the lens of cultural symbolism and expressed in art. His book "*Life Strategies, Human Evolution, Environmental Design, Toward a Biological Theory of Health*" was written because of the problems he encountered when teaching graduate students of highly diverse backgrounds aspects of human biology relevant to environmental design. Val was one of the few people who could tackle such a demanding subject.

Valerius Geist was a prolific writer producing numerous scientific papers and books as well as contributing dozens of popular articles to outdoor and natural history magazines. Topics ranged from wildlife ecology, behaviour, evolution, the biology of health, and wildlife conservation policy. Conservation became a major focus of his work. Val was a serious hunter and understood the importance of the North American Model of wildlife conservation. He wrote about it profusely, co-editing books on "*Wildlife Conservation Policy*" and "*The North American Model of Wildlife Conservation*".

Val met his beloved wife Renate while at university. They married in 1961 and raised a loving family of three children. He was a gracious host and treated visitors as if they were royalty, plying them with food and drink that he and Renate had prepared themselves. Val was born February 2, 1938, in Russia. His family was disrupted by WWII and Val ended up in Germany with his mother, aunt, and grandmother. The family eventually reunited and immigrated to Canada in 1953. Val died July 6, 2021, at 83 years of age. He lived a full life - full of curiosity, wonder and exploration and he used his intellect to its fullest. To remind us of how special he was and how wonderful it was to have known him, he left behind an unfinished book on human evolution entitled *"Condemned to Art and Insanity. Our Natural History."*

Kevin Hurley
Northern Wild Sheep and Goat Council (volunteer) Executive Director (1992-present)

Like so many others, Val Geist was an inspiration, mentor, and role model for me, for so many years. My lifelong fascination with mountain sheep and mountain goats drew me like a magnet to Val, who published, wrote, and spoke so prolifically. Although my time in the field with Val was very limited, his books, articles, columns, and manifestos always grabbed my attention, and piqued my interest. Those of us who love mountain ungulates were so blessed to have a man like Val in our midst; we may never know another like him, and we thank him for all that he left with us.

Eldon Bruns
Alberta Fish and Wildlife (retired)

Yes, I was his first grad student. After taking one of his courses in 1968, I talked him into letting me complete a Masters degree in one year rather than the usual two or three by doing my field work in the winter rather than the summer. Val provided me with a University of Calgary truck and a rental snowmobile. I was 28 years old, married, and had worked as a Hydrographic surveyor for 9 years, so I guess he decided I might make it. He only came out in the field with me for one *day since the winter of 1968-69 was the most severe winter we had in the previous 30 years. Val had opposition from the other professors for letting me risk my life that winter, but he generously provided me letters of recommendation to help me get biology jobs in New Zealand, Australia, and Alberta. He was a tireless field worker and prodigious author. He likely wrote hundreds of wise pages for every hour he spent in the field!*

Mark Boyce
Professor of Ecology, University of Alberta

*Val and I shared many interests and spent many delightful hours talking about them. Often we disagreed, which made his conversations even more engaging. I first met Val in 1975 when I was a Ph.D. student at Yale where Val had invited himself to give a seminar, and I was delegated to take him to the Faculty Club for dinner. I recall our discussion about antlers in female caribou and we argued about Val's idea that those antlers were important to females in late winter when they could dominate over males at feeding craters. Before I moved to Alberta Val arranged a few days visit in 1998 with Norm Simmons at his ranch near Pincher Creek. Norm had initiated indigenous co-management of wildlife in the Northwest Territories when he was Director of Fish and Wildlife for the territorial government. As always, we learned valuable insights from hours of discussion with Val about the very fabric of wildlife management in North America – grand scale insights that evolved to become the "*North American Model of Wildlife Conservation*."*

Alexander Sharif
Principal Engineer, Fluor Canada

I met Dr. Val Geist in 1994 in a lecture he was presenting on mule deer and our friendship continued until death took him away. When a man of his caliber dies, it is as though a library burned down. To my family and myself, Val was more than just a friend/mentor. Every question we ever asked him; whether it was on ungulate behavior, evolution of species, predator-prey relationship, or even common subjects such as wine, mushrooms, or berries was always answered accurately, patiently, and with gusto. I always said that after I read his answers, I felt I had taken a university crash course on the subject. Besides academic achievements, what made Val even more special was his treatment of others with utmost respect. Having been in his entourage of friends is one of my biggest blessings in life and I am glad I was able to host him on his last hunt in Nov 2020 here in Alberta.

November 2020
Alexander Sharif with Valerius Geist

Kirby Smith
Alberta Fish and Wildlife (retired)

I only met Val a few times. His contribution to wildlife science speaks for itself. In addition, he was always contemplating the natural world and passing on his ideas. Moreover, I thought he epitomized the penultimate scientist by constantly challenging his own ideas. I remember him stating, "you know what I said before about a particular subject - well I think that was wrong and based on new information, I now have a different take".

Marco Festa-Bianchet
Université de Sherbrooke

Val was different. He did not fit the mold of a North American University Professor, or of a conventional scientist. His mind was constantly generating ideas and his ability to present those ideas with great authority was unparalleled. His artistry helped both his science and his communications with the general public. Val was courageous in defending his ideas, even when his opposition to game ranching brought death threats. Events since have shown he was completely right on that issue. One of the creators of the North American Model of Wildlife Conservation, I always thought he was deeply affected by his knowledge of Central European management, helped by his ability to read German and Russian. A person of great integrity, he was also very kind and conversations with him were always entertaining.

Shane P. Mahoney
CEO, Conservation Visions Inc.

Dr. Valerius Geist was an extraordinary man, gifted intellectually, and blessed with a prodigious capacity for work. His mark on North American conservation is indelible. We became very close, and I knew him as a mentor, colleague, and friend; and I valued him more in all these regards as time passed. His warmth and joy in conversation were an unending source of inspiration to all of us who knew him and a reminder that to be human means to care about other people, their lives, and ideas. To walk with him in nature was to be in the presence of someone who truly cared and who was forever fascinated by the wondrous complexity and nuanced beauty of the world we inhabit and share. His passing represents a deep and profound personal loss, and it is hard to comprehend that it will never again be possible to see that wonderful smile or sit quietly on the phone or in person and listen to his latest insights. There are few who will ever match the breadth and depth of his contributions to our understandings of wild ungulates, of course; but his intellectual legacy is far more wide-reaching and envelops a virtual universe of thinking on the wildness of humanity and humanity's responsibility to wildness. Sadly, it will be impossible not to miss him always. Like others who knew him well, I consider having known Dr. Geist as I did to be one of the true blessings of my life and career. Like all forces of nature, many will forage and discover new pathways to purpose and understanding in his wake.

Susan Lingle
Professor, Department of Biology, University of Winnipeg

I did my Master's in Environmental Design at UCalgary in the mid-1980s, with Val as supervisor. It was a treat to stop by Val's house to pick up a book or paper. He and his wife, Renate, were always welcoming and engaging. One term, Val held a small class on the Evolution of Mammals at his house one evening each week. The atmosphere was *warm and filled with interesting ideas. Renate invariably offered us freshly baked and delicious German coffee cake. I was always impressed by Renate, equal parts grace, and keen intellect.*

Val gave his research students incredible independence and was always brimming with positivity. I decided to work with Bill Wishart's herd of hybrid deer for my Master's thesis, and this involved moving 16 deer from Edmonton to the Calgary Zoo in a horse trailer, making the return trip a year and a half later with what had multiplied into 33 deer; building fences, runways and obstacle courses so I could film the deer in a study of their locomotion. This was not your typical student project, but I don't remember Val uttering a doubting word. Since this note is for a sheep and goat group, I'll add that Bill Wishart was pretty darn supportive too – this project and the logistics required a major investment of time and hard work for Bill and many of his colleagues.

Val was off the charts when it came to his many talents. Scientist. Artist. Public speaker. Nearly always controversial. I was reminded of one of these talents just yesterday, when I went back to his classic descriptive chapter on mule deer behaviour published in the 1981 book edited by O.C. Wallmo. This is a paper I regularly dig up to introduce new students to deer behaviour. Val had the ability to notice and describe fine details of an animal's behaviour remarkably accurately – from feeding to dominance interactions, courtship, scent-marking, to antipredator behaviour. I really don't know how he acquired the breadth and depth of observation revealed in that paper. It is remarkable. And those illustrations!

Bill Wishart
Alberta Fish and Wildlife, (retired)

Val and I had many spirited discussions over the years about his developing hypotheses. I will never forget running downhill from a ram that had learned to butt people to try to dislodge salt they may have been carrying. This was in Banff during Val's behavioural studies. Concerned over his 'Teutonic English', Val asked me to read and provide constructive criticism of the first and second drafts of his 1971 book "Mountain Sheep, a Study in Behaviour and Evolution". He was a gifted artist and illustrated his articles and books with skill. We remained great friends.

Jim Bailey
Belgrade, Montana

I first met Val when I was on sabbatical leave at Calgary University. He and his family were exceptional hosts for our family, including a day of ice-fishing and jackrabbit hunting. Our friendships lasted throughout their lives. Renate and my wife, Nan, exchanged letters often and Val and I corresponded with the internet. We visited them at Port Alberni and were treated to roast bear.

Val was the most intellectual person I have known. His interests were broad and thoughtfully deep. He was a true philosopher – a lover of knowledge. Over lunches in the Calgary University cafeteria, we talked about what Val was thinking about each day. He was so intense, that one could not deter him from his subject. At the time, he was working on "Life Strategies, Human Evolution, Environmental Design: Toward a Biological Theory of Health", probably his most important, yet under-appreciated work.

Val was unaffected by his broad reputation. He always had sincere interests in differing points of view. At home, there was no pretense. Visiting them at Port Alberni, I recall arising early to find Val, in a bathrobe, feeding scrambled eggs to his turkeys. We also had wonderful home-made wine during that visit.

I miss Val, not being able to "bounce ideas" off him as I once did. His works deserve rereading for a long time. They contain much more than "just wildlife". But habitat managers who reread "Mountain Sheep" will again find that a complete bighorn range consists of six seasonal ranges, juxtaposed, and connected with migration corridors. Val is telling us that too many of our bighorn herds suffer with less.

Darryn Epp

Dr. Geist was a scientific visionary, performing research through a larger diagnostic lens than most others in his time and space. His intellect and curiosity of the way species evolution impacted our understanding of ethology was impactful. His characteristic passion to share his learnings and an ability to communicate them to a wide diversity of audience was key to his ability to deeply influence so many throughout his journey.

June 22, 2021
Dr. Valerius Geist discussing mountain goat skulls collected during his time doing behavioral studies in the Spatsizi, British Columbia. Darryn Epp took this photo when he and his partner Cathy visited Val at his Port Alberni home.

Wayne E. Heimer
Alaska Department of Fish and game (retired)

Valerius Geist always made me feel like what I thought was important, and that I was actually his friend and colleague. This, for better or worse, encouraged me to think further. I loved the man.

Our final great adventure was an elk hunt together in Alberta with a mutual friend, Pat Long. Pat had built several "stands" around a hay field he owns near the Peace River. The days spent sitting in one or another of these stands with Pat or Val as they shared their knowledge and impressions of what we were seeing in nature were precious for me. Can you imagine a biologist's thrill at having two founts of local and intercontinental knowledge and creative ideas "captive" for hours while numerous deer came and went? Priceless!

Cliff White
Parks Canada biologist (retired)

Thanks to Val Geist

Val Geist thought big: Big in time – hundreds of thousands of years; big in space – continental patterns of species evolution; big in numbers of species – he could recognize and draw thousands of them, ancient to current. But most importantly, he thought big in the ancient, current, and future roles of human societies in the evolution and conservation of this global biodiversity.

Over the decades, I was fortunate to talk with Val about our joint interests of the day. In the 1980s, we discussed cultural, prescribed burning of his mountain sheep study areas in the Cascade valley in Banff and the Spatsizi valley in northern BC. In the '90s he advised on helicopter tour impacts on mountain goats in Banff and Assiniboine parks. Later, we had some great discussions about how to manage the 300 or so super-habituated elk that had taken possession of Banff townsite. Most recently, we shared our thoughts on how the socio-economic patterns of humans in the southwest from 1000 AD to 1600 AD could have influenced the western edge of bison range near the Gulf of Mexico. I think no one was more aware than Val that western North America's diversity of wildlife is the legacy of human long-term keystone role. Our species evolved as a valley bottom, but wide-ranging omnivore, skilled in communal hunting, fishing, gathering, culturing, burning, and always keeping a deep symbiotic relationship with dogs, both wild and tame. By filling this niche, we created living space for species ranging from bison to caribou, to bighorn sheep, to aspens, and beaver.

Today, as the Anthropocene creates a globalized economy, destroying long-term, more localized human subsistence patterns, we desperately need visionaries like Val Geist who can put this massive change in the context of big space and big time. He had so many interests, wrote so well, and connected with so many people in so many different ways. He will be deeply missed.

Paul R. Krausman
Emeritus Professor, University of Arizona

Knowing Valerius (Val) Geist

As an undergraduate and graduate student, I was well aware of Val and his work with bighorn sheep and was honored to meet him. After the meeting, we communicated often, and he visited me, my graduate students, and bighorn sheep study sites when I was a professor at the University of Arizona. I can still see and hear him speaking skillfully about bighorn sheep as he stood atop a rock in the Harquahala Mountains. His knowledge of wildlife worldwide was legendary, but his humanity and activities as a responsible world citizen were more important. Val was always kind and considerate of others. He may not have always agreed with everyone, but always had justification and literature to back up his reasoning. He was a gentleman and true scholar and I learned much from him.

Equally important, Val loved his family and life. Hearing him talk about his wife and life were topics few discuss, but they were woven into the fabric of his being. I was fortunate to work in the wildlife arena with Val and to see that his profession was only one part of the life he lived so well.

Denis Chabot
Ecophysiologist, Department of Fisheries and Oceans, Maurice Lamontagne Institute, Mont-Joli, QC, Canada

I was a Ph.D. student with Val in the 80s and early 90s. Encountering Val when I started was quite a shock. I had never met a professor who could be so animated and switch from talking about animal behavior to cooking to hunting, remaining passionate and knowledgeable on all of these subjects! He kept surprising me when I took some classes he was teaching. Each time he started with three huge blackboards, absolutely empty, and a pile of coloured chalk. Before the class was over, all three blackboards were full of fantastic drawings, each one would have taken me an evening to complete (if I could complete it), with a model to guide me. Val drew those from memory while telling *us stories and concepts, as if it was as simple a task as breathing. Every class, a large number of large mammals, living or extinct, took shape before our very eyes. Val was a very charismatic and skilled teacher; this is for sure.*

During my Ph.D. under Val, I saw a brilliant man driven by passion and his love of large mammals, but also one who enjoyed controversy. He had high expectations of what biologists should do: they should further knowledge, for sure, but they should make sure this knowledge had concrete applications for our fellow citizens. And Val did all this with an infinite supply of energy. Honestly, I was humbled and wondered if I could live up to his standards.

Helen Schwantje
BC Wildlife Branch (retired)

My first exposure to Dr. Valerius Geist was to read about his work on Stone's sheep, to me a species I was entranced with due to their remoteness and the relatively little known about them. What he did for the species was brought home to me in the late 1980s when I visited the jewel-like Gladys Lake, a new ecological reserve. His cabin was on a little islet at the base of a huge slope that was home to the herd of Stone's he had observed and described. He had sat on the porch of the cabin, a luxurious location to study animal behaviour. I was quite jealous and told him so when we eventually met Val became a friend. He loved to ponder and work out the whys animals do what they do. Wolves, sheep, humans, it did not matter. We had some wonderfully challenging and thought-provoking conversations. I told him often, "Val, you think too much". But I didn't mean it, I was jealous (again). He was a quintessential gentleman who loved his work, his family, his friends but mostly the love of his life, Renate. I'm so very glad we met, shared Stone's sheep, had those discussions, and a friendship. Love to you Val, Helen

Northern Wild Sheep and Goat Council
Position Statement
Commercial and Recreational Disturbance of Mountain Goats: Recommendations for Management

PROJECT BACKGROUND:

In 2004, the Northern Wild Sheep and Goat Council (NWSGC) published a position statement on management of helicopter-supported recreation and mountain goats (Hurley 2004). This document was intended to represent the scientific consensus regarding the effects of helicopter-supported recreation on mountain goats, primarily in the context of commercial activities (e.g., summer and winter helicopter-based tourism). The position statement included a summary of the available literature and associated recommendations for management. This document has been widely used and referenced by wildlife and land-management agencies as well as non-government organizations (NGOs) to inform land management decisions in the U.S. and Canada. Since publication of the original NWSGC position statement, new research has been conducted on helicopter and other types of disturbance, resulting in a need for updates. There has been recognition that expanding the scope of the position statement to include management guidance related to helicopter and other disturbance activities in broader industrial and recreational contexts would be useful for wildlife and land managers. During 2019–2020, a NWSGC working group comprised of 18 subject matter experts convened to update and expand the scope of the 2004 NWSGC position statement. The revised position statement was reviewed and unanimously endorsed by the executive committee and membership at the November 2020 NWSGC business meeting.

INTRODUCTION:

Anthropogenic disturbance of wildlife from both commercial and smaller-scale independent recreational activities is an increasingly widespread conservation issue globally (Naugle 2011, Larson et al. 2016, Shannon et al. 2016). Mountain goats are a highly valued and iconic species of western North American mountain landscapes and are particularly sensitive to human disturbance, relative to other ungulates (Côté 1996, Gordon and Reynolds 2000, Festa-Bianchet and Côté 2008, B.C. Ministry of Environment 2010). Mountain goats are habitat specialists that persist under extreme environmental conditions (Festa-Bianchet and Côté 2008). As a consequence, the species has a conservative life history strategy and low potential for population growth across its native range (Bailey 1991, Festa-Bianchet et al. 1994, Hamel et al. 2006, Festa-Bianchet and Côté 2008, Rice and Gay 2010, White et al. 2018). Combined with strict habitat requirements, high fidelity to seasonal home-ranges, and a high degree of fine-scale genetic population structure, the species is particularly vulnerable to negative perturbations; demographic recovery following declines can often be prolonged or uncertain (Fox et al. 1989, Keim 2004, Festa-Bianchet and Côté 2008, Shafer et al, 2011, 2012). As a result, conservation strategies for mitigating negative effects of human disturbance are necessary to ensure mountain goat population productivity and viability, and ultimately, effective stewardship of this iconic wildlife species for future generations (B.C. Ministry of Environment 2010).

Less is known about mountain goats than other North American ungulates due to their relative scarcity and the inaccessible terrain they inhabit (Smith 1982, Festa-Bianchet et al. 1994, Wilson and Shackleton 2001). Nonetheless, important advances have been made in our understanding of disturbance effects on mountain goats with respect to effects of helicopters and other commercial or recreational disturbance. Helicopters are used widely in many industrial activities conducted in remote areas (e.g., mining, logging, hydroelectric development, telecommunications, seismic exploration), and are increasingly used in the context of all manner of summer and winter tourism activities (B.C. Ministry of Environment 2010). For example, the Juneau Icefield is a world-class tourism destination located in Southeast Alaska that receives more than 20,000 summer helicopter landings annually (J. Schalkowski, U.S. Forest Service – Tongass National Forest, personal communication). In British Columbia and Alaska, over 50 different helicopter-based skiing companies are in operation. Other forms of helicopter-supported adventure tourism, involving hiking, mountain biking, glacier exploration, dog mushing and numerous other activities, are locally prevalent and growing in many jurisdictions with some previously inaccessible wilderness areas now experiencing a high intensity of recreational use.

Mountain goats exhibit particular sensitivity to aerial

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disturbance such as helicopters (Foster and Rahs 1983, Côté 1996, Goldstein et al. 2005, Cadsand 2012, Côté et al. 2013) that may have arisen as an adaptation to predation risk occurring from terrestrial carnivores and aerial predators. Indeed, Frid and Dill (2002) described human disturbance as a form of predation risk that can lead to deleterious individual and population-level effects; a useful conceptual framework for understanding disturbance in an ecological context. Mountain goat responses to aerial and other industrial, commercial and recreational disturbances can involve reduction of foraging, increase in movement rates and energetic expenditure, and spatial displacement from important habitats during critical periods (Foster and Rahs 1983, Côté 1996, Goldstein et al. 2005, Cadsand 2012, Côté et al. 2013, Richard and Côté 2016, White and Gregovich 2017). Less visible physiological stress responses can also occur in response to anthropogenic and natural forms of disturbance and result in negative effects on immunological health and reproduction (MacArthur et al. 1982, Stemp 1983, Harlow et al. 1986, Chabot 1991, Downs et al. 2018, Dulude-de Broin et al. 2020). Such responses, if sufficiently intense, can result in negative effects on population demography, such as decreased reproduction and recruitment, as documented by Joslin (1986; also see Figure 1).

Although the short-term behavioral responses of mountain goats to helicopter activity have been documented, longer-term habitat use and demographic consequences of disturbance remain only partially understood. These recommendations are intended to minimize short-term behavioral disruptions that are correlated with long-term individual and population-level impacts. Existing research indicates a broad consensus on the pathways leading to detrimental effects, but additional research is required to better characterize effect sizes and interactions. While this work continues, we provide specific mitigation measures as precautionary recommendations, based upon the current body of available science. The following is a synopsis of the identified impacts addressed by research, to date. Each impact is summarized and includes relevant science-based recommendations (also see Appendix Table 1) intended to provide guidance regarding mitigating potential impacts to ensure effective conservation of mountain goats.

MANAGEMENT RECOMMENDATIONS:

Habitat exclusion zones:

Mountain goats live in highly seasonal environments and utilize their landscapes in spatially- and temporally-specific ways to optimize reproduction and survival. In this context, the parturition (kidding) and winter seasons are particularly important for reproduction and survival; excluding disturbance of habitats used during these periods is essential to sustain population viability and productivity.

Mountain goats are habitat specialists and rely on specific

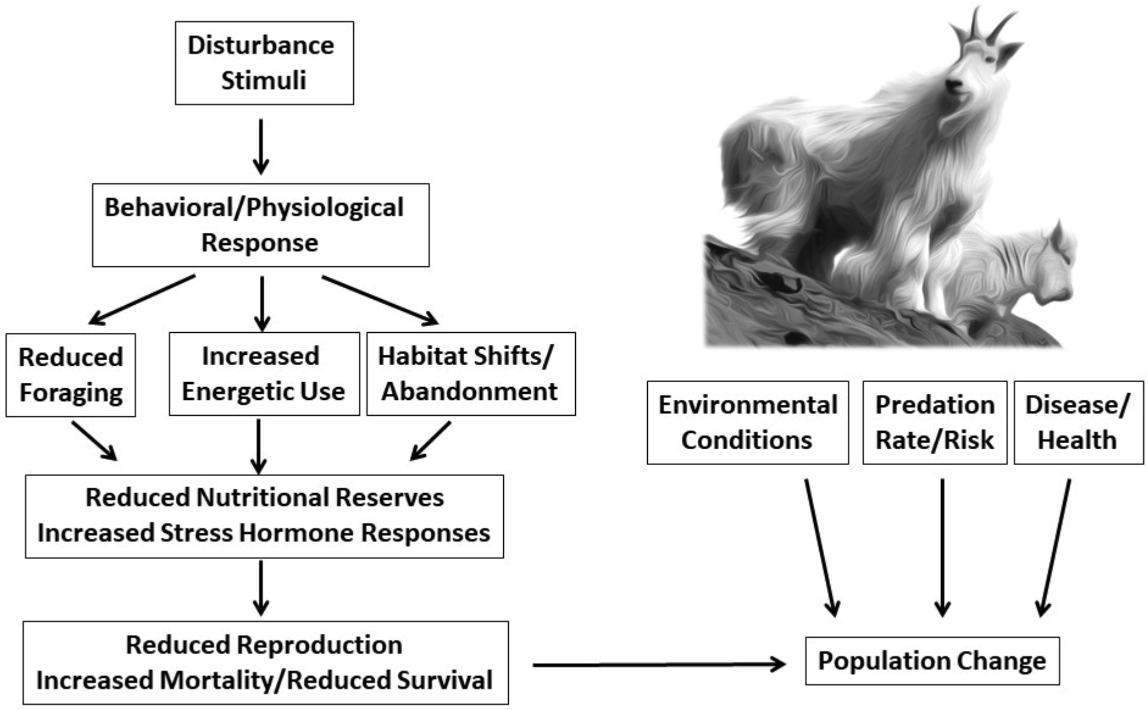

Figure 1. Conceptual framework for characterizing disturbance effects on mountain goats, in the context of other drivers of population demography (adapted from Frid and Dill 2002, Wilson 2011). Expected impacts of disturbance can be exacerbated, or buffered, depending on demographic conditions, environmental conditions, predation, and disease.

habitat features with narrow topographic and vegetative attributes. Studies have consistently documented mountain goat selection of steep, rugged terrain in close proximity to cliffs (Fox et al. 1989, Gross et al. 2002, Festa-Bianchet and Côté 2008, Poole et al. 2009, Shafer et al. 2012, White and Gregovich 2017). Given these preconditions, mountain goat habitat selection can vary with respect to elevation, slope, and aspect, depending on season and region (Hebert and Turnbull 1977). In coastal ecosystems, mountain goats typically migrate from alpine summer ranges to low-elevation, forested winter ranges to avoid deep, wet maritime snowpacks (Hebert and Turnbull 1977, Fox et al. 1989). In forested winter ranges, a strong association to mature, old growth forest stand structure is evident (Fox 1983, Fox et al. 1989, Jex 2004). Conversely, in interior climates mountain goats commonly inhabit windblown subalpine and alpine habitats during the winter season with localized variation in wintering strategies often occurring in coastal-interior transitional climates (Hebert and Turnbull 1977, Jex 2004, Festa-Bianchet and Côté 2008, Poole et al. 2009, White and Gregovich 2018). During the kidding season, mountain goats typically utilize subalpine and alpine habitats in close association to escape terrain regardless of climatic regime or region.

Sexual segregation is typical of many ungulate species (Main et al. 1996), including mountain goats. During the non-breeding season, adult male mountain goats are often spatially segregated from nursery groups, composed of adult females, subadults and neonates (Geist 1964, Foster 1982, Risenhoover and Bailey 1982). Habitat selection does not differ strongly between the sexes. Females with offspring, however, display a stronger affinity to escape terrain as compared to other individuals (Hamel and Côté 2007) and show heightened sensitivity to disturbance (Penner 1988). The vitality of mountain goat nursery groups provides obvious contributions to the productivity and viability of mountain goat populations. Due to the sensitivity of adult female mountain goats to disturbance, and the importance of this age/sex class to the persistence of local mountain goat populations, restrictions on late spring and early summer helicopter activities should focus on areas used by parturient females and nursery groups.

During spring and summer, mineral licks represent an important resource for mountain goats, especially females with kids (Singer 1978, Ayotte et al. 2008, Corbould et al. 2010, Poole et al. 2010, Rice 2010, Jokinen et al. 2014). Mineral licks are rare features on the landscape and deserve special management consideration due to the important role they play in providing key nutritional resources during a critical time of year. In some instances, mineral licks occur near human access or commercial activities (i.e. logging), and can increase mountain goat vulnerability to disturbance (including nanny-kid separation) or, in the case of roadside mineral licks, direct mortality (Singer 1978, Corbould et al. 2010).

Mapping mountain goat habitat is an important step for identifying and managing exclusion zones. Advances in radio-tracking technology (e.g. GPS radio-collars; Cagnacci et al. 2010) and analytical methods (e.g. resource selection function modeling; Boyce et al. 2002) have enabled greater understanding of mountain goat habitat relationships and enhanced our ability to delineate (and validate) important seasonal habitats for mountain goats (Lele and Keim 2006, Shafer et al. 2012, Wells et al. 2014, Richard and Côté 2016, Lowrey et al. 2017, White and Gregovich 2017). Such tools are important for developing scientifically-defensible strategies for protecting important mountain goat habitats. Implementation of such methods can aid in clearly articulating trade-offs and development mitigation strategies to reduce disturbance effects to mountain goats (Figure 2).

Recommendation - Habitat exclusion zones:
•Commercial and recreational disturbance activities, including helicopter overflights and landings, should not occur in important seasonal habitats (e.g. winter, kidding, mineral licks).

•The distribution and abundance of mountain goats and their habitats should be determined before commercial permits are issued to inform operating requirements and provide a baseline for monitoring. Permits should allow for changes to operating requirements as new information becomes available.

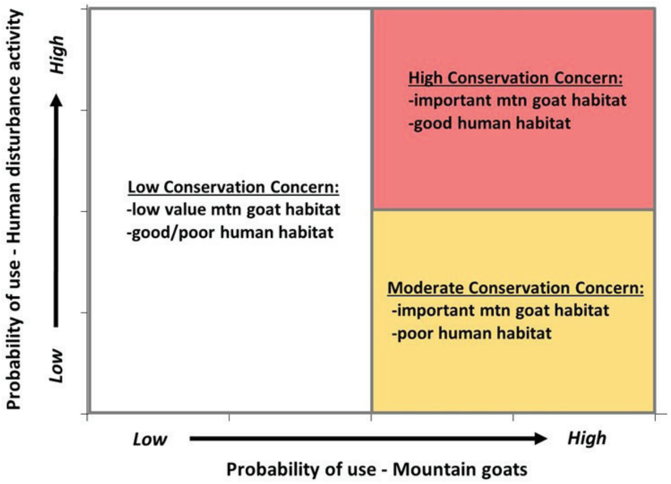

Figure 2. Conceptual framework for evaluating habitat conservation concerns associated with commercial and recreational disturbance in mountain goat habitat (adapted from Nielsen et al. 2006, White and Gregovich 2018).

Timing of disturbance activities:

The winter and parturition (kidding) seasons are of particular concern for management of disturbance stimuli. Winter is a period of severe nutritional deprivation for mountain goats (Chadwick 1974, Fox et al. 1989, Shackleton 1999). Periods of deep snow can reduce food availability and dramatically increase locomotory costs (Fox 1983, Dailey and Hobbs 1989). In winter, mountain goats are relatively immobile (i.e., movements not exceeding 50 m/hour; Poole and Heard 2003, Keim 2004, Richard et al. 2014), occupy small home ranges (<4 km^2; Keim 2004, Poole et al. 2009, White 2006, Shakeri and White 2018), and exhibit a high degree of site fidelity to seasonal ranges (Schoen and Kirchhoff 1982, Keim 2004, Shakeri and White 2018). Selection and use of important winter and kidding habitats may be reduced or abandoned if disturbance is not effectively managed to consider mountain goat habitats and the needs of parturient and/or wintering goats. Evidence suggests more conservative approaches are merited in winter as compared to summer even though growth and nutrition attained during summer can be important for subsequent winter survival (i.e., Mautz 1978, White et al. 2011).

Defining periods of residency on winter range, kidding areas, and mineral licks is important to inform recommendations needed to mitigate disturbance impacts to mountain goats. Residency on winter range is correlated with snowfall in alpine habitats, and for migratory animals, timing windows and important habitat can be quantified using analysis of seasonal migration events (i.e., Spitz et al. 2017, 2018). Variability in weather and climate can alter timing of migratory events and residency time from year to year. For example, in some areas of coastal British Columbia, newborn kids have been observed in late-April, three weeks earlier than normally documented (B. Jex, British Columbia Ministry of Environment, personal communication). While most births normally occur between May 12–June 5, vulnerable neonates are especially dependent on mothers until mid-July (Côté and Festa-Bianchet 2001, Festa-Bianchet and Côté 2008). During a long-term study at Caw Ridge, Alberta (1989–2018), the earliest date a kid survived after losing or being permanently separated from its mother was July 16 (Festa-Bianchet and Côté 2008). Consequently, it is not only important to avoid disturbance of nursery groups during parturition, but during the post-parturition weaning period as well.

Recommendation - Timing of disturbance:

•Disturbance activity should not occur on or near important mountain goat winter range habitats between November 1–April 30. (i.e. Figure 3a, 3b).

•Disturbance activity should not occur on or near important mountain goat kidding habitats between May 1–July 15 (i.e. Figure 4).

•Disturbance activity should not occur at mineral licks used by mountain goats during peak use periods generally occurring between May 1–August 31, recognizing that local variation in periods of use can span a different period of time (Figure 5, Table 1).

•Timing windows could be adjusted, as appropriate, based on the best available data for a given area and while recognizing that specific conditions may vary from year-to-year.

Figure 3a. Photograph of mountain goats in forested winter range habitat in coastal Alaska (Photo: K. White)

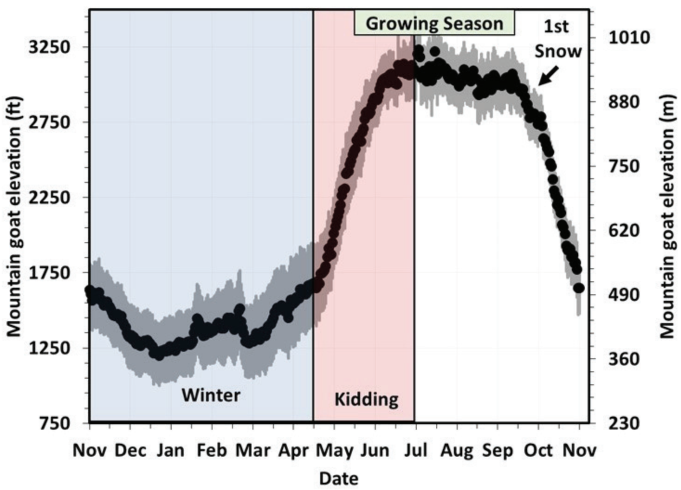

Figure 3b. An example illustrating how elevational migration patterns can define timing and duration of winter range use in coastal Alaska. Data were collected from GPS radio-collared mountain goats (n = 172) 2005–2019 (White et al. 2012, unpublished data). Timing or occurrence of elevational shifts may vary by year or locality.

Table 1. Timing of mineral lick use by mountain goats summarized across six study sites in North America. Data are summarized in relation to first and last months, as well as the peak month during which mountain goats were documented at mineral licks. Data were pooled for male and female mountain goats in this summary, however, timing differences between female vs. male mountain goat use of mineral licks were reported.

Area	Start	Peak	End	Source
Glacier National Park, Montana	April	June/July	September	Singer 1978
Muskwa-Kechika, British Columbia	May	July	August	Ayotte et al. 2008
Caw Ridge, Alberta	May/June	June	August	Festa-Bianchet and Cote 2008
Rocky & Purcell Mtns, British Columbia	February	June/July	August	Poole et al. 2010
Cascade Mtns., Washington	January	July	December	Rice 2010
Southwest Alberta	May	July	Oct	Jokinen et al. 2014

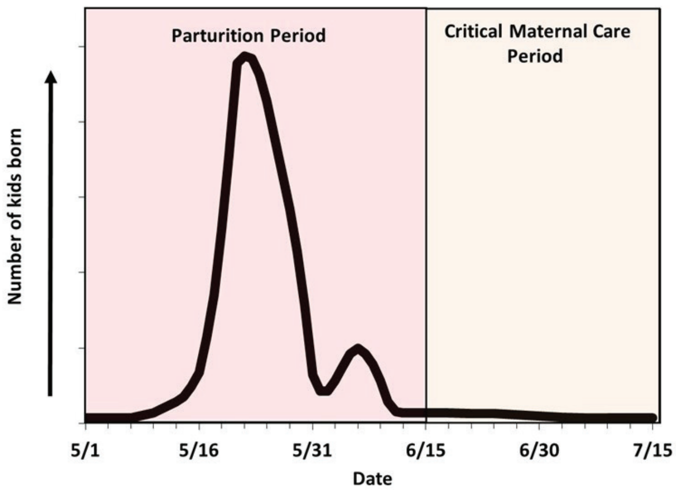

Figure 4. Generalized pattern of mountain goat parturition and the critical post-birth maternal care period (based on Côté and Festa-Bianchet 2001, Festa-Bianchet and Côté 2008). Timing may vary across years and by locality.

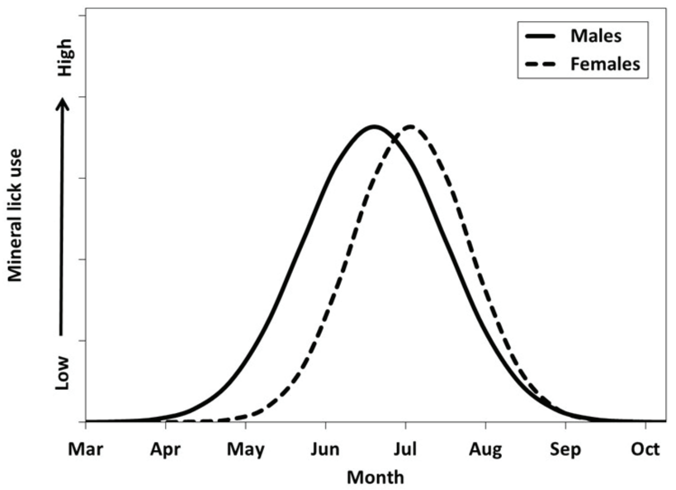

Figure 5. Generalized pattern of mineral lick use by male and female mountain goats (based on sources in Table 1). Timing may vary across years and by locality.

Distance from important seasonal habitats

Acute, short-term behavioral responses to helicopter activity have been consistently documented at distances of 1.5 km, and up to 2 km, for mountain goats (Côté 1996, Frid 2003, Gordon 2003, Cadsand 2012, Goldstein et al. 2005, Côté et al. 2013). Mountain goats within 2 km of winter helicopter skiing exhibited medium-term behavioral responses, involving alteration of movement patterns and habitat selection up to 48 hours following disturbance events (Cadsand 2012). Helicopters used for tourism are typically lighter and quieter than those used for larger, industrial-scale commercial activities such as mining and logging. Thus, response distances from these studies, primarily conducted in lighter-duty helicopter recreation/tourism contexts, may underestimate responses both in terms of distance and overtness to industrial-sized helicopters. Examination of mining-related disturbance, including helicopter activity, blasting, heavy machinery operation and other operations, indicate mountain goat avoidance of suitable winter habitat within 1.8 km of point-source disturbances (White and Gregovich 2017). Similar responses were observed during behavioral spot-monitoring assessments focused on mountain goat responses to helicopters and horn signaling during logging activities adjacent to known winter range habitat, showing temporary habitat abandonment during active operations (Jex 2007). It is important to consider the surrounding terrain or relative position of mountain goats to helicopters/machinery may amplify noise or visual disturbance stimuli, and increased buffers may be required in confined geographies such as canyons or for direct and overhead approach vectors (i.e., Andrus 2005).

Recommendation - Distance from important seasonal habitats:

•Commercial or recreational disturbance activity that includes the use of light helicopters[1], should not occur within 1.5 – 2.0 km of winter and kidding habitats or mineral licks, depending on the local context or human safety considerations[2].

•Additional setbacks should be considered where the use of medium and heavy helicopters are proposed.

•Industrial scale mining activity should not occur within 1.8 km of mountain goat winter habitat.

Habituation and sensitization to disturbance:

Factors influencing whether an animal moves away from a site of human disturbance, either temporarily in the case of a fleeing response, or more permanently in the case of habitat displacement, are complex and can be influenced by a wide range of factors (Bejder et al. 2009). These factors are related to the nature of the disturbance stimuli and the quality of the site, availability of alternative suitable habitat, the perceived risk of predation and competition by individuals (Gill et al. 2001, Bejder et al. 2009). For example, wildlife may remain in an area and tolerate a high level of disturbance if the benefit (e.g., access to a critical resource or habitat) is perceived to outweigh the immediate risk (e.g., use of road-side mineral licks by mountain goats in National Parks) and the level of tolerance displayed can vary by individual, age and sex. In some instances, animals choosing to be tolerant to a known disturbance may be incorrectly described as being habituated to it (Penner 1988, Côté 2013). Similarly, an animal may not immediately flee following disturbance if the energetic costs of moving are exceedingly high, or if the animal is already occupying the safest or most suitable terrain accessible. In instances where an animal does not demonstrate an overt disturbance response, the individual may still experience a negative impact, either due to physiological stress response (often only detectable via laboratory analyses; sensu Dulude-de Broin et al. 2019, 2020), or a behavioral response that does not involve fleeing (i.e. increased vigilance and less foraging). An animal is considered habituated if its response to disturbance (both behaviorally and physiologically) decreases with increasing exposure to the disturbance stimuli. Conversely, an animal becomes sensitized to disturbance when its stress response increases with repeated exposure; the opposite of a habituation or tolerance response (Frid and Dill 2002). In practice, true habituation of wildlife to disturbance stimuli is uncommon and may not occur if stimuli are sufficiently strong (Bleich et al. 1994, Steidl and Anthony 2000, Frid 2003). Further, animals are less likely to habituate to irregular and/or unpredictable disturbances (Bergerud 1978, Risenhoover and Bailey 1982, Penner 1988).

Recent analyses of long-term data collected at Caw Ridge, Alberta, demonstrated limited evidence of habituation of mountain goats to helicopter disturbance over a 15-year period of regular overflights (Côté 1996, Côté et al. 2013). Similarly, Cadsand (2012) found that the likelihood of a mountain goat fleeing in response to helicopter activity was not affected by that individual's cumulative disturbance history. Frid (2003) found that the proportion of Dall's sheep fleeing did not decrease with the number of cumulative weeks of disturbance. In contrast, Goldstein et al. (2005) reported that mountain goats in the study site with greatest prior exposure to helicopters seemed to have the most tolerance to helicopters, relative to less impacted sites; yet the authors indicated that disturbance responses were potentially confounded by terrain characteristics. For example, abundant steep terrain and proximity to escape terrain may have influenced responses by limiting the distance mountain goats could, or needed to, run following disturbance (Goldstein et al. 2005). Thus, comparison between areas, as a means of assessing habituation, resulted in limited inference due to presumed differences in landscape composition among sites. Existing literature suggests that mountain goat responses to commercial activities and helicopter disturbances are complex and likely alter risk/reward trade-offs associated with fitness-linked behavioral decisions thereby reducing benefits; apparent tolerance of disturbance does not mean that negative effects are absent.

Recommendation - Habituation and sensitization:

•Habituation of mountain goats to helicopter or other disturbance should not be assumed to occur over time. Existing scientific evidence, including data from a long-term study indicates that mountain goats do not habituate to helicopter overflights.

•Recognize that disturbance alters risk: reward trade-offs associated with fitness-linked behavioral decisions and may have negative effects. In some instances, effects may not be overtly visible.

•Recognize the possibility that exposure to disturbance stimuli may result in heightened sensitivity to disturbance and that the degree of sensitivity can increase with the frequency of exposure to the disturbance.

[1]'Light' helicopters include, but are not limited to: Hughes 500, Bell 206, A-Star AS350. 'Medium' helicopters include Bell 212 and Kamov Ka-32A. 'Heavy' helicopters include Sikorsky Sky Crane CH-54, Boeing Vertol, Boeing 234 Chinook.

[2]In some jurisdictions, a 400-600 m vertical buffer is considered in cases where avoidance of habitat is not possible due to weather or other human safety considerations (i.e. British Columba Ministry of the Environment 2010).

Other motorized and non-motorized recreational activities:

Projected increases in both motorized and non-motorized recreational disturbance creates concerns about the effect on wildlife and their habitats (Wisdom et al. 2004, Ciuti et al. 2012, Harris et al. 2012, Courtemanch 2014, Crisfield et al. 2018, Wisdom et al. 2018). Off-highway vehicles, including single operator all-terrain vehicles and over-snow vehicles (e.g., snowmobiles, snowcats, snowbikes) are increasingly popular for recreational access into backcountry areas, with numbers of recreational users in the US projected to increase to 62–75 million participants by 2060 (Bowker et al. 2012). Mechanical innovations, such as tracked modifications to stock vehicles and greater engine horsepower have expanded the capability of off-road machines and their use into mountain goat habitats (BVORS 2011, St-Louis et al. 2013). Recreational activity is largely unregulated and management/mitigation strategies are often limited or lacking (Flood 2005). Research has documented adverse effects of off-highway use on movement and/or habitat use across a range of ungulate species including moose (Colescott and Gillingham 1998), elk/red deer (Wisdom et al. 2018, Ciuti et al. 2012), caribou (Seip et al. 2007) and thinhorn sheep (Freeman 2018). Physiological stress responses to all-terrain vehicles has also been documented in elk (Creel et al. 2002). Specific to mountain goats, research documented all-terrain vehicle use resulted in moderate-significant spatial displacement and reduction in foraging of mountain goats 44% of the time (St-Louis et al. 2013). Negative responses were greater when vehicles approached at higher speeds and directly towards animals (St-Louis et al. 2013). Similar to helicopter-disturbance studies, approach trajectories and distance-specific responses of mountain goats to all-terrain vehicle disturbance also occur, but more research is needed to identify appropriate buffer distance guidelines.

Recommendation - Other recreational activities:

- **Recreational activity should be regulated near important seasonal wintering and kidding habitats, and near mineral licks.**

- **Regulation of off-highway vehicles and recreational activity should include seasonal timing of use, proximity to important habitat, speed and approach vectors.**

Monitoring and regulatory enforcement of disturbance activities:

Monitoring the spatial distribution, intensity, and frequency of disturbance is critical for assessing effects of activities on mountain goats and for ensuring regulations are effective and followed (B.C. Ministry of Environment 2010). Comprehensive, long-term land use, resource management and project-specific activity plans, are important policy tools ensuring proposed management actions characterize impacts to mountain goats and include adaptive management mitigations. Planning incorporates strategies and mitigation measures to protect important mountain goat habitats yet still allow commercial and recreational activities to occur, where appropriate. Effective plans address disturbance effects on wildlife, both short and long-term. Enforcement of terms and conditions of permitted commercial activities is important to ensure operating plans are effective. Monitoring and enforcement policies should be data-based and consistent across jurisdictions to ensure social acceptance and provide a predictable economic and regulatory environment for commercial and recreational entities.

Recommendation - Monitoring and regulatory enforcement of disturbance activities:

- **Permitting policy should be based on scientific data and analysis, and consistent with other jurisdictions/agencies, to the extent possible. Consistent regulatory frameworks aid in acceptance among diverse stakeholders.**

- **Monitoring should include compliance monitoring and evaluation of the effectiveness of mitigation strategies. Baseline environmental reviews should be conducted to inform local mitigation approaches as part of permitting processes. Use of permitting fees to fund monitoring and review activities can be an effective and appropriate mechanism for ensuring data collection and analyses occur over the long-term.**

- **Commercial use permits should include provisions to address cases of non-compliance. Provisions should be included to modify permitted areas or conditions, based on new information.**

- **Disturbance activities (i.e., helicopter flight activity/landings, ski run boundaries/use, commercial development activity/infrastructure) should be spatially referenced (recommended resolution = 100 m) and quantified. Monitoring and data collection is most effective when occurring at the scale of mountain goat management (i.e., population or sub-population scale).**

- **Establishment of management control areas, in which commercial and recreational activity is not permitted, is important to enable interpretation of changes in populations, trends and assign changes to the activity vs. other factors.**

Monitoring mountain goat populations:
Monitoring mountain goat population dynamics and distribution is important for understanding how populations respond to anthropogenic changes. This knowledge is critical for informing land-management decisions and devising conservation strategies which can, at times, involve significant trade-offs in economic return. Despite the inherent difficulty of collecting field data on mountain goats, rigorous techniques have been developed for gathering scientifically defensible population data needed for monitoring populations. Collection of data in a rigorous sampling design framework, including control-treatment designs when possible, that directly feeds into decision-making frameworks, including adaptive management systems, can help ensure scientific understanding and social acceptance of outcomes. Programs may be technical to implement but are considered critical preconditions when anthropogenic manipulations of mountain landscapes are proposed.

Recommendation - Monitoring mountain goat populations:
•Monitoring and assessment of mountain goat demography, including population abundance, composition and distribution, at appropriate spatial and temporal scales is critical and represents an important pre-condition for all permitted disturbance-related activities.

•Rigorous sampling designs, including monitoring areas pre- and post-activity with spatial control areas when possible, should be implemented. Monitoring programs should also include collecting relevant ecological covariate data to improve inference and ensure assessment of disturbance effects are not confounded by other factors.

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Appendix: Information Needs and Research Gaps

Management/Monitoring:

Currently, there is little information available to track the location and intensity of human activities in or near mountain goat habitats. Helicopter activity in particular is poorly monitored because it does not leave physical evidence. The following management and monitoring approaches are recommended:

•Spatially-referenced GPS flight track, landing site and area use information associated with commercial helicopter activities is needed to ensure compliance with permit requirements (as applicable) and quantify disturbance activities (i.e. necessary for monitoring disturbance effects on mountain goat populations).

•Geographical Information System (GIS) analyses (currently in development; S. Gordon, pers. comm.) are needed to enable analysis of incursions into pre-identified exclusion zones (where these have been defined) and assessment of relative differences in disturbance activity among areas. Such analyses would aid an understanding of flight safety-necessitated incursions, localized compliance and determination of mountain goat disturbance response thresholds.

•Compilation of a database detailing management strategies and responses across jurisdictions would provide a basis for ensuring range-wide policy is science-based and consistent, to the extent possible.

•Development of policy that fosters data sharing between operators and local biologists to aid in development of effective mitigation strategies needed to reduce risk of potential disturbance to mountain goats (sensu Wilson et al. 2011).

•Development of decision-making frameworks, or risk matrices, that are explicitly parameterized using ecological and socioeconomic data is needed to provide an improved means for implementing policy decisions that are scientifically defensible and socially acceptable.

Research:

•Long-term population monitoring in an experimental framework focused on assessing impacts of disturbance intensity on population dynamics would enable greater understanding of population-level responses to disturbance activities.

•Collection of broad-scale population and demographic monitoring data (i.e. province/state-wide) is important for establishing regional baseline population conditions, and aid in detection of whether disturbance related effects are occurring in affected mountain goat populations.

•Additional studies on movement responses to disturbance under different intensities of disturbance and temporal scales (sensu Cadsand 2012) would provide a more comprehensive understanding of how disturbance influences movement behavior.

•Study of the effect of different helicopter types (light, medium, heavy) on mountain goat disturbance responses, including how orientation (above, level, below) and local topography (terrain masking/amplification) influence responses.

•Studies on the effects of snowmobiles, all-terrain vehicles and non-motorized backcountry recreational activities such as mountain biking, hiking and skiing (sensu Courtemanch 2014) on mountain goats would fill existing knowledge gaps and provide effective guidance for managing these activities in mountain goat habitat.

•Future studies focused on relationships among disturbance and endocrinology, immune function, gut microbiome, and the extent to which they are ultimately linked to population performance (sensu Downs et al. 2018), would improve our understanding of disturbance responses that are not easily detected through direct observation.

•Research on climate effects to assess shifting baselines (i.e. plant phenology, thermal stress, etc.) and possible interactive effects on disturbance. Such studies would advance our understanding of bottom-up effects on mountain goats and provide important ecological context for observed population-level changes, particularly as they relate to disturbance responses in the context of cumulative effects.

Appendix, Table 1. Summary of recommendations and additional standards and guidance for effective management of commercial and recreational disturbance in mountain goat habitat.

Mitigation Guideline	Recommendation	Additional Standards/Guidance
Habitat exclusion	-Avoid important seasonal habitats, especially during winter and kidding seasons, and mineral licks. -Delineate important habitat using best available data and analytical techniques.	-Habitats used by nursery groups are key for population persistence and should be prioritized in management/mitigation strategies. -Include provisions to support inclusion of new habitat and use information as well as adaptive management approaches. -Most effective to delineate habitat prior to permitting/management of disturbance activities
Distance from important seasonal habitats	-Commercial or recreational disturbance activity, including use of light helicopters, should not occur within 1.5–2.0 km of winter and kidding habitats, or mineral licks, depending on the local context. -Industrial-scale mining activity should not occur within 1.8 km of important winter range	-Greater separation distances should be considered when medium and heavy helicopters are used[1]. -Approach vectors and surrounding topography should be considered.
Timing of disturbance activities	-Avoid critical periods during the mountain goat life cycle: winter (Nov 1–Apr 30), kidding (May 1–July 15), mineral licks (May 1–Aug 31).	-Critical periods can vary geographically, and timing windows should be adjusted based on local data.
Habituation/sensitization	-Recognize that habituation of mountain goats to helicopter or other disturbance should not be assumed.	-Disturbance alters fitness. If apparent tolerance of disturbance occurs, it does not infer effects are absent (physiological stress responses are often not visible). -Exposure to disturbance, especially if intense or chronic, may result in heightened sensitivity to disturbance.

Appendix, Table 1 (continued). Summary of recommendations and additional standards and guidance for effective management of commercial and recreational disturbance in mountain goat habitat.

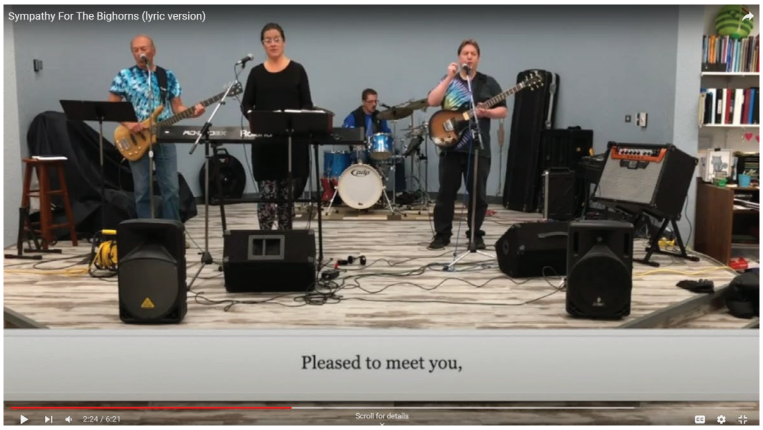
Mitigation Guideline	Recommendation	Additional Standards/Guidance
Other motorized and non-motorized recreational activities	-Recreational activity should be regulated near important seasonal wintering and kidding habitats, and near mineral licks.	-Regulation of off-highway vehicles and recreational activity should include seasonal timing of use, proximity to important habitat, speed and approach vectors.
Monitoring: Policy	-Permitting policy should be based on scientific data and analysis, and consistent with other jurisdictions, to the extent possible.	-Consistent regulatory frameworks aid in acceptance among diverse stakeholders.
	-Monitoring should include compliance and evaluation of the effectiveness of mitigation strategies.	-Investment into pre-permitting baseline environmental reviews should directly inform local permitting mitigation.
	-Commercial use permits should include enforceable provisions to address cases of non-compliance.	-Provisions should be included to modify permitted areas or conditions based on new information.
	-Disturbance activities should be spatially referenced and quantified (i.e. number of landings, flight paths, area use boundaries, etc.)	-Monitoring should occur at the scale of management (i.e., population or sub-population scale).
Monitoring: Mountain goat populations	-Long-term monitoring of mountain goat population abundance, composition and distribution at the appropriate scale should be a precondition of all permitted disturbance-related activities.	-Rigorous sampling designs, including treatment-control areas and collection of relevant ecological covariate data, should be used to appropriately interpret factors driving population changes.

[1] 'Light' helicopters include, but are not limited to: Hughes 500, Bell 206, A-Star AS350. 'Medium' helicopters include Bell 212 and Kamov Ka-32A. 'Heavy' helicopters include Sikorsky Sky Crane CH-54, Boeing Vertol, Boeing 234 Chinook.

VIRTUAL SOCIAL

As the 2020 proceedings took place virtually due to COVID-19 restrictions, the committee wondered how best to keep the social aspect of the conference alive. Kirby Smith took on the task of arranging a virtual entertainment session. As it happens, some contributors of these proceedings are very clever musicians! Thanks to Doug McWhirter, Kirby Smith and Wayne Heimer for sharing their talents with an audience from Wyoming to Alaska.

"Wayne and the Dalls"



"Sympathy for the Bighorn"

The following page is an excerpt from the virtual entertainment, written by Kirby Smith and illustrated by Kathreen Ruckstuhl and Jon Jorgenson.

SYMPATHY FOR THE BIGHORNS (Rolling Stones)

Lyrics by Kirby Smith

Ewe – Lamb – Ram – Oh – Oh

Please allow me to introduce myself; I'm a disease of stealth and haste.
I've been around for a long, long year; I may be the biggest problem you'll ever face
I was round when the settlers all, brought sheep to the western states
Made damn sure that domestics met bighorns, which often sealed their fate.

Chorus
Pleased to meet you, hope you guess my name,
But what's puzzling you, is the nature of my game

I stuck around Hell's Canyon – when they thought it was a time for a change.
Killed the reintroductions and residents too – Idaho and Oregon screamed in vain.
I broke the bank – pulled management rank
While the die-offs raged – and the bodies stank.

Chorus

I watched with glee – while Canadians too,
Fought for five decades – against a problem we made.
I shouted out – who killed the bighorn lambs
When after all – it was you and me.
Let me please introduce myself, I'm a disease of
stealth and haste.
And I laid traps for many herds, well before they even reached K.

Chorus (get down Barrie) – LEAD – Chorus

Just as every disease – is a criminal, and all the remedies saints
As heads is tails – just call me M. Ovi – cause I'm in need of some restraint.
So if you meet me, have some vigilance, have some sympathy and some haste.
Try your best to maintain separation - or I'll lay your herd to waste.

Chorus

Tell me Tom, what's my name - Tell me Helen, can ya guess my game
Tell me Francis, what's my name – Tell me Peri, what's my game
Tell me Kezia, what's my name – Tell me Doug, what's my game
Tell me Anne, what's my name - Tell me Jane, what's my game
Tell me Mark, what's my name - I tell you one time, I'm a virulent strain.

Bighorn sheep (*Ovis candensis*) disease management in Wyoming

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WILLIAM H. EDWARDS, Wyoming Game and Fish Department, Laramie, WY
PEACH VAN WICK, Wyoming Game and Fish Department, Wheatland, WY

ABSTRACT: Like most jurisdictions at the turn of the 20th century, Wyoming's bighorn sheep suffered from unregulated take, forage competition with livestock, loss of habitat, and the introduction of novel pathogens. Although regulated hunting and translocations into historic habitats substantially increased numbers by the end of the 20th century, impacts from disease persist and statewide populations are currently lower than they have been in several decades. Recent statewide disease surveillance efforts have greatly increased understanding of respiratory pathogens, while a statewide collaborative group and the actions of numerous non-governmental organizations (NGO's) and federal land management agencies have dramatically reduced the risk of pathogen introduction from domestic sheep to high-priority, core-native herds. Other specific management actions, including removal of wandering bighorns, feral livestock, and non-native mountain goats have also reduced pathogen transmission risk in specific situations. Ongoing research efforts are focused on how respiratory pathogens, habitat, and ewe body condition influence lamb survival. Disease prevention and management in bighorn sheep requires consistent collaboration and coordination among various agencies, entities, private landowners and other stakeholders.

Biennial Symposium of Northern Wild Sheep and Goat Council 22:1-12; 2020

KEY WORDS: bighorn sheep, disease, domestic sheep, respiratory pathogens, Wyoming

INTRODUCTION

Distribution 1865 to 2020

At one time, the distribution of bighorn sheep in Wyoming spanned all of the mountainous habitats in the state, but also included badland, and riverine/prairie bluff habitats. Although depicted at a large scale, the map produced by Seton (1929) is a relatively accurate portrayal of pre-settlement distribution (Figure 1).

Sheep did not escape direct mortality from settlers and market hunters, and shortly after the turn of the 20th century bighorns associated with the badland and riverine bluff habitats were the first to be extirpated, along with some of the more isolated, lower elevation mountain ranges. The next distribution map produced in 1942 revealed the occurrence of bighorn sheep was restricted to the Absaroka, Wind River, Gros Ventre, Teton, and Wyoming Ranges of northwest Wyoming, and a small reintroduced population in the Bighorn Mountains (Figure 1). Forty years later Buechner (1960) found essentially the same distribution (Figure 1).

Aside from the first in-state translocation (in 1934) mentioned above, reintroduction efforts began in earnest in 1949, using the Whiskey Mountain herd as a source population. Between 1949 and 2018, a total of 1,654 bighorn sheep were translocated within Wyoming, and another 144 were brought into the state from other jurisdictions (Wild Sheep Working Group, 2015). These efforts included attempts to restore sheep to all of their former mountain range habitats, but did not include previously occupied badland and river bluff habitats. Success was variable, but by 2020 the distribution of bighorn sheep was expanded substantially, however did not rival presettlement distribution or abundance (Figure 1).

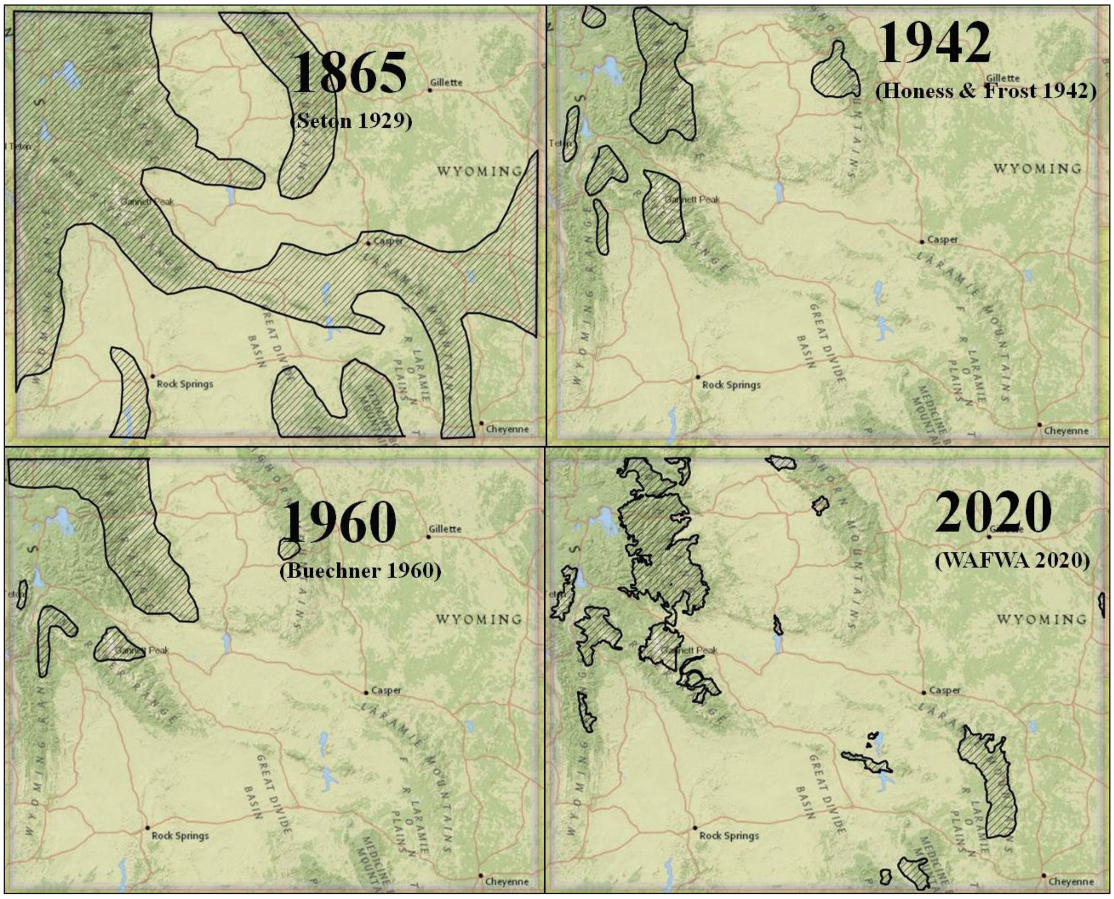

Figure 1. Distribution of bighorn sheep in Wyoming, 1865-2020.

Population Trends

It is hard to know how many bighorn sheep resided in Wyoming prior to European settlement, but it was likely in the tens of thousands. The earliest estimates of sheep numbers in Wyoming at the turn of the 20th century ranged from "a few hundred" to approximately 1,000 (Nowlin, 1904, Nowlin, 1910). In 1942 an estimated 2,500 sheep inhabited Wyoming (Honess and Frost, 1942), and by 1960 that estimate was 2,000 sheep (Buechner, 1960). The 1,798 sheep released into new habitats throughout Wyoming from 1949 to 2018 resulted in the establishment of new populations, although several experienced initial growth followed by precipitous declines and eventually stabilizing, with some becoming totally extirpated (Wild Sheep Working Group, 2015). These translocations, accompanied by the recovery and growth of the large Core-Native herds in the Absaroka and Wind River Mountains brought sheep numbers to a recent high of over 7,300 sheep by the early 1990s. Population declines in these same large Core-Native herds occurred in 1991 (Wind River Mountains) and 2011 (Absaroka Mountains), to where there are an estimated 6,300 bighorn sheep in Wyoming today. Hunter numbers and ram harvest approximate this trend in abundance through time (Figure 2).

Detection of Disease Events

Due to the vastness of bighorn sheep ranges and the widespread distribution of sheep exhibiting a diversity of migratory behaviors (Lowrey *et al.* 2019), detection of disease events can be challenging. The Absaroka Mountains alone contain almost 2,000,000 acres (3,030 mi^2) of occupied bighorn sheep habitat, and perhaps as many as 4,700 sheep. Monetary and logistical

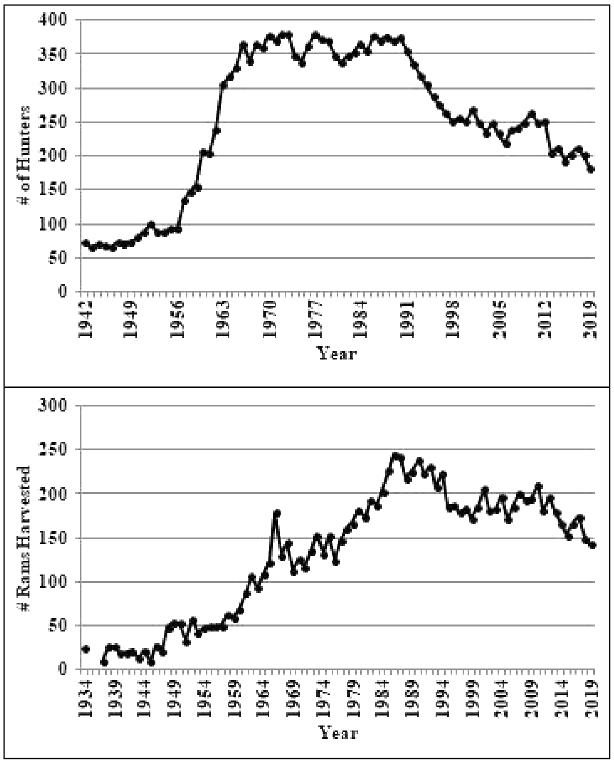

Figure 2. Hunter numbers and ram harvest in Wyoming, 1942-2019.

constraints make surveying such an area difficult, and disease events could be occurring in subpopulations that are rarely monitored.

One valuable avenue to detect mortality events are pick-up heads. In Wyoming, the horns of dead bighorn sheep are allowed to be picked up (hence the name), although they must be registered at a Wyoming Game and Fish Department Regional Office within 15 days of their discovery (Wyoming Statute 23-3-117). As a result, mortality events can be detected when unusually high numbers of pickup heads are found. Figure 3 shows evidence of the all-age pneumonia die off in the Whiskey Mountain herd in 1991 and a similar event in the Jackson herd in 2001. Pick-up head registrations in the Absaroka herd represent a general population increase from in 1977 (when registration became mandatory), a mortality event in 1995 that affected a portion of the herd, and recovery before another more widespread mortality event in 2011. These mortality events were triggered by unusually severe winter conditions but likely may have included a disease component as well.

Disease Surveillance

In an attempt to understand pathogen communities in bighorn sheep herds across Wyoming, a statewide disease surveillance effort was initiated in 2011 and over the course of ten years sheep from every herd in Wyoming were captured and sampled. Due to sympatric populations of mountain goats in specific bighorn sheep herds, mountain goats were sampled also. This resulted in the capture of 976 bighorn sheep from 12 herds and 64 mountain goats from two herds. Sampling methodology for this surveillance

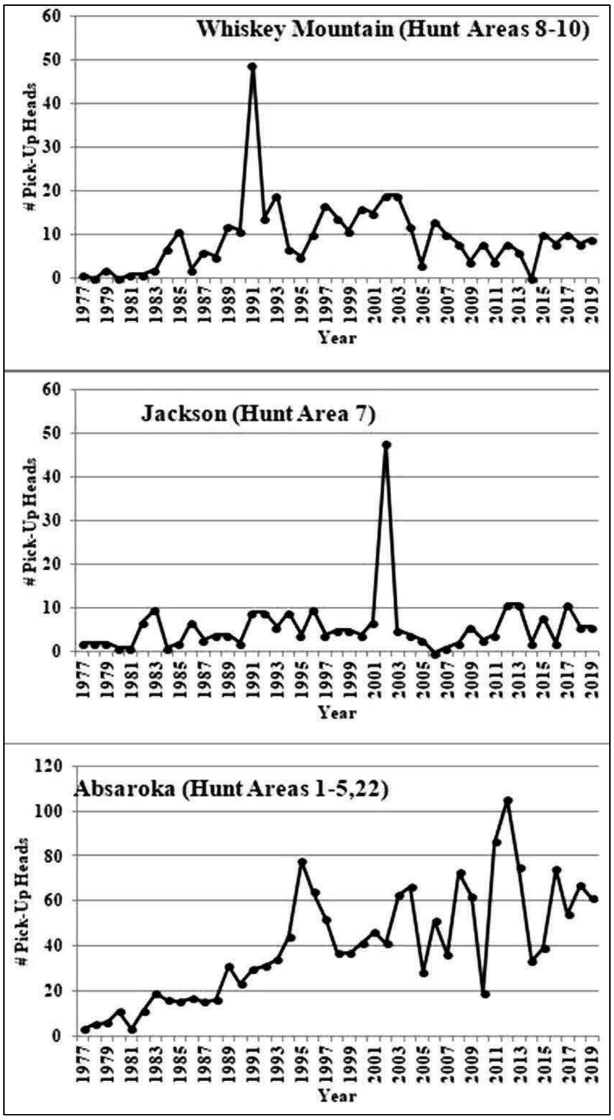

Figure 3. Registered bighorn sheep pick-up heads from the Whiskey Mountain, Jackson, and Absaroka herd units, 1977-2019.

effort is discussed in detail in Butler *et al.* (2018), but included collection of nasal and tonsil swabs, blood, ear swabs, and fecal samples.

Findings from this work documented the presence of concerning pathogens in most populations of both sheep and mountain goats. *Mycoplasma ovipneumoniae* was found in three of the four Core-Native herds in northwest Wyoming (Absaroka, Whiskey Mountain, Jackson), but not in the Targhee herd in the Teton Range (Figure 4). Absaroka, Whiskey Mountain, and Jackson herds also harbored leukotoxin positive *Bibersteinia trehalosi*. *M. ovipneumoniae* was also found in two transplant herds (Temple Peak, Laramie Peak), as well as the remnant Shell Canyon herd. Six other transplant herds (Devils Canyon, Ferris-Seminoe, Kouba Canyon, Douglas Creek, Encampment, Darby Mountain) had leukotoxin positive *Mannheimia haemolytica/M. glucosida*), leukotoxin positive *Mannheimia* species (*M. granulomatis, M. ruminalis, M. varigena*), and *Pasteurella multocida* (Figure 4). The Targhee herd, the smallest of the Core-Native herds, had the fewest pathogens which included only leukotoxin positive *Mannheimia* species (*M. granulomatis, M. ruminalis, M. varigena*) and *Pasteurella multocida* (Figure 4).

In addition to pathogen presence, the occurrence of sinus tumors was determined through incidental sampling of animals and by taxidermist collected samples. To date, samples have been collected from nine of the 12 sheep herds in Wyoming with sinus tumors documented or suspected in six (Absaroka, Whiskey Mountain, Jackson, Laramie Peak, Douglas Creek, Encampment) (Figure 5). Sinus tumors were also documented in wandering bighorn rams that were euthanized, and in a mountain goat from the Absaroka Mountains. Much is still to be learned about the origin of sinus tumors and the role they play in pathogen shedding and their contribution to the persistence of disease in bighorn sheep populations.

Research

To untangle some of the relationships among disease status, nutrition, and lamb survival, research was initiated in 2015 to evaluate how

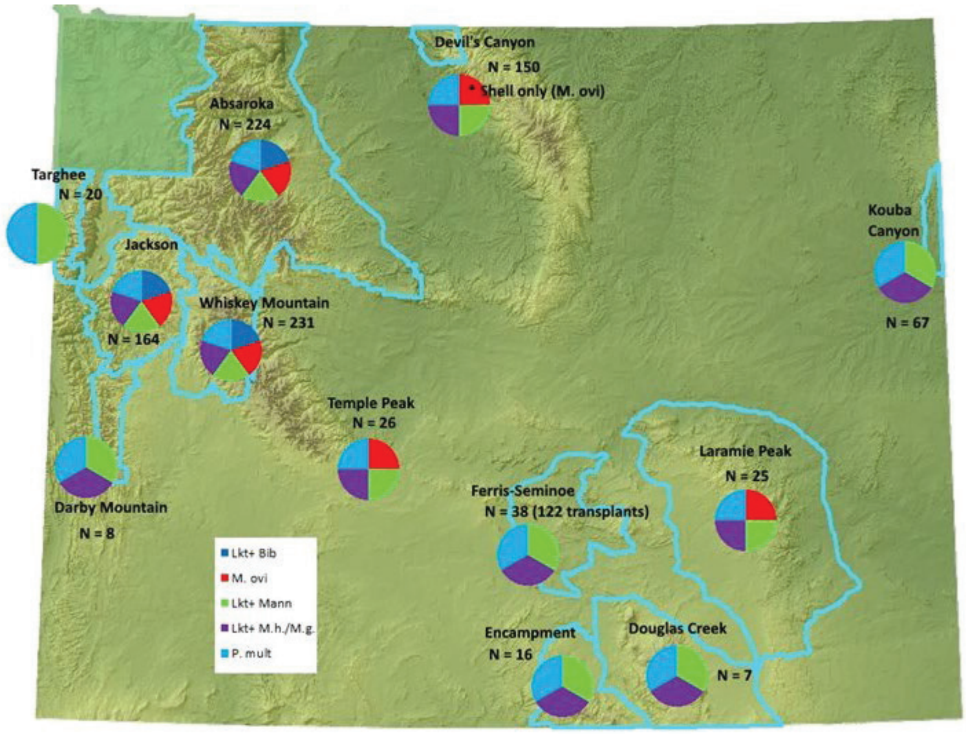

Figure 4. Distribution of bighorn sheep respiratory pathogens in Wyoming, sampled from 2011-2019.

Figure 5. Distribution of nasal tumors in Wyoming bighorn sheep, 2011-2019.

environmental and physiological factors interact with immune function to affect a ewe's susceptibility to pneumonia and how that in turn affects her ability to raise a lamb. Herds involved with this research include the Absaroka, Whiskey Mountain, and Jackson herds which all possess a full complement of respiratory pathogens but differ with respect to nutritional status and lamb recruitment.

Wyoming Bighorn Sheep-Domestic Sheep Interaction Working Group

Due to conflicts arising on public lands between bighorn sheep populations and domestic sheep grazing, then Governor Jim Geringer and Senator Craig Thomas convened a group to collaboratively develop solutions to conflicts between wild and domestic sheep. That initial meeting turned into a working group that developed a plan to address these conflicts that was eventually translated into Wyoming Statute 11-19-604 and thereby guiding these efforts.

The group was named the Wyoming Bighorn Sheep-Domestic Sheep Interaction Working Group that continues to meet over 20 years after the first gathering. A key component of the plan authored by the Group (referred to as "the Wyoming Plan") includes the stated goal of maintaining healthy bighorn sheep populations while sustaining an economically viable domestic sheep industry. Another key component are the terms of agreement that guide how this goal will be achieved. These terms of agreement are extremely important and include the following (not a complete list):

- The domestic sheep industry is important to Wyoming and should be protected; this includes protection and stability of grazing allotments and management changes only on a willing permittee basis - not under a sense of urgency or duress.
- Bighorn sheep are important to Wyoming and should be protected and enhanced in terms of numbers, health, and distribution.
- There is a need for open, non-inflammatory communication. There is a risk of disease transmission but rhetorical dialogue and

interchange among all parties on degrees of risk is not beneficial or desirable.

- Existing and/or potential conflicts between domestic and both Core-Native and transplanted bighorn sheep should not be used as surrogate issues to force or effect resource management decisions; the retirement, reduction, or removal of grazing allotments and management changes should be only on a willing permittee basis - not under a sense of urgency or duress.
- No net loss of domestic sheep industry AUMs in Wyoming is an important goal. While that may not be achievable in every given retirement, reduction, or removal of grazing allotments or management change, an honest effort to achieve that goal will be made in every case, with the economic viability of the individual permittee and the industry as the foremost concerns.

The other key component of the Wyoming Plan is the prioritization of sheep herds throughout Wyoming into three specific management areas (Figure 6). These are:

Core-Native Herds

These sheep herds occur in the Teton, Absaroka, Gros Ventre, and Wind River ranges, have never been extirpated then reestablished via transplants, and are the highest priority areas for bighorn sheep management in Wyoming. Although domestic sheep may occur within the boundaries of the Core-Native bighorn sheep herds, all efforts are made to prevent contact between bighorn and domestic sheep, as agreed to by the Statewide Bighorn/Domestic Sheep Interaction Working Group.

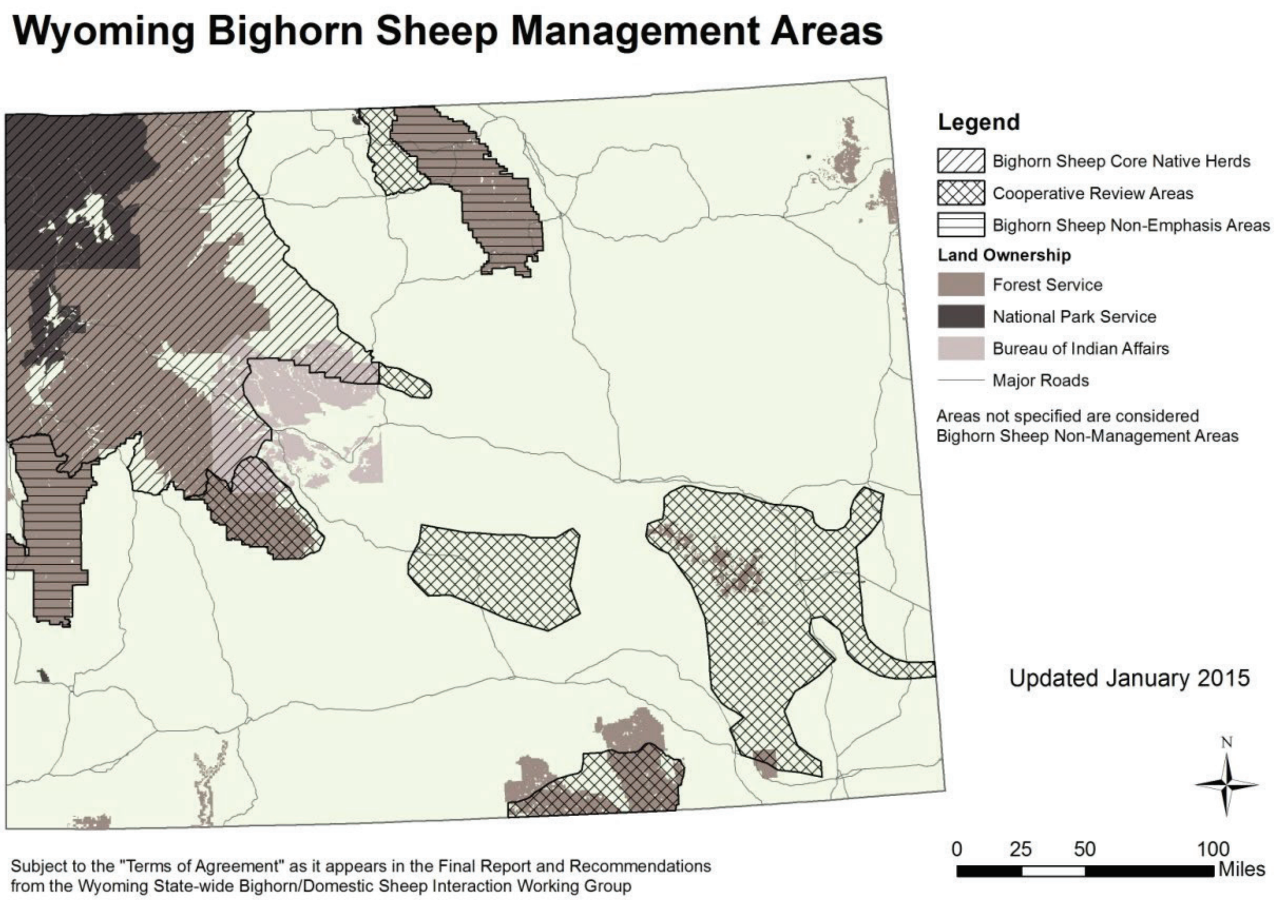

Figure 6. Bighorn sheep management areas as defined by the Wyoming Bighorn Sheep – Domestic Sheep Interaction Working Group Final Report and Wyoming Statute 11-19-604.

Cooperative Review Areas

These are the areas of suitable bighorn sheep range where proposed changes in bighorn sheep management or domestic sheep use are cooperatively evaluated and include the most suitable bighorn sheep ranges in Wyoming not addressed in the Core-Native herds, or Non-Emphasis Areas.

Bighorn Sheep Non-Emphasis Areas

These are the lowest priority areas for bighorn sheep management and include the Wyoming, Salt River, and Bighorn Mountain ranges on National Forest lands. In these areas, no effort is to be made to prioritize/emphasize bighorn sheep populations unless agreed to by the Statewide Bighorn/Domestic Sheep Interaction Working Group. Additionally, any existing bighorn sheep populations will not be protected at the expense of domestic sheep grazing.

Areas outside of these delineated areas are referred to as Non-Management Areas where bighorn sheep are permitted to occur but are not actively encouraged. Wandering bighorn sheep with known, suspected, or potential contact with domestic sheep, with likelihood of subsequent contact with established bighorn sheep populations are to be captured/removed from the wild.

Domestic Sheep Allotment Negotiations

One of the tools to minimize disease risk between domestic and wild sheep is changing management of domestic sheep grazing allotments on public land. This has involved financial compensation from non-governmental organizations to domestic sheep permittees to alter where domestic sheep are grazed. In Wyoming, these negotiations have ranged from reconfiguring allotments to shift use from higher risk allotments to lower risk allotments and conversion to other classes of livestock (usually cattle) to complete removal of domestic sheep grazing. It must be clearly understood that in following the terms of agreement in the Wyoming Plan, such negotiations will only occur with willing permittees and that where possible, should result in no net loss of domestic sheep grazing animal-unit months (AUMs).

To date, such negotiations have taken place in not only Core-Native herds but also in Cooperative Review Areas and Non-Emphasis Areas. As a result of such efforts, there are currently no domestic sheep grazing allotments in any Core-Native herds in Wyoming.

Removal of Wandering Bighorn Sheep

Since 2006, the Wyoming Game and Fish Department has had protocol direction to address known, suspected, or likely contact between bighorn sheep with domestic sheep/goats (Appendix 1). When a wandering bighorn sheep is involved, the bighorn sheep should be live-captured and transported to the Department's Tom Thorne/Beth Williams Wildlife Research Center if capacity exists there. However, any live bighorn sheep taken to the research center shall never be released back to the wild.

If the bighorn sheep cannot be live-captured, or if it is not feasible to transport the animal(s) to the aforementioned research center, it shall be lethally removed by Department personnel. Collection of samples up to and including transportation of the entire carcass to the Wildlife Health Laboratory in Laramie is encouraged if at all possible. Since disease issues of concern in these situations do not impact edible portions, carcasses may be donated for human consumption.

Designation and Removal of Feral/Stray Livestock

Per Wyoming Game and Fish Department protocol direction, where there is known, suspected, or likely contact between bighorn sheep and a wandering or stray domestic sheep/goat, the owner of the stray domestic sheep/goat should be notified and asked to remove them in order to eliminate the threat of disease transmission. It will, however, be the owner's prerogative to determine what course of action should be taken.

In the event that the owner of the stray domestic sheep/goats cannot be determined or the owner refuses to remove the domestic sheep/goats, Department employees shall work with the Director of the Wyoming Livestock Board and/or state veterinarian to declare the domestic sheep/goats feral as per Wyoming Statute 11-48-102 (Appendix 2). Under no circumstances is any Department employee allowed to lethally take any domestic sheep/goat without the written authorization of either the owner of the domestic sheep/goats or from the Director of the Wyoming Livestock Board or state veterinarian.

Expansion of non-native mountain goats

Mountain goats are not native to Wyoming (at least in historic times), but were translocated near the Wyoming border in both Montana and Idaho in the 1940s and the 1960s-70s, respectively (McWhirter, 2004). These translocation efforts succeeded and populations expanded into Wyoming establishing populations in the Beartooth Mountains and the Snake River Range. These populations are highly regarded by the Wyoming Game and Fish Department and the public and have provided hunting opportunities since 1969 in the Beartooths and 1999 in the Snake River Range.

Mountain goat populations continued to expand into adjacent areas that include the Absaroka and Teton Mountains which are both home to Core-Native bighorn sheep herds. This classification translates into a higher priority being placed on bighorn sheep. Along with pathogen transmission from mountain goats to bighorn sheep, a primary concern over expanding mountain goat populations is competition for forage and space on high altitude winter ranges, which are common in the Core-Native bighorn sheep herds of northwest Wyoming (Lowrey *et al.* 2017, 2018). Modeling efforts have shown the potential for dramatic increases in both the distribution and abundance of mountain goats within the mountainous habitats of Core-Native herds (DeVoe 2015, DeVoe *et al.* 2021).

As a result, management efforts have been implemented to eliminate or dramatically reduce mountain goat numbers or discourage them from becoming established in other high priority areas for bighorn sheep. These management efforts include increased hunting pressure under existing statutory limitations that specify certain mountain goat licenses are subject to once-in-a-lifetime issuance and adoption of a new license type in 2019 that is not subject to such limitations and allows for much more liberal seasons to be implemented.

Mountain goats have expanded into both Yellowstone and Grand Teton national parks with goat numbers increasing from 24 in 1997 to 209 by 2014 in Yellowstone, and numbers in Grand Teton increasing from 1978 when they were first documented to 2019 when the 88 mountain goats observed during annual surveys exceeded the number of bighorn sheep seen.

Although competition between the introduced mountain goats and bighorn sheep is a concern in the Absarokas, disease is less of a concern as both goats and bighorn sheep in that area already share the same potentially lethal pathogens. In addition, comparatively little of the occupied sheep and mountain goat habitat of the Absaroka Mountains is within Yellowstone National Park which means fewer sheep are potentially affected by expanding goat numbers and that hunting seasons in Wyoming can exert more of an influence over goat abundance.

The situation is different in the Teton Range because the overwhelming majority of bighorn sheep and mountain goats live within Grand Teton National Park. This means that liberal hunting seasons outside of Grand Teton National Park have relatively little influence on overall goat numbers in the Tetons, and this necessitated a very active role of the National Park Service (National Park Service, 2018). Therefore, the Park Service implemented aerial lethal removals of goats which was met with considerable opposition and was subsequently curtailed. The Park Service then instituted a skilled volunteer program that used members of the public to lethally remove mountain goats from within Grand Teton National Park. Volunteers were allowed to retrieve the meat from goats they killed, but were not allowed to keep the head, horns, or hide.

It is a delicate balancing act to accurately portray that the Wyoming Game and Fish Department values mountain goats and manages for robust populations that provide hunting and viewing opportunities in some locations but seeks to remove them or prevent their expansion in other areas where bighorn sheep are a higher priority.

CONCLUSIONS

- Bighorn sheep distribution and abundance is reduced from pre-settlement conditions.
- From lows near the turn of the 20th century, bighorn sheep numbers in Wyoming have rebounded to approximately 6,300 currently.
- Mandatory registration of dead bighorn horns found in the field allows for documentation of mortality events that may not otherwise be detected.
- Statewide disease surveillance efforts have been instrumental in understanding the occurrence and distribution of respiratory pathogens across the state.
- More work is needed to understand the role sinus tumors may play in pathogen shedding and persistence of disease in bighorn sheep populations.
- Current research is attempting to disentangle the relationships among environmental and physiological conditions and how these factors may interact with immune function and susceptibility to disease which can influence lamb survival and population dynamics of bighorn sheep.
- The Wyoming Bighorn Sheep-Domestic Sheep Interaction Working Group has been instrumental in guiding resolution to bighorn sheep and domestic sheep pathogen transmission risks.
- Wyoming Game and Fish Department protocols describes how comingling situations between bighorn sheep and domestic sheep or goats are to be addressed.
- The Feral Livestock Statute (Wyoming Statute 11-48-102) guides how feral or stray livestock deemed to be a disease transmission risk are to be handled.
- Expanding populations of non-native mountain goats into high priority bighorn sheep populations is cause for concern with regard to competition for forage and space as well as pathogen transmission risks.

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APPENDIX 1

April 15, 2013

MEMORANDUM

TO: Wildlife Division Employees
FROM: Brian Nesvik, Chief, Wildlife Division
COPY TO: File
SUBJECT: PROTOCOL FOR HANDLING THE COMMINGLING OF BIGHORN SHEEP WITH DOMESTIC SHEEP/GOATS

This memo provides additional information and direction to the April 5, 2006 memo regarding the protocol for handling the commingling of bighorn sheep with domestic sheep/goats.

Due to the threat of disease transmission and subsequent bighorn sheep die-offs when bighorn sheep commingle with domestic sheep/goats, the following protocol shall be followed.

Wandering Bighorn Sheep:

Where there is known, suspected, or likely contact between bighorn sheep with domestic sheep/goats:

- If possible, the bighorn sheep should be live-captured and transported to the Department's Tom Thorne/Beth Williams Wildlife Research Center at Sybille (Sybille). Any live bighorn sheep taken to Sybille shall not be released back to the wild.
- If the bighorn sheep cannot be live-captured, that bighorn sheep shall be lethally removed (per authority of Chapter 56) and, if possible, transported (either whole or samples) to Sybille or to the WGFD wildlife disease lab in Laramie.

Stray Domestic Sheep/Goat:

Where there is known, suspected, or likely contact by a stray domestic sheep/goat with bighorn sheep:

- The owner of the stray domestic sheep/goat should be notified and asked to remove them in order to eliminate the threat of disease transmission; however, it will be the owner's prerogative to determine what course of action should be taken.
- In the event that the owner of the stray domestic sheep/goats cannot be determined or the owner refuses to remove the domestic sheep/goats, Department employees shall work with the Director of the Wyoming Livestock Board and/or state veterinarian to declare the domestic sheep/goats feral as per Wyoming Statutes 11-48-101 and 11-48-102. Under no circumstances shall any Department employee lethally take any domestic sheep/goat without the written authorization of either the owner of the domestic sheep/goats or from the Director of the Wyoming Livestock Board or state veterinarian.

Reporting:

All documented commingling and any actions taken must be reported in a timely manner to the employee's immediate supervisor, Wildlife Division Administration as well as the Bighorn Sheep Working Group Chairman.

APPENDIX 2

FERAL LIVESTOCK

Original Senate File No. 8

AN ACT relating to feral livestock; providing definitions; providing for the identification and destruction of feral livestock; providing for reimbursement of costs of destruction and removal; and providing for an effective date.

Be It Enacted by the Legislature of the State of Wyoming:

Section 1. W.S. 11-48-101 and 11-48-102 are created to read:

CHAPTER 48

FERAL LIVESTOCK

11-48-101. Definitions.

(a) As used in this chapter:
- (i) "Board" means the Wyoming livestock board;
- (ii) "Director" means the director of the Wyoming livestock board;
- (iii) "Feral" means a domestic animal that is not under the control of nor cared for by a person and which has returned to a wild or semi-wild state;
- (iv) "Livestock" means as defined in W.S. 11-6-302(a)(vi).

187 SESSION LAWS OF WYOMING, 2009 Ch. 88

11-48-102. Destruction of feral livestock.

(a) Before any livestock can be declared feral, a reasonable attempt shall be made by the director or the state veterinarian to locate and identify the owner of the livestock and to notify the owner to take possession of the livestock.

(b) If the state veterinarian or the director are unable to identify and notify the owner of the livestock or the owner refused to take possession for the livestock within five (5) days after receiving notice, the livestock may be declared to be feral livestock.

(c) If the director or the state veterinarian determines that any feral livestock are damaging private or public property, including grass, cultivated crops or stored crops, or determines the feral livestock is on private or public property where the feral livestock are not authorized to be and that capturing the feral livestock is not feasible or is cost prohibitive, the director or the state veterinarian may order the destruction of the feral livestock.

(d) If the state veterinarian determines or suspects any feral livestock are likely to be infected with or able to spread any infectious or contagious disease, the state veterinarian may order the destruction of the feral livestock.

(e) There shall be no right for any future indemnity or payment to the owner for the destruction of any feral livestock destroyed in accordance with this section. Should the owner of any feral livestock destroyed in accordance with this section be subsequently identified, the board may seek reimbursement from the owner for all costs associated with the destruction and removal of the feral livestock.

(f) The Wyoming livestock board shall promulgate rules necessary for the administration of this section.

Section 2. This act is effective immediately upon completion of all acts necessary for a bill to become law as provided by Article 4, Section 8 of the Wyoming Constitution.

Approved March 2, 2009.

"Little Bo-Peep, please test your sheep" Managing disease risk in Alberta

ANNE HUBBS, Alberta Environment and Parks, Wildlife Management, Rocky Mountain House
MARK BALL, Alberta Environment and Parks, Wildlife Management- Disease, Edmonton

ABSTRACT: Mitigating the risk of *Mycoplasma ovipneumoniae*-associated pneumonia in bighorn sheep from domestic sheep and goats has faced significant challenges. Of particular importance has been the impending risk of disease from domestic sheep and goats that, through current legislation, are permitted to utilize areas near native bighorn range. These domestic species are known to carry *M. ovi*. There have been localized outbreaks of pneumonia in southwestern Alberta, the most recent being in 2000. In response to this ongoing risk, wildlife managers from the government of Alberta have been working closely with stakeholders and other governmental agencies to develop a comprehensive plan to protect wild sheep populations. Public education and the development of a domestic/wild sheep separation policy are key components under this mandate. Furthermore, a large scale disease surveillance program was initiated in 2017 to determine the disease status of Alberta's wild sheep populations. This program will provide baseline data that will direct adaptive disease and population management in each area. This presentation will detail the collaborative efforts in the development of bighorn sheep disease protection plan, the current state of disease surveillance, and challenges that still require attention to maintain pneumonia-free bighorn sheep in Alberta.

Biennial Symposium of Northern Wild Sheep and Goat Council 22:13; 2020

KEY WORDS: disease risk, domestics, education, *M. ovi,* pneumonia, policy, protection plan, surveillance program

Mycoplasma ovipneumoniae surveillance in Yukon wildlife

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ABSTRACT: The bacterium *Mycoplasma ovipneumoniae (M. ovi)* has been implicated in outbreaks of pneumonia in bighorn sheep in British Columbia, Canada and the western United States. In Yukon, *M. ovi* has been identified as a pathogen of potential health concern for thinhorn sheep and mountain goats, although no outbreaks of pneumonia have been detected to date. Since 2015, over 450 nasal swabs samples have been collected from harvested thinhorn sheep and mountain goats throughout Yukon and tested for *M. ovi*. Given the recent detection of *M. ovi* in caribou, moose and thinhorn sheep in Alaska, USA, over 160 caribou, moose, deer, elk and muskox samples from Yukon have also been tested for *M. ovi* since 2018. To date, *M. ovi* has not been detected in any wildlife samples. Increased surveillance efforts in wild species is occurring by providing hunters with sample kits in order to collect higher quality samples. *M. ovi* is carried by domestic sheep and goats, and contact between wild sheep or goats and domestic small ruminants is implicated in the transmission of the pathogen and initiation of outbreaks. On January 1, 2020, a control order under the *Animal Health Act* came into effect in Yukon, intended to reduce the risk of transmission of respiratory pathogens, including *M. ovi,* from domestic animals to wildlife.

Biennial Symposium of Northern Wild Sheep and Goat Council 22:14; 2020

KEY WORDS: *Mycoplasma ovipneumoniae,* bighorn sheep, mountain goats, Yukon, control order, respiratory transmission, surveillance

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The role of bighorn ewe infection status in managing pneumonia in lambs

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ABSTRACT: Spillover of the bacterium *Mycoplasma ovipneumoniae* (M. ovi) can have long-term negative demographic impacts on *bighorn sheep* (*Ovis canadensis*) populations, principally through chronically low lamb recruitment associated with pneumonia-induced mortality. Despite the devastating respiratory disease epidemics often observed in all age classes on first exposure to M. ovi, most survivors eventually clear infection. Some individuals do not however, and they can become persistent carriers. We conducted experiments in free-ranging and captive bighorn sheep to test the hypothesis that recurring pneumonia epidemics in lambs are triggered when persistent carrier dams transmit M. ovi to lamb nursery groups. We tested individual sheep repeatedly over at least two consecutive years in two captive research facilities and four free-ranging populations presenting lethal pneumonia in lambs to identify intermittent and persistent carriers of M. ovi. We then moved persistent carriers from free-ranging populations to captivity and conducted lamb survival trials in pens with and without persistent carriers. We observed no M. ovi, no respiratory disease, and increased lamb survival in populations and pens without carrier ewes, whereas high rates of lamb morbidity, M. ovi infection, and low survival were observed in populations and pens with carrier ewes. We also identified cofactors that may contribute to variation in shedding prevalence and persistence. The results of these experiments support the hypothesis that persistent carriers maintain M. ovi infection in bighorn sheep populations and are the cause of recurring pneumonia epidemics in bighorn lambs. These results have important implications for the epidemiology and management of pneumonia epidemics in wild sheep populations.

Biennial Symposium of Northern Wild Sheep and Goat Council 22:15; 2020

KEY WORDS: bighorn sheep, carriers, ewes, *Mycoplasma ovipneumoniae,* M. ovi, *Ovis canadensis*, pneumonia, recruitment, survival, shedding

A preliminary look at what drives individual and herd response to *Mycoplasma ovipneumoniae*: Integrating information from focal herds and wider-scale monitoring

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ABSTRACT: The mechanisms that generate variation in severity of *Mycoplasma ovipneumoniae*-associated pneumonia in bighorn sheep (*Ovis canadensis*) remain poorly understood. Here, we present preliminary evidence associated with several plausible factors, including age, strain type, and herd substructuring, that might help determine outbreak severity. We combine data from a captive disease event, intermediate-term monitoring of more- and less-severe events, and wider-scale statewide monitoring efforts. Our findings suggest roles for age and condition in shaping immunological dynamics, and a key role for strain type in shaping longer-term outbreak severity. Additinally, this preliminary assessment underscores some important data requirements for understanding drivers of variation in outbreak severity more fully going forward.

Biennial Symposium of Northern Wild Sheep and Goat Council 22:16; 2020

KEY WORDS: age, bighorn sheep, condition, herd substructuring, outbreak, mechanisms, *Mycoplasma ovipneumoniae, Ovis Canadensis*, pneumonia, strain type

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Mycoplasma ovipneumoniae: Mitigating the risk of transmission in Yukon

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ABSTRACT: In fall 2018, under the *Animal Health Act*, the Yukon Government announced a 5-year control order, which specifies fencing and testing requirements for farmers keeping domestic sheep or goats in Yukon. The order is intended to protect wild populations of thinhorn sheep and mountain goats from respiratory pathogens, specifically *Mycoplasma ovipneumoniae (M.ovi)*, carried by domestic small ruminants. Prior to the order coming into effect on January 1, 2020 the Yukon Government provided compensation for farmers to either depopulate herds or attain compliance with the terms of the order. We report the success of the government fencing program, summarizing the containment status of sheep and goat farms. We also report results of testing three monthly nasal swabs for *M. ovi*, including prevalence of *M. ovi* at the individual and herd level. Animals testing positive were removed from the population, and a pilot treatment trial was completed in hopes of providing an alternative to removal. We will share the treatment trial outcome and report trends observed that relate test results with herd dynamics. Annual testing and containment inspections will be ongoing and permits, with conditions, will be required to acquire sheep and goats from outside Yukon. Actions taken under the control order have increased our understanding of the biology of *Mycoplasma ovipneumoniae* in domestic herds and we expect the results from repeat testing in future years to inform control measures.

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KEY WORDS: Mycoplasma ovipneumoniae, livestock-wildlife interface, regulatory medicine, thinhorn sheep

Bighorn movement and domestic sheep presence surrounding a case of acute fatal pneumonia in a bighorn sheep

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ABSTRACT: Mortality of bighorn sheep (*Ovis Canadensis*) after contact with domestic sheep (*Ovis aries*) has been documented in controlled pen studies, and through anecdotal observations in the wild. As a result, euthanasia of bighorns in contact with domestic sheep has become a routine management strategy for controlling introduction of pathogens to bighorn herds. Information regarding bighorn behavior before, during, and after contact with domestics may help further guide management practices. While studying the movements of a bighorn meta-population, we detected an acute pneumonia fatality of a GPS telemetered bighorn after contact with a recently introduced pen containing three hobby domestic sheep, immediately adjacent to a bighorn subherd's home range. GPS data on this and other telemetered bighorn in the vicinity revealed a variety of interesting movements temporally proximate to the contact event. Respiratory disease was not identified in any of the domestic sheep by routine veterinary exam. However, nasal and tonsil swabs confirmed the presence of respiratory disease-associated pathogens in all three domestic sheep. One domestic sheep was culled and necropsied revealing chronic upper respiratory disease. Coincidentally, in the years leading up to this event, this small bighorn subherd was already trending toward extirpation due to an aging herd and near-zero recruitment, likely facilitated by chronic respiratory disease in the herd. Although various factors prevented bighorn euthanasia as a management strategy, the GPS telemetry data from this herd provides insights as to how bighorn sheep movements may be affected by the presence of domestic sheep on the landscape, leading to interspecific contacts.

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KEY WORDS: Bighorn sheep, domestic sheep, GPS collar, space use, movement, comingling, contact, Colorado, step-selection function, pneumonia

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INTRODUCTION

Respiratory disease is considered the most important limiting factor of maintaining and growing bighorn sheep (*Ovis canadensis*) populations (George *et al.* 2009, WAFWA 2017). Comingling between bighorn sheep and domestic sheep has been proven to result in fatal pneumonia in numerous experiments using captive animals (Wehausen *et al.* 2011, Subramaniam *et al.* 2011, Besser *et al.* 2014). These comingling experiments appear to be corroborated by various field accounts of wild bighorns dying after coming into contact with domestic sheep (Foreyt and Jessup 1982, Coggins 2002, George *et al.* 2008). In some cases, the wild-domestic interactions are circumstantially implicated for all-age die-off events of bighorn sheep (George *et al.* 2008, Cassaigne *et al.* 2010, Besser *et al.* 2021), causing sudden population declines. In at least two cases to date, the same bacterial genetic strain underlying a bighorn die-off event has even been found in nearby domestic caprinae flocks and is thus presumed to be the infection source (Kamath *et al.* 2019, Besser *et al.* 2021). Aside from a few published circumstantial accounts (George *et al.* 2008, Besser *et al.* 2021), detailed descriptions of natural comingling interactions between bighorn and domestic sheep leading to pathogen transfer are lacking. The ultimate source of these infection episodes are rarely, if ever, known given these transmission events are difficult to predict and presumably uncommon.

Despite a variety of controlled captive experiments that support observations from free-ranging animals, (Wehausen *et al.* 2011), it is not universally accepted by all stakeholders that wild-domestic comingling events can introduce respiratory pathogens to bighorn sheep populations. This is partially due to the inability to collect data during natural comingling events. In the rare instances when these events are detected, management practices to euthanize in-contact animals eliminate the opportunity for monitoring the interactions.

One potential source of wild-domestic comingling are small hobby flocks of domestic sheep housed in the proximity of established bighorn sheep herds. Current patterns of exurban (i.e., ranchette, high density rural) development in Western North America include the placement of homes adjacent to wildlife habitat (Riebsame *et al.* 1996), and this pattern is likely to continue with increased residential development. Exurban hobby domestic sheep are therefore a growing concern due to the risk of transferring disease from domestic to bighorn sheep (Sells *et al.* 2015, Heinse *et al.* 2016).

We provide a case study of a domestic sheep hobby flock introduced to a pen immediately adjacent to a free-ranging bighorn sheep herd, which coincided with the second year of a three-year study on bighorn sheep movements and distribution. One mature (~10 years of age) ram outfitted with a GPS satellite collar died of acute fatal bronchopneumonia ~500 m away from the occupied domestic sheep pen. The domestic sheep were removed by the owners shortly after this mortality was detected. The remaining GPS satellite collared bighorn were monitored for an additional fall season after removal of the domestic sheep.

First, a summary of pathogens detected in the bighorn and domestic sheep is provided. Next, basic descriptive proximity measures are used to test for a shift in the bighorn's space use in relation to when domestic sheep occupied the pen (treatment period) versus when the pen was vacant (control period). Then, a step-selection movement model analysis is used to test the hypothesis that wild bighorn sheep exhibit attraction to domestic sheep (comparing control and treatment periods), by accounting for the spatio-temporally dynamic movements of bighorn ewes, spatio-temporally dynamic snow cover data, and various static landscape characteristics.

Study Area

This study focuses on a subherd (Colorado Bighorn Game Management Unit: S52) of the Central San Juan bighorn sheep population (Colorado Bighorn Data Analysis Unit: RBS-22). The RBS-22 population has ranged from approximately 50 bighorn sheep in 1965 to a peak of 450 in 1989. The S52 subherd once contained ~100 individuals during RBS-22's population peak in 1989. All-age die off events in 1989 and 1993 reduced the RBS-22 population size to 150, but have since slowly rebounded to approximately 325 in 2019. Males between S52 and a neighboring (≥4 miles away) subherd of RBS-22 frequently interact. Although records are sparse (Spicer 1999), contact between domestic and bighorn sheep in summer of 1989 occurred due to a one-time "trailing" permit issued to a nearby domestic sheep grazer of federal land, is suspected to have led to the winter 1989 die-off event in RBS-22. Potentially extirpated (Spicer 1999), the S52 subherd was augmented with approximately 33 bighorns in 2001. Evidence of disease, via low lamb recruitment and pneumonia related mortalities, continued to be exhibited throughout RBS-22 since the 1989 die-off event, and the 1993 die-off event (originating in the S36 subherd of RBS-22). This study's original intent was to monitor the GPS satellite collar movements of a sample of bighorns representing the RBS-22 population over a three-year period (January 16, 2016 - February 15, 2019). Ground surveys were implemented approximately monthly, where vehicle access permitted (GMUs: S52, S-36, and S-53), to monitor lamb survival (via lamb ratios), opportunistically record group composition, and estimate abundance via mark-resight.

METHODS

Bighorn Movement Study Design

Of 40 GPS satellite collars (Vectronic-aerospace, GmbH) deployed in the RBS-22 population, three were deployed in the S52 subherd via chemical immobilization with a dart projector. Collars were programmed to collect a location every four hours. All capture and handling followed that of the Colorado Parks and Wildlife (CPW) Bighorn Capture Guidelines (IACUC protocol # 04-2007). Within S52, GPS collared ewe BH0018 was monitored 2016/01/30 through 2019/01/28, collared ram BH0015 was monitored 2016/06/03 through 2018/11/22, and collared ram BH0020 was monitored 2016/12/09 through 2018/01/25. GPS collar monitoring periods of BH0015 and BH0020 concluded with their deaths, while BH0018 concluded with detonation of the collar's timed drop-off mechanism.

Over the three-year study period, field staff were present 54 days to collect bighorn group locations, composition observations, and resight surveys in S52, of which bighorns were observed on 42 of those days. A maximum of 17 adults (12 rams and 5 ewes) were observed to be present in S52 near the start of the study (June 2016). Simple mark-resight abundance indices (Chapman and Overton) estimated 12.2, 10.1, and 4.9 bighorn in the S52 subherd for 2016, 2017, and 2018 respectively. The S52 subherd was normally divided into $\leq$3 primary social groups. Ewes (and associated lambs) were observed in a single group all but twice and sometimes as solitary individuals during the lambing season. Rams were congregated in one or two groups of 4-7 animals. Ram group social dynamics changed drastically in response to the rut period (fall and early winter) and relatively fluid with inconsistent interchange with the neighboring subherd. Evidence of individual transient bighorns (young rams and 1 yearling ewe) immigrating or foraying into S52 did exist on three survey efforts. No evidence of lambs greater than 2-3 months of age existed the first two years (2016-2017). All resident bighorn groups in S52 were assumed to be known considering a relatively small amount of suitable bighorn habitat and consistent group composition observations across survey efforts.

Using a quasi-experimental design (Butsic *et al.* 2017), we defined the treatment period as the study's second year (2017) fall and early winter, when a group of three domestic sheep (adult female, yearling female, adult male) were introduced to a small pen and remained for approximately four months (~2017/09/27 – 2018/02/07), within 300 m line of site of an area commonly used by the GPS collared bighorns. The pen's structure was physically present on site during the control period, but only occupied by the domestic sheep during the treatment period, allowing us to mask out the influence of other static landscape features on bighorn movement patterns. One GPS collared ram suffered acute fatal pneumonia after presumed infrequent interaction with the domestic sheep pen. No records exist of direct contact between bighorns and the domestic sheep, but one bighorn was documented (via photograph) at the pen's fence. Control periods were assigned as the fall and early winter of the study's first year (2016) and third year (2018) matching the Julian calendar dates of the treatment period. Exact dates of the treatment and control periods varied by individual given that one bighorn capture event occurred in mid-fall of the first year, and two of the bighorn died during the treatment period or during the control period (see exact dates of bighorn GPS collar monitoring above).

Pathogen and Disease Diagnostics

Serum samples were collected at the time of wild bighorn capture to test for presence of *Mycoplasma ovipneumoniae* antibodies (Washington Animal Disease Diagnostic Laboratory). The bighorn ram that died on January 24, 2018 remained in the field under cold conditions and was necropsied five days after death. Lung tissue was fixed in 10% neutral buffered formalin and prepared for histologic examination by paraffin embedding, sectioning at approximately 5 μm, and staining with hematoxylin and eosin. Samples were not suitable for culture, but PCR diagnostics included testing for *Pasteurellaceae* leukotoxin A gene (Fox *et al.* 2015), and *M. ovipneumoniae* (McAuliffe *et al.* 2003) of the lung and upper respiratory sinus tissues. Additional PCR and strain-typing methods were developed for this project, and results of those assays were pending at the time of submission of this paper. The domestic sheep owners agreed to relinquish one adult ram to a local veterinarian for euthanasia (Gunnison Valley Veterinary Clinic), which was then transferred immediately to the authors for necropsy and ancillary diagnostics on 2018/02/07. Lung and upper respiratory sinus tissues were submitted to the Wyoming Game and Fish Health Laboratory for aerobic culture and PCR for *Mannheimia* species, *Bibersteinia* species, *Pasteurellaceae* leukotoxin gene, and *M. ovipneumoniae*. The samples were also tested in-house at the CPW wildlife health lab for *Pasteurellaceae* leukotoxin A and *M. ovipneumoniae*. Prior to euthanasia of the domestic ram, the domestic ram and both domestic ewes were sampled by swabbing of the nasal passages and tonsil crypts. Swabs were preserved in transport media (ESwab: *COPAN Diagnostics Inc.* and BD Culture Swab*, Becton Dickinson and Company*) for bacterial culture and PCR as described above for the domestic sheep necropsy tissues (Wyoming Game and Fish Health Laboratory). Lung and upper respiratory sinus tissues from both the bighorn ram mortality and the euthanized domestic ram were submitted to the Texas A&M Veterinary Medical Diagnostic laboratory for a PCR-based respiratory pathogen screen including bovine respiratory syncytial virus, bovine viral diarrhea virus, bovine parainfluenza-3 virus, bovine herpesvirus-1, and bovine coronavirus.

Basic Proximity Analysis

For each bighorn GPS collar location, a proximity measure (Euclidean distance) was calculated with respect to the domestic sheep pen's location and the other bighorns' temporally dynamic location. Proximity was summarized by mean and median values. We used a generalized additive model (R package: 'MGCV') with a first order autoregressive correlation structure, accounting for serial dependencies in the GPS collar location data, to assess whether statistically significant differences in the proximity measure existed between the control and treatment periods. With the proximity as the response variable, a model with a factor indicating domestic sheep occupancy of the pen (experimental group), was compared using delta AIC scores to a null model without the experimental group factor.

Movement Analysis

A step-selection function based movement model (Thurfjell *et al.* 2014) was used to measure attraction of bighorns to various landscape features including the domestic sheep pen. Each bighorn sheep GPS collar location were input as "use" locations. For each ending node of a movement step, a set of 20 matched available locations were generated by projecting a set of potential step distances and turning angles from the initial node of the step. These available locations were ones that a bighorn could have chosen at the end of a step but did not for whatever reason (Thurfjell *et al.* 2014). Each matched available location was generated by drawing a random step length and turning angle from a negative binomial and wrapped normal distribution (respectively). Mu and theta parameters of the negative binomial distribution, and mu and rho parameters of the wrapped normal distribution, were derived from the observed step length and turning angle for each location. Generated step distances were restricted to be less than 20 km. Spatial environmental covariates of used (response variable = 1) and available locations (response variable = 0) were compared in a case-control design using a conditional logistic regression model (Therneau 2012). Each pair of the used corresponding available locations were assigned as stratum cases to partition variance appropriately.

A candidate set of models, based on all combinations of 28 landscape covariates found in prior studies to influence bighorn sheep habitat selection, was built to inform basic landscape use decisions, outside those potentially determined by the locations of other bighorn or domestic sheep on the landscape. This basic model included topographic variables (slope, roughness, terrain ruggedness, aspect, topographic position index, and distance to perennial stream), vegetation landcover based (grass patch, canopy cover percentage, and distance to forest edge), daily winter precipitation (snow depth and snow water equivalent), and anthropogenic covariates (Euclidean distance to nearest roofed structure, distance to nearest road). The roofed structure covariate included a shed (barn) in the middle of the domestic sheep pen, but also all other houses and other man-made buildings within the vicinity of S52. Various spatial scales and forms of the topographic covariates regarding aspect, terrain ruggedness, and topographic position, were tested. Winter precipitation metrics were available at a daily temporal resolution, where snow depth and snow water equivalent for each step's use and available location was updated accordingly. Collinear predictor variables were screened with a Pearson correlation coefficient threshold of 0.6. Model selection was then used to choose the most parsimonious candidate models (Burnam and Anderson 2002) to create a baseline bighorn movement selection model that disregards bighorn selection with respect to the domestic sheep pen's location or other bighorns. Data for all three bighorns were consolidated in this model.

In a second iteration of model construction, the proximity (Euclidean distance) to the domestic sheep pen was included as a covariate. This model was run separately for each of the three collared bighorns and the two experimental groupings to allow comparison of avoidance/attraction coefficients across individuals and to contrast the treatment period to the control period within each individual. The conditional logistic regression beta coefficient estimates (+/- 95% confidence intervals) for domestic pen proximity were extracted for the control and treatment periods. Inverse of coefficient estimates were displayed to ensure that positive coefficients indicate attraction to the domestic sheep pen, while negative coefficients indicate avoidance of the domestic sheep pen. Coefficient estimates near zero (approximately -0.2 to 0.2) with confidence intervals overlapping zero indicated ambivalence to the domestic sheep pen.

In a third iteration of the model, the proximity of the collared bighorn rams to each other, on a movement step-by-step basis, were added as covariates to the baseline model. Beta coefficient estimates for these paired bighorn proximity metrics were extracted and examined similarly to the domestic sheep pen coefficients for each bighorn and experimental grouping.

RESULTS

Pathogen and Disease Diagnostics

Results of the respiratory diagnostics conducted on eight of the estimated 12 resident bighorns known to exist in S52 during the study, and all three domestic sheep inhabiting the pen, are shown in Table 1. Four of the eight bighorns showed evidence of exposure to *M. ovipneumoniae* based on serology, or active infections with *Mycoplasma ovipneumoniae* based on PCR diagnostics. Three of the eight bighorns were PCR positive for *Pasteurellaceae* leukotoxin A in lung and sinus lining tissues. The collared bighorn ram (BH0020) that died near the domestic sheep pen was determined to have acute bronchopneumonia via gross pathology and histopathology, and confirmed to have *Pasteurellaceae* leukotoxin A and *M. ovipneumoniae* present in sinus lining and lung tissues via PCR. BH0020 serology was also positive for *M. ovipneumoniae* antibodies when captured approximately one year earlier.

Necropsy examination of the adult domestic ram showed abundant fat stores, an overall body condition within normal limits, and evidence of chronic respiratory disease including chronic sinusitis of the nasal and ethmoid turbinates, and mild chronic tracheitis. PCR of cultured swabs (nasal and tonsil swabs) from the domestic sheep verified hemolytic *Bibersteinia trehalosi, Mannheimia hemolytica, Pasteurella multocida, Pasteuellaceae* leukotoxin A, and *Mycoplasma ovipneumoniae.* Overall, different sample sources within and among the three domestic sheep revealed slightly differing bacteriology results.

Table 1. Respiratory pathogens detected in S52 during the study for wild bighorn sheep and domestic sheep.

Species	Animal ID	Date	Source	Method	Respiratory Pathogens/Diagnostic
Wild Bighorn	BH0018 (collared ewe)	2016/01/30	Serum	Antibody	Not detected
	BH16_225 (unmarked ram)	2016/02/11	Whole carcass	Gross- and histo-pathology	Not detected
			Serum	Antibody	*M. ovipneumoniae*
	BH17_089 (unmarked ewe)	2017/01/16	Sinus lining	PCR	Not detected
	BH18_235 (unmarked ram)	2017/05/27	Lung	PCR	Not detected
			Sinus lining	PCR	Not detected
	BH0020 (collared ram – disease related mortality)	2016/12/09	Serum	Antibody	*M. ovipneumoniae* positive
		2018/01/29	Whole carcass	Gross- and histo-pathology	Acute bacterial bronchopneumonia
		2018/01/29	Lung	PCR	*Pasteurellaceae* leukotoxin A, *M. ovipneumoniae*
		2018/01/29	Sinus lining	PCR	*Pasteurellaceae* leukotoxin A, *M. ovipneumoniae*
Domestic Sheep	DS18_219 (adult ram)	2018/02/07	Whole carcass	Gross- and histo-pathology	Chronic sinusitis
			Lung	PCR	Hemolytic *B. Trehalosi, Mannheimia hemolytica, P. multocida*
			Sinus lining	PCR	*Pasteurellaceae* leukotoxin A*, Mannheimia hemolytica, P. multocida, M. ovipneumoniae*
			Tonsil swab	PCR & culture	Hemolytic *B. Trehalosi, Mannhaeimia hemolytica, P. multocida*
			Nasal swab	PCR & culture	*Mannhaimia hemolytica, Bibersteinia trehalose, P. multocida, M. ovipneumoniae*
	DS18_220 (yearling ewe)	2018/02/07	Nasal swab	PCR & culture	*M. ovipneumoniae*
			Tonsil swab	PCR & culture	*Pasteurellaceae* leukotoxin A, *Bibersteinia trehalosi*
	DS18_221 (adult ewe)	2018/02/07	Nasal swab	PCR & culture	Not detected
			Tonsil swab	PCR & culture	*Pasteurellaceae* leukotoxin A, *Mannheimia hemolytica, Mannheimia glucosida*
Wild Bighorn	BH18_635 (unmarked ram)	2018/04/14	Whole carcass	Gross- and histo-pathology	Not detected
			Lung	PCR	Not detected
			Sinus lining	PCR	Not detected
	BH18_663 (unmarked ewe – disease related euthanasia)	2018/05/14	Whole carcass	Gross- and histo-pathology	Chronic bronchopneumonia
			Lung	PCR	*Pasteurellaceae* leukotoxin A, *M. ovipneumoniae*
			Sinus lining	PCR	*Pasteurellaceae* leukotoxin A, *M. ovipneumoniae, Mannheimia* w/leukotoxin
			Nasal swab	PCR	*M. ovipneumoniae*
	BH0015 (collared ram)	2018/11/22	Whole carcass	Gross- and histo-pathology	Not detected
			Lung	PCR	*Pasteurellaceae* leukotoxin A
			Sinus lining	PCR	*Pasteurellaceae* leukotoxin A

However, we detected *P. multocida* and *M. hemolytica* in all samples from this ram. Results from a PCR-based respiratory virology panel did not indicate presence of bovine respiratory syncytial virus, bovine viral diarrhea virus, bovine parainfluenza-3 virus, bovine herpesvirus-1, or bovine coronavirus.

Basic Proximity Analysis

Mean and median proximity measures for each bighorn and experimental group with respect to the domestic sheep pen are shown in Table 2. Proximity to the pen significantly differed between the control and treatment periods for ram BH0015, ram BH0020, and ewe BH0018 based on delta AIC scores comparing a model with the experimental group variable to a null model without (Table 2). During the treatment period, the two collared rams were usually closer to the pen, while BH0018 appeared to be usually further from the pen. Including the experimental grouping variable into the statistical model explaining proximity to the pen greatly improved model parsimony (ΔAIC) for BH0018 and BH0020: BH0018 was significantly further from the pen and BH0020 was statistically significantly closer to the pen when domestic sheep were occupying it during the treatment period. However, the change in proximity was much less explainable by the experimental grouping for BH0015 due to only minor improvement (ΔAIC = 3.4) of AIC change over the null model.

Mean and median proximity measures among the unique bighorn sheep pairings by experimental group are shown in Table 3. Proximity between bighorns significantly differed between the control and treatment periods for all three pairings based on delta AIC scores comparing a model with the experimental group variable to a null model without (Table 3). During the treatment period, bighorn rams were a median 2.52 (BH0015) and 1.89 (BH0020) times further away from bighorn ewe BH0018, than during the control period (Table 3)."

Movement Analysis

The most parsimonious bighorn movement step-selection model was informed by a combination of four topographic covariates (southeastern aspects, terrain ruggedness at the 250 m scale, terrain ruggedness at the 2000 m scale, and topographic position at the 500 m scale), four vegetation covariates (grass habitat landcover type, canopy cover percentage, distance to nearest forest edge, and the interaction between canopy cover and forest edge), and one anthropogenic covariate (quadratic form of distance to nearest road). Spatio-

Table 2. Mean, median, and minimum distance (m) proximity of three collared bighorn sheep to pen during control (domestic sheep absent) and treatment (domestic sheep present) experimental grouping periods. Statistical significance described by comparing AIC of a null model with the experimental grouping. Increasing AIC, when > 2, indicate greater significance and effect size.

Bighorn ID	Control			Treatment			Significance (ΔAIC improvement over null model)
	Mean	Median	Minimum	Mean	Median	Minimum	
BH0015	3704.1	3202.6	298.0	2685.0	1286.8	316.8	3.4
BH0018	2017.2	1790.9	270.8	2408.7	1887.1	339.6	93.1
BH0020	1285.6	1053.4	489.3	1033.8	733.6	338.5	252.6

Table 3. Mean and median distance (m) proximity of three collared bighorn sheep to each other during control (domestic sheep absent) and treatment (domestic sheep present) experimental grouping periods. Statistical significance described by comparing AIC of a null model with the experimental grouping. Increasing AIC, when > 2, indicate greater significance and effect size.

Bighorn Pairing	Control		Treatment		Significance (ΔAIC improvement over null model)
	Mean	Median	Mean	Median	
BH0018 & BH0015	3375.0	1976.3	6242.1	4944.8	77.9
BH0018 & BH0020	562.9	532.4	3911.5	1011.5	56.4
BH0015 & BH0020	452.4	38.7	634.1	26.0	12.8

temporally dynamic snow covariates (snow depth and snow water equivalent) and distance to nearest roofed structure were not explanatory variables in the most parsimonious model. Coefficients and model selection outputs for the most parsimonious baseline model are available upon request.

Expanding this baseline model with the additional pen proximity covariate and running the model individually, bighorn's attraction to the pen varied according to the experimental grouping (Figure 1). During the control period, all three bighorns were ambivalent to the domestic sheep pen's location; 95% confidence intervals of the beta coefficient greatly overlapped zero (Figure 1). During the treatment period, the degree of attraction to the pen (when occupied by the domestic sheep) increased for all three bighorn (Figure 1). Ewe BH0018 showed the least attraction and was slightly insignificant given the lower confidence interval extending to just -0.14. Compared to the other two bighorn, ram BH0020 showed a significantly high level of attraction to the pen during the treatment period (Figure 1).

Applying the baseline model to each ram separately and adding the proximity of ewe BH0018 as a covariate showed mixed results.

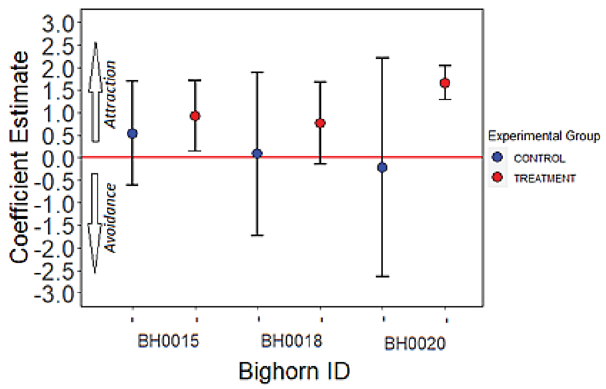

Figure 1. Step-selection movement behavior analysis by individual bighorn with respect to the domestic sheep pen's location during the control and treatment periods. Positive and negative coefficients represent attraction and avoidance respectively. Error bars (95% confidence intervals of the model selection coefficient) overlapping zero represent ambivalence behavior.

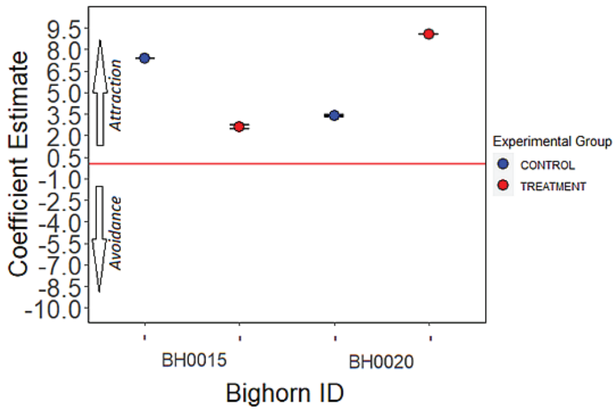

Figure 2: Spatio-temporally dynamic step-selection movement analysis by the individual bighorn rams with respect to the GPS collared bighorn ewe's (BH0018) locations during the control and treatment periods. Positive and negative coefficients represent attraction and avoidance respectively. Error bars (95% confidence intervals of the model selection coefficient) overlapping zero represent ambivalence behavior.

Although both bighorn rams were always attracted to the bighorn ewe, BH0015 showed less attraction to the ewe during the treatment year (relative to the control period), while BH0020 showed more attraction to the ewe during the treatment year (relative to the control period) (Figure 2).

DISCUSSION

In this case study, we provide a rigorous demonstration of free-ranging bighorn sheep movements in the presence of three penned domestic sheep. One wild bighorn sheep demonstrated behaviors suggesting attraction to the penned sheep, and subsequently died due to acute fatal pneumonia in the same season.

Step-selection movement models of the bighorn showed ambivalence toward the pen during the control periods (the year before and year after pen was occupied by the domestic sheep), and attraction during the treatment period, when the domestic sheep were present. The attraction was statistically significant in both rams (BH0015 and BH0020), but not for the ewe (BH0018). Of the three, ram BH0020 demonstrated the highest degree of attraction, and BH0020 was also anecdotally observed at the pen's fence line during the treatment period, while no anecdotal evidence exists of BH0015 and BH0018 at the pen. Ram BH0020 is also the only bighorn known to have died of pneumonia during the domestic sheep's occupation of the pen.

The attraction of BH0015 and BH0020 to the domestic sheep was not explainable by bighorn ewes. The two resident bighorn ewes in S52, with movements represented by GPS collared BH0018, were nearly always observed together during the study. Although both ram BH0020 and BH0015 were very attracted to ewe BH0018, the ewe was statistically further away from the domestic sheep pen during the treatment period, and showed little attraction to the pen, if any.

Other environmental variables do not explain the bighorn movements and proximity to the pen. In a nearby (~65 km) case study, extreme snow depths were implicated as a factor for increasing interactions (and subsequent all-age die off event) between a wild bighorn sheep herd and a winter-feeding operation of domestic cattle (Wolfe *et al.* 2010). However, snow depth was not a driver in our baseline movement model selection results, and the treatment year's snow depth was lower than the control year's (National Operational Hydrological Remote Sensing Center data). Other geographic covariates, which would be associated with inherent annual differences in vegetation quality and quantity did not provide a confounding explanation for the attraction observed. Bighorn's forage quantity and quality appeared excellent for the bighorn sheep during the treatment period and snow was not limiting bighorn access to forage as seen elsewhere (Wolfe *et al.* 2010); there is no reason to believe that bighorn were seeking the domestic sheep's food.

Respiratory pathogens were detected in all three of the domestic sheep, and chronic respiratory disease was observed in the domestic ram at necropsy. However, clinical disease was not observed in the domestic sheep by the owners or at a veterinary examination performed at the time that the ram was euthanized. Asymptomatic bighorn sheep and domestic sheep individuals are well documented in the wild and in confinement. Other wild bighorn and domestic sheep, marked or unmarked, may have been an undetected pathogen source for BH0020. Ewe BH18_663, was euthanized five months after ram BH0020's death and was revealed to have a case of chronic pneumonia that likely pre-dated the arrival of the domestic sheep. This uncollared ewe was known to interact with the ram (BH0020) that died. During the treatment period, BH0020 made one long distance foray (~35 km straight-line) into an area unoccupied by bighorn but which had recently been occupied by a large band of domestic sheep from a nearby federal allotment. Stray domestic sheep from multiple federal grazing allotments near (7 – 35 km) S52, each with a history of stray domestic sheep, may have also made contact with BH0020.

Poor herd performance characterized S52 long before this study, likely due to chronic pneumonia in lambs, which can impact bighorn population performance for over a decade (Grigg *et al.* 2017, Manlove *et al.* 2016). Other respiratory pathogens were detected in S52 bighorns prior to the arrival of the hobby domestic sheep (Table 1). Based on ground observations, none of the five lambs detected at 1-3 months of age in S52 during the first two years of the study reached adulthood. Facing extirpation, the S52 subherd was reduced to one resident ewe (BH0018) expected to be the sole matrilineal founder moving forward. In the three years (2018 – 2020) subsequent to the deaths of the other S52 bighorn ewes, all of BH0018's offspring survived to at least one year of age.

Efforts are ongoing at the time of this publication's submission date to strain type the *Pasteurellaceae* and *M. ovipneumoniae* bacteria detected in the wild and domestic sheep. This pairing of movement observations and strain typing diagnostics may be useful in future efforts to document wild/domestic sheep interactions and pathogen transfer.

Studies in free-ranging animals have unavoidable limitations and challenges. Regardless of strain-typing outcomes, this study cannot explicitly prove that directional disease transfer from domestics to wild sheep took place, as a full examination of pathogens present in the wild and domestic sheep was not conducted before the arrival of the domestic sheep. Proving directional disease transfer from domestics to wild sheep can be done in experimental pen studies where the interactions between wild and domestic sheep are controlled. However, experimental pen studies of confined animals can be accused of not representing realistic field conditions. In the wild, quasi-experimental analysis (Butsic *et al.* 2017) have potential to shed light on bighorn movement (as done in our retrospective movement analysis), but pre-comingling pathogen data of both wild and domestic sheep are impractical to collect, as comingling events are difficult to predict. Also, if a wild-domestic comingling event was known to be imminent, wildlife managers will often err on the side of caution and take action through wild bighorn euthanasia or removal of domestics to prevent comingling. We implore wildlife management agencies and land managers to engage in research efforts that capitalize on inevitable wild and domestic sheep interactions with a carefully planned prospective analysis of the pathogens in wild and domestic parties before and after interactions occur.

ACKNOWLEDGEMENTS

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Symptom progression and serological dynamics following introduction of a low-virulence *Mycoplasma ovipneumoniae* strain in a desert bighorn herd

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ABSTRACT: *Mycoplasma ovipneumoniae* was detected in the Zion desert bighorn sheep herd in July of 2018 following observation of respiratory symptoms by Zion National Park staff and visitors. The herd had been tested through routine sampling in 2017 and showed no serological or PCR evidence of *M. ovipneumoniae*, providing strong evidence that this was a novel introduction event. The ensuing *M. ovipneumoniae* event produced symptoms similar to those reported during other introductions of *M. ovipneumoniae* into bighorn sheep herds, but without any documented mortality. Thus, the Zion herd provides us a unique opportunity to closely observe disease progression in a desert bighorn system after an apparently low-virulence pathogen introduction event. Animal testing in the 18 months following introduction indicated that *M. ovipneumoniae* continued to circulate in the Zion population, and mild symptoms were observed with some regularity. However, intensive monitoring throughout 2019 revealed a symptom progression in lambs that was substantially delayed from patterns reported in other systems. Additionally, serological patterns deviated from those of other well-studied bighorn populations, with animals producing lower percent inhibition values than is typically observed in infected herds. Taken together, these observations suggest that low-virulence *M. ovipneumoniae* events may exhibit fundamentally different dynamics, requiring a prolonged follow-up monitoring structure compared to that typically required for higher-virulence events. More generally, this work underscores the utility of collecting directly comparable data on disease progressions across a variety of bighorn herds.

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KEY WORDS: *Mycoplasma ovipneumoniae*, strain virulence, disease severity, desert bighorn sheep, serology, Zion bighorn herd

Identifying drivers of bighorn sheep population recovery in the wake of pneumonia die-off events

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ABSTRACT: Bighorn sheep populations across the Intermountain West are subject to disease pressure from the respiratory pathogean *Mycoplasma ovipneumoniae*. Although the effects of *M. ovipneumoniae*-associated disease die-offs are well documented, less is known about the factors driving long-term variation in post-die-off demographic responses. While many herds experience years to decades in which recruitment is less than 20 lambs per 100 ewes, some herds' lamb survival rates are able to rebound rapidly following die-off events. The reason why these herds recover quickly while others do not is currently unknown. Here, we assess the roles environmental, demographic, and pathogen-associated factors could play in shaping bighorn sheep herd recovery. Our analysis relies on more than 30 years of data from over 40 bighorn sheep herds across the state of Nevada. Our results suggest that herd demographic responses to *M. ovipneumoniae* vary dramatically across subspecies, and that environmental factors may be more important in shaping those demographic responses in desert bighorn than in Rocky Mountain or California bighorn herds. Our results could have important implications on prioritization of bighorn sheep recovery efforts throughout the Intermountain West.

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KEY WORDS: *Mycoplasma ovipneumoniae*, bighorn sheep, herd recovery, die-offs, Nevada

Health surveillance of thinhorn sheep (*Ovis dalli*) herds in British Columbia and Alaska

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ABSTRACT: The health of wildlife populations influences their sustainability in the face of ecological challenges. There is a paucity of information about the health status of free ranging thinhorn sheep populations (*Ovis dalli*), despite their economic, ecological, and cultural significance. Identification of health concerns in related species, bighorn sheep (Ovis canadensis), as well as concern from local communities, First Nations, hunters, and conservationists that thinhorn subpopulations may be declining in some areas, prompted the call for comprehensive thinhorn sheep herd health assessments. We used a standardized approach based on similar work on bighorn herd health and conducted herd health assessments of thinhorn sheep in five study herds across their range that included both subspecies, Dall's sheep (*O. dalli dalli*) and Stone's sheep (*O. dalli stone*i).

We used a broad definition of health and surveyed exposure to multiple pathogens common to domestic small ruminants and other wildlife species, and evaluated other comprehensive health measures including nutritional status, parasite burden, contaminant exposure, stress, pregnancy, and indices of body condition. From 2017 to 2020 we collected tissue and blood samples from 46 Stone's sheep ewes and immature rams live-captured in the Skeena and Peace regions of British Columbia (BC), and 67 Dall's sheep in the Talkeetna and Chugach mountains of Alaska (AK). We also analyzed samples from 63 hunter-harvested Stone's sheep rams from the Skeena region of BC from 2016 to 2019.

We found evidence of *Mycoplasma ovipneumoniae* exposure in Dall's sheep in Alaska and inconclusive results in Stone's sheep in BC. There was minimal evidence of exposure to other bacterial and viral respiratory pathogens in all subspecies and herds. A high seroprevalence to ovine herpesvirus (P = 89.5%) was detected in all Stone's sheep. Parasite burdens were similar to previously reported results, including winter tick (*Dermacentor albipictus*) infestations of Stone's sheep sampled at low elevation along the Peace Arm of Williston reservoir. A high seroprevalence to *Toxoplasma gondii* was detected in sheep in Alaska (P = 100% in 2019, and 73.9% in 2020). Fecal glucocorticoid metabolite concentrations determined from hunter-harvested and live-captured sheep increased annually. Serum and tissue copper levels in some herds were in the range considered deficient for domestic sheep. Other trace minerals, including zinc and selenium, were deficient only in some study areas. Body condition of hunter-harvested rams decreased annually from 2016 to 2018.
Our findings confirm that thinhorn sheep, in general, are relatively naïve, and in some populations, very naïve, to diseases carried by domestic ruminants and other wildlife species. This information provides a baseline for thinhorn sheep herd health monitoring. If continued, it will allow for early detection of disease introductions and other population-limiting health factors. The results inform conservation and One Health decision making and can be incorporated into science-based management of thinhorn sheep in BC and Alaska.

Biennial Symposium of Northern Wild Sheep and Goat Council 22:31; 2020

KEY WORDS: *Mycoplasma ovipneumoniae* , One Health, *Ovis dalli*, *Pasteurellaceae*, respiratory disease, thinhorn sheep, wild sheep, wildlife health

Determining the source of the *Psoroptes* outbreak in British Columbian bighorn sheep

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ABSTRACT: *Psoroptes* mites have been documented in American bighorn sheep (*Ovis canadensis)* populations throughout the 19th and 20th centuries however they were not reported in Canadian populations until 2011. Determining the source of the BC outbreak is necessary to understand the risk to other naïve populations and of re-exposure following disease eradication efforts. We hypothesized that rabbits known to be infested in the area were the source of infestation in the Canadian herd. *Psoroptes* mites recovered from bighorn sheep in British Columbia and northern Washington were compared to those found on pet rabbits and on historically infested bighorn sheep in Nevada, Oregon and Idaho using morphologic and molecular methods. Measurement of outer opisthosomal setae lengths of mature male mites and sequencing of mitochondrial genes Cytochrome B and Cytochrome C oxidase subunit I was performed to compare the relatedness of mites collected from these different hosts. *Psoroptes* mites acquired from BC and northern Washington bighorn sheep were more morphologically and genetically similar to those collected from rabbits than to those of bighorn origin collected south of Washington state. This is the first report of *Psoroptes* mites matching the rabbit ecotype (previously called *P. cuniculi*) parasitizing bighorn sheep in a natural setting. This information suggests that the *Psoroptes* introduction into Canadian bighorn populations was through a disease spillover event from rabbits rather than from spread of the parasite through bighorn movements. *Psoroptes* susceptible hosts such as rabbits and horses should be considered when managing *Psoroptes* in bighorn sheep.

Biennial Symposium of Northern Wild Sheep and Goat Council 22:32; 2020

KEY WORDS: Bighorn sheep, *Oryctolagus cuniculus*, *Ovis canadensis*, Psoroptes, *Psoroptes cuniculi*, *Psoroptes ovis*, rabbit

Testing new options for the treatment of *psoroptes ovis* in bighorn sheep

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ABSTRACT: Bighorn sheep (*Ovis canadensis)* in North America have shown significant declines after the outbreak of *Psoroptes;* a highly pruritic skin mite. Currently used medications do not last long enough to eliminate the parasite and so multiple drug applications and needed, thereby limiting their value in free-ranging wildlife situations. This study aimed to identify a treatment for *Psoroptes* that is effective and appropriate for use in free-ranging bighorn sheep. A randomized, controlled, treatment trial was performed to test the efficacy of two different anti-parasitic drugs: eprinomectin and fluralaner, using injectable, oral, and topical routes of administration. Twenty naturally infected bighorn sheep were captured and housed in two purpose-built 5-acre enclosures. Animals were monitored daily and sampled monthly to assess disease resolution following treatment through evaluation of clinical signs, microscopic skin crust analysis, and antibody titer testing. Eprinomectin, (used at 2mg/kg of an extended release solution) and the topical form of fluralaner (used at 5mg/kg and 10mg/kg) were ineffective. The oral formulation of fluralaner showed encouraging results when administered at either 5 or 25mg/kg dosages. All orally treated individuals showed resolution of clinical signs lasting for one to four months following treatment despite cohabitation with other persistently infected individuals. Due to a lack of host immunity, the treatment of entire herds is essential for disease eradication. Longer lasting effects of orally administered fluralaner present a new management option for the treatment of psoroptic mange in free-ranging bighorn sheep. The potential exists for remote application using medicated feeds, enabling a cost-effective, low-stress option for the management of this disease in affected free-ranging bighorn sheep herds.

Biennial Symposium of Northern Wild Sheep and Goat Council 22:33; 2020

KEY WORDS: Bighorn Sheep, Eprinomectin (Longrange™), Fluralaner (Bravecto™), Mange, *Ovis canadensis, Psoroptes*, Psoroptic mange

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Mapping Alberta bighorn sheep winter range – RSF validation and inter-jurisdictional collaboration

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ABSTRACT: Poole *et al.* (2016) derived a winter range resource selection function (RSF) for bighorn sheep (*Ovis Canadensis*) populations in Elk Valley, British Columbia which are contiguous with those in south west Alberta. Alberta Environment and Parks staff and collaborators utilized an Alberta updated 2020 Earth Observation for Sustainable Development of Forests (ESOD) spatial dataset and are validating this RSF using additional GPS radio collar data collected during 2002-2020 (by Hogg, Paton, Ruckstuhl and Parks Canada). Albertan RSF values are being derived and validated using 95% kernel home ranges and methods similar to k-fold cross validation (Boyce *et al.* 2002). A Spearman's rank correlation coefficient is being calculated between the area-adjusted frequency for each class and the class rank (1-10). Preliminary results of the Spearman correlation using a sample of collar data indicate a significant positive association between the RSF values and winter habitat use ($P = 0.005$). These results demonstrate the utility of RSF's in describing sheep habitat use at the inter-provincial scale and highlights the benefits of multi-agency collaboration and data sharing. The results have already been used to efficiently inform prescribed burning planning in the Canmore area in Alberta. Additional efforts are underway to extend these products to northern Alberta sheep ranges. The supporting geographical information system products and methods may enable efficient creation of similar products for adjoining agencies.

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KEY WORDS: Alberta, bighorn sheep, British Columbia, *Ovis canadensis*, resource selection function, validation, winter range.

Evaluating summer migrations to mineral licks by two mountain ungulates

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ABSTRACT: A deficiency in trace minerals is a common cause of impairment to an organism's physiological functions and can negatively affect the demographic vigor of populations. Bighorn sheep (*Ovis canadensis*) and mountain goats (*Oreamnos americanus*) often ingest soil at areas called "licks" to obtain trace minerals that are lacking in their diets. Based on location data from collared bighorn sheep females in 5 herds in Montana, USA, we observed a common occurrence of short-duration migrations to specific, low elevation sites of most instrumented individuals during the summer months. We predicted these movements were to mineral licks to satisfy mineral imbalances associated with pregnancy and lactation. Our objectives of this study were to 1) identify potential mineral lick sites through collar location data and satellite imagery, 2) quantify bighorn sheep movements to potential licks, and 3) assay soil samples from 17 known mineral licks used by bighorn sheep and/or mountain goats for the concentration of 7 trace minerals. We successfully identified 5 – 14 potential lick sites per herd based on the physical characteristics shown by satellite imagery and locations of collared bighorn sheep. Based on 429 movement paths from 118 individuals that contained locations within potential lick sites, we found that summer migrations averaged 2.82 – 17.18 km in length and 50 – 100% of collared animals travelled to potential lick sites per herd. We found that sodium, calcium, and magnesium were overwhelmingly abundant at known lick sites, which is in accordance with past mineral lick site studies for bighorn sheep and mountain goats. These 3 minerals are known to be important for pregnancy and lactation, and support our hypothesis that these minerals are the reason for long-distance, energetically costly, and potentially dangerous summer migrations to lick sites.

Biennial Symposium of Northern Wild Sheep and Goat Council 22:35; 2020

KEY WORDS: bighorn sheep, geophagia, migration, minerals, Montana, *Ovis canadensis,* salt lick, Wyoming

Estimating nutritional carrying capacity of bighorn sheep in the Elk Valley

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ABSTRACT: Bighorn sheep (*Ovis canadensis*) in British Columbia's Elk Valley utilize high elevation grasslands during winter. Grasslands that serve as winter range are uncommon in the Elk Valley and may contribute to an upper limit to bighorn sheep population size. We developed an approach to estimate the nutritional carrying capacity for bighorn sheep winter range in the Elk Valley to determine whether availability and quality of winter range may limit bighorn sheep populations. Our aim was to produce a tool capable of supporting current and future resource management decisions by permitting bighorn sheep population size to be compared with nutritional carrying capacity of available winter range, including predicted changes in winter range carrying capacity over time. We developed a winter resource selection function using global positioning system telemetry data and mapped bighorn sheep winter ranges to constrain forage availability spatially. Species contributing to bighorn sheep winter diet were identified through a literature review of previous diet composition studies and consultation with experts. We estimated energy available to bighorn sheep at >2,000 vegetation plots using a relationship between the forage biomass of plant species consumed by bighorn sheep and percent cover of that forage species at each plot. Data were used to develop a spatially explicit forage model to estimate the distribution of energy across bighorn sheep winter ranges in the Elk Valley. Finally, we calculated nutritional carrying capacity by summing the energy available across winter ranges, weighted by relative selection, and divided this total by the average winter energetic requirements.

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KEY WORDS: bighorn sheep, carrying capacity, forage quality, winter range, resource selection

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Spatial genetic structure of Rocky Mountain Bighorn Sheep (*Ovis canadensis canadensis)* at the northern limit of their native range

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ABSTRACT: The Canadian Rocky Mountains are one of the few places on Earth where the spatial genetic structure of wide-ranging species have been relatively unaffected by anthropogenic disturbance. We characterised the spatial genetic structure of Rocky Mountain bighorn sheep (*Ovis canadensis canadensis* (Shaw, 1804)) in the northern portion of their range. Using microsatellites from 1495 individuals and mitochondrial DNA sequences from 188 individuals, we examined both broad and fine scale spatial genetic structure, assessed sex-biased gene flow within the northern portion of the species range, and identified geographic patterns of genetic diversity. We found that broad-scale spatial genetic structure was consistent with barriers to movement created by major river valleys. The fine-scale spatial genetic structure was characterized by a strong pattern of isolation-by-distance, and analysis of neighborhood size using spatial autocorrelation indicated gene flow frequently occurred over distances of up to 100 km. However, analysis of sex specific spatial autocorrelation and analysis of mitochondrial haplotype distributions failed to detect any evidence of sex-biased gene flow. Finally, our analyses reveal decreasing genetic diversity with increasing latitude, consistent with patterns of post-glacial recolonization of the Rocky Mountains.

Biennial Symposium of Northern Wild Sheep and Goat Council 22:37; 2020

KEY WORDS: spatial genetic structure, post-glacial recolonization, ungulates, terrestrial, alpine, Rocky Mountain bighorn sheep, *Ovis canadensis canadensis*

Evaluating bighorn sheep restoration using genomics

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ABSTRACT: Wildlife restoration often involves translocation efforts to reintroduce species and enhance genetic diversity of small, fragmented populations. We examined the genomic consequences of bighorn sheep (*Ovis canadensis*) translocations and population isolation, to enhance understanding of evolutionary processes that affect population genetics and inform future restoration strategies. We conducted a population genomic analysis of 511 bighorn sheep from 17 areas, including native and reintroduced populations with contrasting translocation histories. Our analyses determined that most examined populations were isolated from recent, unassisted gene flow, including two pairs of native herds that had past connectivity but were recently fragmented. To identify which augmentation and reintroduction efforts made a genetic contribution, we synthesized genomic evidence across three analyses to evaluate 24 different translocation events. We detected five successful augmentations and eight successful reintroductions based on genetic similarity with the source populations. A single native population founded most of the reintroduced herds, suggesting that genetic diversity of founders may have been more important to successful reintroduction than matching environmental conditions. We looked for genetic signatures of adaptation to pathogen presence by comparing herds that recovered after respiratory disease die-off events to those that did not, to identify candidate genes important to the disease process in bighorn sheep. Finally, we examined the relationship between herd inbreeding and recruitment rates. Our results provide insight on genomic distinctiveness of native and reintroduced herds, the relative success of reintroduction/augmentation efforts and their associated attributes, and guidance for genetic rescue augmentations and reintroductions to aid in bighorn sheep restoration.

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KEY WORDS: bighorn sheep, genetics, reintroduction, translocation

Despite denials, persistent harvest-based selection leads to the evolution of smaller horns in mountain sheep

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ABSTRACT: Pedigree-based evidence from one population, analyses of hunter-killed rams from several populations, and basic quantitative genetic theory provide strong evidence that intense selective harvests lead to evolutionary changes in mountain sheep horns. Yet, a modelling paper in the Journal of Wildlife Management claims that evolutionary change under heavy selective harvests is unlikely. Contrary to that claim and the supportive editorial, when the model is parameterized with values of additive and phenotypic variance, estimated for bighorn sheep, it predicts an evolutionary change comparable to that measured empirically at Ram Mountain. A paper in Evolutionary Applications compares changes in size of horns of harvested bighorn rams in 72"hunt units" in western North America. It uses a biased adjustment to account for differences in age at harvest and defines 'no change' for each unit as lack of a statistically significant trend. When considered together, the slopes of temporal changes in horn size in all 'hunt units' suggest a decline in horn size in 93% of units in Alberta, and 58% in the USA. Contrary to their conclusion that harvest-induced evolutionary change is not a management concern, these publications further emphasize the urgent need for regulatory changes in the quota-free, morphology-based management of bighorn rams in Alberta, and possibly elsewhere.

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KEY WORDS: Hunting-induced evolution, bias, modelling, rebuttal, horn size

Size-at-Age of Alberta's bighorn sheep (*Ovis canadensis*)

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ABSTRACT: As with many jurisdictions, the harvest and monitoring of bighorn sheep in Alberta relies on size-classes, which must be incorporated into a population-modelling framework for the results to be relevant to management. Using morphological measurements collected at registration from 193 male bighorn sheep, we developed a size-at-age relationship to describe the range of variability in how rams grow through these size classes to become available for harvest. Applying the size-at-age relationship within a population model allows wildlife managers to simulate size-restricted harvest, and compare the likely outcomes of a variety of alternative management scenarios.

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KEY WORDS: bighorn sheep; size-selective harvest; horn growth; population modelling

INTRODUCTION

Population models have many applications in wildlife management, including illustrating the likely results of changes to management. Alberta Environment and Parks (AEP) is currently using such a model for this purpose: to foster a common understanding of the trade-offs between alternative management regimes for bighorn sheep. Knowledge of these trade-offs is essential for stakeholders to provide informed opinions on their preferences, and to have confidence that the species is being managed in the best interest of Albertans.

Harvest of male bighorn sheep in Alberta is currently enabled by one of two minimum size restrictions defined under Alberta's *Wildlife Regulation*: either 'Trophy Sheep'- a ram having at least one horn tip crossing a line from the anterior edge of the horn base through the anterior edge of the eye (hereafter referred to as '4/5'); or 'Full Curl Trophy Sheep'- a ram having at least one horn tip crossing a line from the posterior edge of the horn base through the bottom edge of the eye socket (hereafter referred to as 'Full curl'). Prior to 1968, Alberta's bighorn sheep harvest was subject to a 3/4 curl restriction, which was defined under the regulation of the day as a ram having at least one horn tip crossing a line from the anterior edge of the horn base through the posterior edge of the eye. Size class definitions may vary in other jurisdictions, despite having similar naming conventions.

AEP's aerial survey program relies on a similar system for assigning sheep to classes based on maturation (adult; young of year), sex (male; female), and horn size for males over 1 year of age (1/4; 1/2; 3/4; 4/5; and Full curl). The larger ram classes (Full curl, 4/5 and 3/4) are defined according to Alberta's *Wildlife Regulation*, but the 1/2 curl class is only defined in the aerial ungulate survey protocol as a ram having at least one horn that has grown to point down and forward rather than down and backward when the head is held in a neutral anatomical position. The 1/4 curl class includes all rams >1 year of age that have not achieved 1/2 curl (Figure 1).

These size classes are defined by morphological landmarks so they can be applied in the field, but they are based on the proportion of a circle described by the horn (hence the naming convention). Therefore, while a ram's size class is primarily driven by horn length, it is also affected by how tightly the horn curls: A ram with tight curling horns could fall into a larger size class than one with wider curling horns even if there was no difference in horn length (*sensu* Wishart 1958; Heimer and Smith 1975; Wendling 2018). Describing bighorn sheep horn growth rates based on a two-dimensional approximation of their angular size class allows for a more explicit representation of how sheep grow to become available for harvest as compared to more simplistic linear models of horn growth that only consider horn length (e.g., Bonenfant *et al.* 2009; Douhard *et al.* 2016; Monteith *et al.* 2018).

Population models use survival rates reported from detailed demographic studies of bighorn sheep to determine which individuals advance to the next year (e.g., Loison *et al.* 1999; Portier, 2006). However, these survival rates are reported based on a sheep's age in years (rather than by the size of its horns), and population models are typically structured accordingly: allowing surviving individuals to advance to the next age class at each annual time step. To simulate size-restricted harvest of rams in an age-structured population model based on their size, we need to answer the following question: *Of rams that reach a given age, how many would belong to each size-class?*

In addition to deterministic patterns of horn growth rate, size-restricted harvest truncates the range of variability above the minimum size restriction. This is especially pronounced in the older age-classes, which are primarily represented by slower growing individuals who have experienced less cumulative exposure to harvest mortality than the faster growing members of their birth-year cohort. Lee (1912) was the first to describe the demographic effect of size-restricted harvest on population structure, which could conceivably contribute to an evolutionary effect depending on the heritability of the trait under selection. The Lee effect has been widely explored in fisheries management literature, but only recently has it been explicitly accounted for in predicting the outcomes of alternative management regimes (Kvamme and Frøysa 2004; Punt *et al.* 2013; Taylor and Methot 2013; Kraak *et al.* 2019). In this context, the survivor bias in the data is not

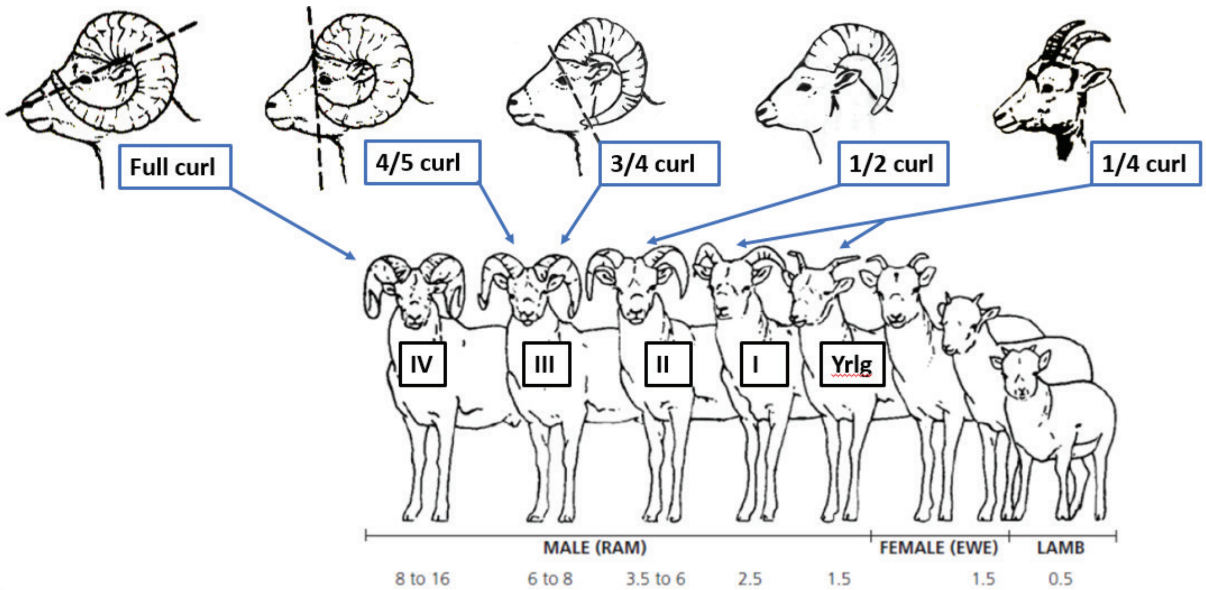

Figure 1. Size classes used by Alberta for harvest and monitoring of bighorn sheep rams (top), and how this system compares to the classification system developed by Geist (1966): Alberta divides Class III rams into separate 4/5 and 3/4 classes, but lumps yearlings and Class I rams together as 1/4 curls. Note that Alberta's *Wildlife Regulation* does not provide a legal definition for 1/2 curl, as this has never been used as a minimum size restriction. Likewise, Geist (1966) only defines class II rams as having horns that "form about ½ circle." On surveys, the 1/2 curl class has been defined by having a horn that has grown to point down and forward rather than down and backward, and serves as an approximate separation between 2 and 3 year old rams (though these age-classes have considerable overlap in size).

necessarily a problem because it is an accurate representation of the individuals that have survived to remain part of the population under the current management regime. However, the nature of the bias is dependent on both the minimum size restriction and the harvest rate of individuals above that minimum size, so survivor bias in the size-at-age relationship must be adjusted appropriately for the scenario to which that relationship is applied- especially those with alternative size restrictions (Kraak *et al.* 2019).

Any model requires a starting point, and a realistic initial population structure can improve the reliability of model projections, especially in the short term. To convert size-structured survey results to an age-structured initial population, we need to answer the following question: *How old are the sheep in a given size class?*

Non-hunting mortality is presumed to be dependent on age rather than size (Bonenfant *et al.*, 2009). Therefore, accounting for such mortality was not necessary to convert from age to size class. However, non-hunting mortality must be considered to convert from size to age because older sheep have been exposed to more years of mortality from all sources and thus will be less common relative to the younger members of the same size class. Therefore, the cumulative effects of both size-restricted harvest mortality and age-specific non-hunting mortality must be accounted for to determine the age distribution of sheep within a given size class.

To illustrate how AEP has addressed the challenge of simulating size restricted harvest in recent population modelling exercises, this paper examines the development of a preliminary size-at-age relationship to describe the realized results of the current management regime in Sheep Management Areas 7 and 8 (north of the Athabasca River to the border with British Columbia) from 2009-19: a 4/5 minimum size restriction with 32% of legal rams being harvested annually; 0.6% of ewes and lambs being harvested annually; and age-specific non-hunting mortality rates reported from Alberta's Ram Mountain study area (Loison *et al.* 1999; Portier 2006). The size-at-age relationship presented in this paper should be considered preliminary, with a more robust analysis of a larger dataset expected in the near future.

METHODS

Of rams that reach a given age, how many would belong to each size-class?

Measurements of annuli and curl diameter (Figure 2) from 193 of the rams harvested in Alberta between 2015 and 2019 were used to develop a relationship between a ram's age and the angular size class of his largest horn. Age-specific cumulative horn length for each year of a ram's life was used to maximize the information available from each sheep, providing a total of 1331 sheep-years (though sample size declines in the older age classes, and no sheep over 11 years of age were available in the dataset). Only complete years of growth were included in this dataset (the incomplete year of growth in the ram's final year of life was not included), thus the size-at-age relationship reflects individuals at the end of the growing year. The size of a ram at the end of the growing season is a reasonable representation of how large that individual would grow by the end of the hunting season (typically October 31st across most of Alberta), and therefore whether that individual should be considered to have been available for harvest. This relationship would also be representative of the sizes observed on late winter surveys (typically conducted in February, before horn growth has resumed in spring).

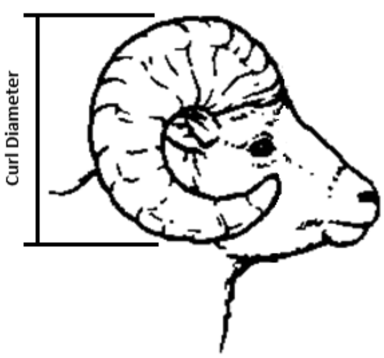

Figure 2. Diameter of curl. This measurement is used to convert linear annuli measurements into a 2-dimensional approximation of size class for male bighorn sheep based on the proportion of a complete circle described by the horn.

The cumulative length of the horn in each year of a ram's life was divided by the circumference of the circle described by the horn (*pi* x curl diameter) to convert length into proportion of a circle (*sensu* Wishart 1958; Heimer and Smith 1975; Wendling *et al.* 2018). Curl diameter was measured either in hand, or from photos taken at the time of registration, and the availability of this metric was the main constraint on sample size. From a subset of these sheep where the data were available, morphological landmarks were used to establish the average threshold for each size class (1/4 < 0.454; 1/2 > 0.454 and < 0.635; 3/4 > 0.635 and < 0.795; 4/5 > 0.795 and < 0.901; and Full curl > 0.901). These values are likely to be refined and updated as sample size increases, but are adequate to illustrate the concept. Note that the half curl threshold is not precisely defined in regulation- the value of 0.454 was chosen based on the less precise definition used on aerial surveys (i.e., horns that have grown to point down and forward rather than down and backward when the head is held in a neutral anatomical position) and the size at which a ram is equally likely to be either 2 or 3 years old.

Non-hunting mortality of adult sheep varies by age-class, but is not strongly correlated with horn size within an age class (Bonenfant *et al.,* 2009). As a result, there is no need to account for non-hunting mortality to address the size of rams within a given age-class, but the bias introduced by size-restricted hunting mortality must be addressed. First, the expected size of each individual was projected for the years after its death based on the consistent pattern of declining growth as a ram ages (made relative to the combined length of the 2nd, 3rd and 4th growth increments, Table I). This effectively erases the survivor bias, and provides an approximation of the size-at-age relationship in the absence of size restricted harvest. Next, an appropriate bias is reintroduced by weighting each sheep-year above the minimum size restriction according to the cumulative probability of that individual escaping harvest to that point (i.e., multiplied by $[1-\text{harvest rate}]^{[\text{years legal}]}$, or in this example: $0.68^{[\text{years legal}]}$).

The population model developed by Alberta Environment and Parks reports the population before harvest mortality has been applied (i.e., a preseason population representing the animals available to be harvested in that year). Therefore, sub-legal and first year legal sheep have not been exposed to harvest, and so these sheep-years are weighted as $0.68^0 = 1.00$. In this example, a second year legal sheep has been exposed to harvest for one year and is weighted as $0.68^1 = 0.68$; a third year legal sheep has been legal for two years and is weighted as $0.68^2 = 0.46$; and so on. The weighted sheep-years are then summed for each combination of age- and size-class (e.g., 4 year old 3/4 curls), and converted to proportion of the total for that age-class. This approach to weighting sheep-years should yield equivalent frequencies for age-and size-class combinations, as would be achieved on average by repeatedly removing individual rams,

Table I. Summary of the simplistic horn growth model used to project the hypothetical horn size of a ram after death. Average length of each annual increment is expressed relative to the combined length of the 2nd, 3rd, and 4th increments (which were present and complete in all individuals) so that the projected growth accounts for that individual's growth trajectory. Estimates of variance are not presented here, because this growth projection model was applied deterministically without any inclusion of stochastic variance. Sample sizes are included to give some indication of the relative reliability of the projection model across age-classes.

Increment	Average Length	Average of Prop_234	Sample Size
1	6.1	0.136	193
2	16.0	0.348	193
3	15.8	0.347	193
4	13.8	0.305	193
5	11.8	0.266	185
6	9.5	0.219	152
7	7.1	0.165	113
8	5.8	0.138	67
9	4.5	0.104	25
10	3.3	0.082	11
11	3.2	0.087	5
12	2.5	0.071	1

but allows for somewhat more straightforward computation.

How old are the sheep in a given size class?

To address the second question, both hunting and non-hunting mortality must be accounted for, because older sheep within a size class will have experienced more cumulative mortality from all sources and will therefore be less common than the younger age classes. The weighted frequencies calculated previously already account for the size specific hunting mortality, and only need to be multiplied by the cumulative probability of escaping non-hunting mortality up to that age to allow for conversion from size to age. Rows and columns are transposed, and the proportions are calculated relative to the size-class totals rather than the age-class totals. There is only one size class for female sheep (adult ewes), but observed individuals still need to be distributed amongst the many age-classes. The proportion of adult ewes belonging to each age class is derived the same way as for rams, by weighting according to hunting and non-hunting mortality.

RESULTS

The truncating effect of size-restricted harvest is evident in the raw data (Figure 3), and leads to declining sample sizes for the older age-classes. Figure 4 includes the simulated data projected after the death of each ram, showing the hypothetical size-at-age relationship in the absence of size-restricted harvest. After weighting sheep-years in the combined dataset by cumulative probability of escaping harvest under a 32% harvest of rams >4/5, the adjusted frequencies of occurrence are presented in Table II, and these have been translated into proportions in Table III to answer the question: *Of rams that reach a given age, how many would belong to each size-class?*

In Table IV, the frequencies from Table II have been transposed, and corrected to account for cumulative probability of escaping non-hunting mortality to answer the question: *How old are the sheep in a given size class?* A similar table is also included for female sheep, with appropriate survival rates applied to the adult females to distribute them across age-classes.

DISCUSSION

Incorporating size-restricted harvest in simulation modelling allows Alberta Environment and Parks to illustrate the likely outcomes of a variety of alternative management regimes in a data-driven manner. Using a scenario specific conversion table, sheep can be removed from the population based on their size while still retaining the high level of demographic detail provided by an age-structured model. The simulation model integrates many different types of data (e.g., inventories from aerial surveys, detailed demographic studies, radio collaring programs, habitat models, hunter harvest surveys, compulsory registration, annuli measurements). Using data from multiple sources encourages buy-in from a diverse group of experts and stakeholders because each can see how they are contributing to a big picture understanding of species management.

The objective of these simulations is to illustrate the relative trade offs between alternative management strategies in a format that is easily digestible for a wide range of stakeholders. The intent is not to predict the future with precision, but simply to compare relative differences. We have not attempted to propagate uncertainty through the simulation model, and so have not included confidence limits for the proportions reported in this paper. If the objective was to provide a reliable forecast (e.g., for populations in years between aerial survey inventories), confidence limits for these values could be generated using a subsampling or bootstrapping approach.

Model development to this point has relied on a provincially pooled size-at-age relationship to maximize sample size in each age class. Across Alberta, environmental conditions are likely to influence the way sheep grow to become legal, even in the absence of variable harvest effort. With the addition of the 2020 registrations, the dataset is expected to be large enough to develop regionally specific size-at-age relationships based on the sheep

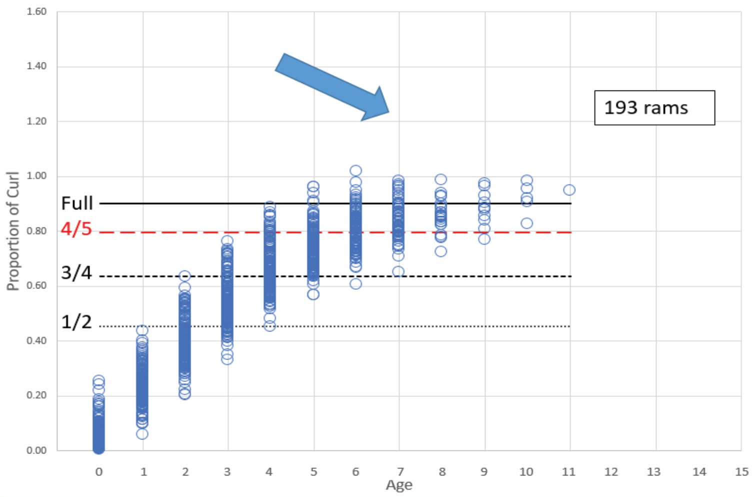

Figure 3. Horn curl data from 193 harvested rams showing size-at-age for 1331 sheep-years. Size class thresholds were averages derived from a subset of sheep where appropriate morphological measurements were taken. The arrow indicates the truncating effect of the current size restricted harvest regime on rams 5 years of age and older.

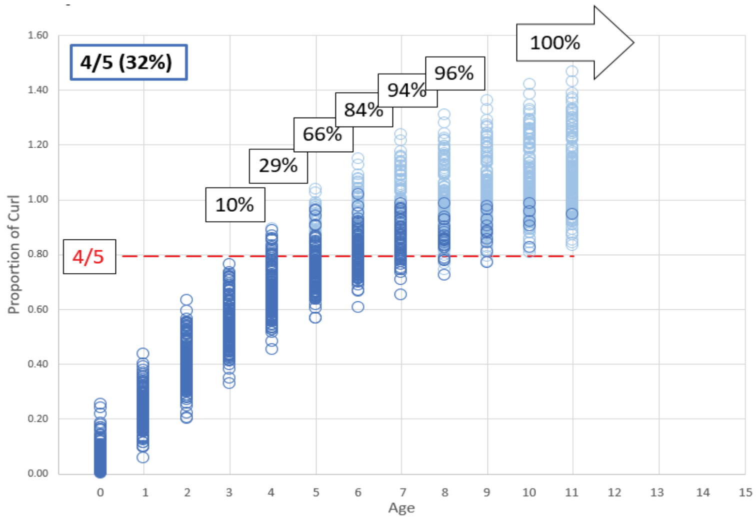

Figure 4. Raw data plus 985 sheep-years that were projected after death to erase survivor bias. The proportion of each age class exposed to harvest mortality reflects weighting of sheep-years by the cumulative probability of that individual escaping harvest to that point, and is based on a minimum size restriction of 4/5 curl, and a Trophy harvest rate of 32% (to approximate the realized harvest regime in north of the Athabasca River to the provincial boundary).

that were harvested in Northern, Central, and Southern Alberta to explore this hypothesis further.

In analyses conducted to date, sheep that have lost their first annulus from both horns have not been included in the dataset. Such sheep account for about 8% of registrations provincially, mostly from southern Alberta. Therefore, the size-at-age relationship presented here describes sheep that wear down the lamb tips, but don't suffer brooming beyond the first annulus. Excluding broomed rams from our dataset further limits the sample sizes available for the older age-classes. We can also expect a slight positive bias in the horn size of older age-classes, although this might not greatly affect the size class assignment if brooming occurs primarily after a ram has reached Full curl.

Table II. Frequency of sheep-years by age and size-class, with bolded values adjusted to reflect the survivor bias expected under a 4/5 curl size restriction when 32% of legal rams are harvested annually. No rams aged 12-15 years were observed in the dataset, so rams in these age classes were presumed to all be Full curl for the purposes of this exercise.

COUNT	Lamb	1/4	1/2	3/4	4/5	Full	Legal	Total
0	193							193.0
1		193						193.0
2		155	38					193.0
3		23	144	26				193.0
4		1	68	104	20		20	193.0
5			5	127	**38.0**	**16.6**	41	186.6
6			1	57	**84.2**	**26.9**	74	169.1
7				21	**64.2**	**48.4**	37	133.6
8				6	**37.9**	**53.6**	15	97.5
9				3	**21.5**	**43.7**	3	68.3
10					**9.1**	**38.3**	3	47.4
11					**3.7**	**28.5**	0	32.2
12						**21.9**	0	**21.9**
13						**14.9**	0	**14.9**
14						**10.1**	0	**10.1**
15						**6.6**	0	**6.6**

Table III. ***Of rams that reach a given age, how many would belong to each size-class?*** Conversion from age to size: Frequencies from Table II, rescaled to proportion of sheep of each size, for each age-class. There is no correction for non-hunting mortality, because this is presumed to be dependent on age, not size.

Proportion	Lamb	1/4	1/2	3/4	4/5	Full	Total
0	1.000						1.000
1		1.000					1.000
2		0.803	0.197				1.000
3		0.119	0.746	0.135			1.000
4		0.005	0.352	0.539	0.104		1.000
5			0.027	0.681	0.204	0.089	1.000
6			0.006	0.337	0.498	0.159	1.000
7				0.157	0.481	0.362	1.000
8				0.062	0.389	0.550	1.000
9				0.044	0.315	0.641	1.000
10					0.191	0.809	1.000
11					0.116	0.884	1.000
12						**1.000**	**1.000**
13						**1.000**	**1.000**
14						**1.000**	**1.000**
15						**1.000**	**1.000**

In this exercise, the measured annuli lengths have been used to model growth of a horn around a two dimensional circle, without accounting for a horn that actually traces a helix in three dimensions. The resulting positive bias in proportion of curl is likely of minimal concern because it also affects the class distinguishing thresholds that were determined relative to the morphological landmarks specified in the *Wildlife Regulation*: Sheep-years would still be assigned appropriately to size-classes, even if the proportion of curl value appears to be exaggerated. To confirm this assumption, size-class assignments using 2D and 3D approximations of the horn growth will be

Table IV. ***How old are the sheep in a given size class?*** Conversion from size to age showing the relative proportion of ages within each size class. The frequencies from Table II have been weighted by cumulative survival from non-hunting mortality sources, and rescaled to reflect the proportion of sheep of each age, for each size class. A similar table is also provided for female sheep, to distribute them across ages in a realistic manner.

Proportion	0	1	2	3	4	5	6	7	8	9	10	11	**12**	**13**	**14**	**15**	Total
Ann. Survival	0.54	0.82	0.89	0.85	0.86	0.84	0.83	0.8	0.79	0.77	0.74	0.71	0.69	0.3	0	0	
Cum. Survival	1	0.540	0.443	0.394	0.335	0.288	0.242	0.201	0.161	0.127	0.098	0.072	0.051	0.035	0.011	0.000	
Lamb (M)	1.000																1.000
1/4		0.572	0.377	0.050	0.002												1.000
1/2			0.172	0.579	0.232	0.015	0.002										1.000
3/4				0.101	0.345	0.362	0.137	0.042	0.010	0.004							1.000
4/5					0.110	0.180	0.335	0.212	0.100	0.045	0.015	0.004					1.000
Full						0.112	0.152	0.227	0.202	0.130	0.088	0.048	**0.026**	**0.012**	**0.003**	**0.000**	1.000

From/To	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	Total
Harv. Survival	1	0.994	0.994	0.994	0.994	0.994	0.994	0.994	0.994	0.994	0.994	0.994	0.994	0.994	0.994	0.994	
Ann. Survival	0.54	0.85	0.95	0.94	0.93	0.92	0.91	0.89	0.88	0.88	0.86	0.82	0.81	0.8	0.77	0.7	
Cum. Survival	1	0.540	0.459	0.436	0.410	0.381	0.351	0.319	0.284	0.250	0.220	0.189	0.155	0.126	0.101	0.077	
Lamb (F)	1.000																1.000
Ewe		0.126	0.107	0.101	0.095	0.089	0.082	0.074	0.066	0.058	0.051	0.044	0.036	0.029	0.023	0.018	1.000

compared in the coming years using a subset of the sheep registered in 2020, from which additional measurements were taken to capture the depth of spiral (i.e., from anterior edge of the horn base to the horn tip).

More sophisticated statistical methods could possibly be used to account for survivor bias in the size-at-age relationship, though these would likely rely on a similar approach to erasing the existing bias and reintroducing an appropriate one. The horn growth model used to project data beyond the death of an individual sheep is crude, but the projected data appear consistent with what might be expected. However, such a conclusion is conjectural and would benefit from a more objective assessment of the reliability of the horn growth projection model.

To date, we have not accounted for potential changes in horn growth rate that might be observed in future as a result of climate change (e.g., Loehr *et al.* 2010), changes in population density (e.g., Monteith *et al.* 2018), genetic effects of artificial selection (e.g., Pigeon *et al.,* 2016; Douhard *et al.* 2016), or behavioural/energetic consequences of departing from a 'natural' male age structure (Schindler *et al.* 2020). While this is a limitation of how the size-at-age relationship is currently being applied, the approach captures the current range of variability in how rams grow to become available for harvest. Using the best available knowledge to explicitly describe size-restricted harvest in population modelling is essential to ensure stakeholders have a clear understanding of the expected trade-offs when exploring the likely outcomes of alternative management, and so they are able to provide informed opinions on how bighorn sheep should be managed in the public interest.

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Management update and summary: Alaskan Dall's Sheep 2020

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ABSTRACT: The Dall's sheep (*Ovis dalli dalli*) management scene in Alaska has been vibrant over the last fifty years. Management and research investments in Alaska's Dall's sheep are presently beyond anything envisioned in the past. These changes followed decades of advocacy by hunter interest groups, plus a high-profile, controversial resident preference movement, and heightened interest in Dall's sheep health. Derivatives of these experiences include the re-discovery and review of forty-year-old management plans based on hunter-desired experiences, and the formation of a resident hunter special-interest group. Although Alaska has never recorded a bighorn pneumonia-type die off, continent-wide interest in *Mycoplasma ovipneumoniae* (*M. ovi.)* prompted the Alaska Department of Fish and Game (ADF&G) to initiate a statewide, interspecific survey to define the presence (or absence) of *M. ovi.* antigens and DNA fragments in Alaska's wildlife. *M. ovi.* DNA fragments (defined as an Alaska-endemic strain) have been found primarily in caribou (*Rangifer tarandus*), but are also widespread in Dall's sheep. *M. ovi.* DNA fragments have also been identified in Alaskan mountain goats (*Oreamnos americanus*). Speculation on the origin of Alaska-endemic *M. ovi*. DNA fragments sparked a review of historic domestic sheep and goat imports to Alaska from the beginning of the 1900s. Tens of thousands of domestic sheep and goats were imported during the last century with some being trailed through (but not ranged in) the heart of Dall's sheep habitats. The Alaska Chapter of the Wild Sheep Foundation's aggressive advocacy of *M. ovi.*-free domestic sheep and goats in modern Alaska drove negotiations between ADF&G and the Department of Environmental Conservation that appear poised to require screening for non-endemic *M. ovi.* DNA fragments prior to import of domestic sheep and goats to Alaska. This paper will describe the past and present situation in more detail.

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KEY WORDS: Dall's sheep, harvest management *Mycoplasma ovipneumoniae*, ram harvest rate

UPDATE

General Wild Sheep Management History

Historically, wild bighorn sheep, having been virtually extirpated with colonization of the American West, were an uncommon landscape feature in the U.S.A. when modern wildlife management emerged over the first third of the 20th century. Consequently, mid-20th century wild sheep biologists struggled to foster agency interest in managing wild sheep on par with the dominant cervid/ursid/small game axis that drove the development of wildlife biology and management (Toweill and Geist 1999).

As wild sheep began to recover from the depredations of predation, competition with domestic livestock (exacerbated by domestic disease introduction), and human cultural evolution, the human-perceived status of wild sheep began to rise. First, predator reductions designed to facilitate domestic livestock operations in the American West lowered resistance to wild sheep population growth. As populations increased, wild sheep eventually came to be seen as another revenue-producing opportunity by state and provincial wildlife managers. As interest (both public and financial) increased, so did the status of wild sheep in the perception of managers concerned about the economic costs of management. This status increase was enhanced by interest in ram hunting fostered by the outdoor press, most famously Jack O'Conner (see for example: O'Connor, J. 1974. Sheep and Sheep Hunting. Winchester Press. 308pp.)

Alaska Dall's Sheep Management History

This appreciation was slow in coming to Alaska where robust populations of Dall's sheep were taken for granted. Subsistence and market hunting for Dall's sheep were locally intense through the first quarter of the 20th century. Other than that, Dall's sheep populations existed in pristine habitats, and human-caused mortality was low to non-existent (Toweill and Geist 1999**).**

The most extensive review of Dall's sheep harvest regulatory history from early territorial days to the present may be found on page 6 of an ADF&G review, *The Dall's Sheep News*, from 2017 *http://www.akleg.gov/basis/get_documents.asp?session=30&docid=42666*

> Author's note: I consider this early review unimpeachable. Some later opinions in "*The Dall's Sheep News*" are less well documented. I'll not be going into those opinions here. WEH

Early (circa 1960-1971) Alaskan wildlife managers had been trained in colleges and universities where the wildlife curriculum was dominated by the cervid/ursid/small game tradition (Toweill and Geist 1999). Consequently, Dall's sheep were considered "typical ungulates," and their specific adaptations to habitat were under-appreciated. Modern reporting and monitoring of Dall's ram harvests began during the 1960s with introduction of a "harvest ticket" program (ADF&G 2017). It continues today.

Any view of Dall's sheep management in Alaska is a matter of perspective. When viewed over the shorter time, management may appear chaotic. However, when viewed over the longer-haul, its development appears more systematic.

Modern Dall's Sheep Management in Alaska

Management beyond the "naturalist" level began with statehood in 1960s (Nichols 1971). In 1968 there was a notable die off of Dall's sheep on the Kenai Peninsula (Nichols 1968, 1971). This die off resulted in a research project to determine the cause. The most likely cause was severe winter weather, and the research position created for that project disappeared at the end of the study. By 1970 a more management-focused position was established in Interior Alaska. This left Alaska with one Dall's sheep position and minimal operating budgets located in the Interior.

The Interior Alaska project focused on management-relevant Dall's sheep biology, driven by the availability of Dall's sheep for inexpensive capture and marking (via drop and rocket-net trapping and primitive neck-banding) at mineral licks. During this period, Dall's sheep management consisted primarily of monitoring ram harvests set at the ¾ curl ram minimum. That eventually changed, but that's another story (Heimer 1990, 1992, 1986, 1998a).

Societal Factors

Dall's sheep management became more complex with Congressional passage of the Alaska Native Claims Settlement Act (ANCSA) of 1972. ANCSA contained a section that reflected the compromise between environmental protection and oil development. This compromise eventually produced the Alaska National Interest Lands Conservation Act (ANILCA) of 1980 (Heimer 1982).

Land Classification and Economics

As detailed by Heimer (2000) Alaska's idyllic neglect of Dall's sheep ended with the development-driven necessity of settling ANCSA land claims and the resulting ANILCA land classifications. In the course of negotiating ANILCA-driven land ownership, half of Alaska's Dall's sheep were declared "off limits" to hunting via executive order of then-President Carter. The resulting loss of revenue to the state focused attention on the value of Dall's sheep in Alaska's economy (Heimer 1982). Eventually, half of the loss was mitigated by amendments to ANILCA legislation, and the net loss to Alaska's economy from federal land reclassifications was reduced to about 25% of the pre-ANILCA resource base (Heimer 1985). The time-adjusted economic benefit to Alaska from Dall's ram harvests is presently estimated at 20-25 million dollars annually (K. Gordon, pers. comm.).

Current Alaskan Dall's sheep management

Today, ADF&G supports two full-time Dall's sheep research positions, their technical support staffs, and associated graduate student programs. Survey, reporting, and regulatory duties are covered by regionally diversified participation by Area Management Biologists. The present fiscal commitment to Dall's sheep management by ADF&G is estimated at about a quarter of a million dollars annually. The revenue to the state is estimated about at roughly 80 times that figure. The National Park Service, the U.S. Fish and Wildlife Service, and the Bureau of Land Management make additional expenditures pursuant to their agency objectives. Unlike the lower USA, Alaska has an insignificant number of wild (Dall's) sheep on U.S. Forest Service lands.

Population Contractions and hunter number declines

Apparent weather-related population contractions occurred ten years later than the losses in harvest opportunity caused by land reclassifications. These population contractions began in the early 1990s, and seemed linked to lamb production failures that, in turn, coincided with changes in weather patterns. Population contractions were more notable in some areas than others, with geography and prevailing weather being the greatest variables between areas (Heimer *et al.* 1994).

The decreases in harvestable Dall's sheep populations (whether due to weather or land reclassification or both) were accompanied by a steady drop in numbers of hunters participating. Over the 15-year period from 1980 to 1995, Dall's ram hunter numbers declined from about 4,500 to half that number reporting. However, the documented decline in hunter participation drew less public or managerial interest than the primarily anecdotal accounts of declines in sheep population sizes (Heimer 2012). Declines in hunter participation have continued through 2021 (J.Want, ADF&G pers. comm.).

Hunter paranoia postulated that deteriorating hunting conditions were occurring because of Dall's sheep population declines (neglecting the decline in hunter numbers, which probably outstripped the losses to sheep population sizes). This paranoia began to drive demands for managers to do something to fix the situation.

Complaints by the Alaska Chapter of the Wild Sheep Foundation lead to a re-awakened interest in management planning without regard to existing plans made operational almost four decades earlier (ADF&G 1974).

Management Planning

Logically, management plans should implement established policy. Alaska's Constitution defines the policy of the state with respect to natural resources. It prescribes making Alaska's natural resources available for maximum sustainable use consistent with public interest and the maximum benefit to 'Alaska's people.' In the early 1970s, this mandate was generally overlooked, because, visionary ADF&G leadership directed inexperienced biologists into Alaska's first management planning effort (ADF&G 1974). In drafting these plans, present management practices were prioritized over the Alaska Constitution. In 1974, there were few enough hunters in Alaska that little attention was paid to what might happen in 50 years. During this management planning effort Dall sheep mangers understood the "maximum benefit" to 'Alaska's people' to mean giving users what they wanted, within the conservation limits imposed by the Alaska Constitution.

Consequently, a comprehensive survey of 'what hunters wanted' was undertaken. The results of this survey (of all hunters in 1973-the average during this period was about 3,000 reporting) showed the highest priority of Alaska's Dall's ram hunters was assurance of continued harvest opportunities. The second highest priority was the opportunity to hunt in un-crowded conditions, and the third priority was to have the opportunity to hunt for trophy rams at some time during a sheep hunter's life.

These hunter-desired priorities were reflected in the 1976 plans for hunter-experience-based objectives. Defined opportunity objectives for specific regions were consistent with existing Dall's sheep populations, and the then-existing uses were the result. Areas with high sheep population densities and ready access were designated as "maximum opportunity" zones. Those areas with less dense populations, more difficult access, and lower hunter use were classified as "aesthetic hunting" opportunity zones, where participation would be controlled by limited-entry permit. The "trophy hunting' desire was limited to two areas (one designated, and the other *de facto*). In the designated area, higher age limits and horn sizes were prescribed. Opportunity to hunt was necessarily limited by lottery permits in areas planned for "aesthetics" and "trophy hunting" to provide these experiences.

These plans were either so successful or forgettable that they were accepted as "the way it had always been" within a decade or two. Then, with changes in personnel, the existence of these formally approved plans was forgotten. Purposeful Dall's sheep management consisted of monitoring ram harvests and administering the designated permit systems for "aesthetic" and "trophy hunting" regions. A few additional "aesthetic" areas were developed along the way and report-requiring subsistence hunting was recognized (Heimer 1986).

As the anecdotally-driven perception of deteriorating sheep hunting conditions spread, a movement advocating establishment of modern management plans as a solution to the perceived problem arose. In contrast with Alaska's hunter-experienced but forgotten management plans, modern management plans typically specify prescribed population size objectives, population composition objectives, hunter participation levels, and harvest objectives (see any published management plan.)

The Alaska Chapter of the Wild Sheep Foundation (a NGO) actively advocated for plans of this type, even offering to pay for the planning effort. However, there was some resistance to this effort on the part of the Department of Fish and Game. The Department seemed to sense that this sort of plan might not be readily applicable to Dall's sheep in Alaska (K. Gordon, WSF pers comm.)

Eventually, it was discovered that the NGO's generous offer to fund management planning was unworkable. In the course of things, the already-existing management plans were discovered. Realizing that sheep populations were virtually certain to be regulated by factors beyond the human harvest of rams as then regulated (at full curl or eight years of age throughout the previous three decades), the Department managed to blunt the "modern trend" in wildlife management plans for Alaska's Dall's sheep. The result was maintenance of the *status quo* of the pre-existing Alaska-relevant "hunter experience-based" objectives from 1976. ADF&G promised more frequent review of the existing management plans linked to reporting on federal funding for wildlife restoration and management (called Pittman-Robertson contracting in the USA

The Resident Hunter Preference Movement

The wide-spread failure to recognize the subtly significant decline in hunter numbers coupled with the obvious decreases in sheep numbers gave rise to the popular impression that hunting conditions were deteriorating statewide.

This popular, anecdotally based perception was soon coupled with allegations that the guiding industry was responsible. Resident hunter efforts to lower nonresident hunter participation via proposed changes in harvest regulations (at the risk of economic losses to Alaska's economy) lead to analysis of hunter behaviors, guided hunter harvests, and ultimately to calculation of harvest rates (Heimer 2012**.** Results indicated no support for the allegations that guides were the problem (*ibid*).

The unexpectedly low harvest rates (Heimer 2012) were publicly criticized by prominent sheep managers who argued that calculating harvest rates based on ram ages was unreliable, because hunters select rams based on horn curl, not age. These criticisms were investigated in detail (J. Want, ADF&G pers. comm.) and found to be without support from harvest statistics (Heimer 2012).

Correct or not, the popular perception, coupled with an influential local resident's vendetta against guide/outfitters lead to the most recent resident hunter preference movement. This was not the first resident-preference movement in Alaska's history. Sheep hunters have always bristled at not having the mountains all to themselves. Here's how this particular movement developed.

Resident Hunters of Alaska (RHAK): Origin of an NGO

An influential resident hunter had flown his personal aircraft into the sheep hills and cached 82 gallons of avgas to use in an upcoming sheep hunt. When he got back to his stash, his aviation fuel was gone. He alleged it had been found, stolen, and combusted by the locally resident, territorial, airplane-using guide in the area. This led to a campaign to punish the guiding industry by amplifying the ancestral animosity of residents toward non-resident hunters, who must have a guide to hunt sheep in Alaska. The aggrieved airplane owner enlisted a cadre of friends in a campaign to limit nonresident hunter participation (i.e., guiding) in Alaska. These residents essentially "buried" the Alaska Board of Game with proposals (which anyone may submit to Alaska's harvest-regulating board) to, among other things, restrict nonresident hunters to 10% of the harvest (Alaska Board of Game Public Proposals 2007-2013).

While the Board of Game was sensitive to the fact that such a restriction would greatly reduce revenue for wildlife management and restoration, the resident hunter preference/anti-guide interests persisted. The public clamor over this issue eventually resulted in an orchestrated effort to address the issue via a broadly based public special interests working group initially organized to solve the problem by delegating management planning (see earlier text). This effort ultimately failed for legal, fiscal, and human logistic reasons.

However, before that happened, the Board directed the Department to contract an assessment of present-day hunter preferences via a survey of hunter attitudes (ADF&G 2014). Complaints about use of aircraft in hunting Dall's rams were predictably prominent in the results of that assessment. Consequently, the Board passed a regulatory proposal prohibiting the use of aircraft in looking for Dall's rams to hunt. In retrospect, the regulation proved basically un-enforceable (and was identified as such by enforcement personnel at the time). My inference that the Board was hoping to tamp down the orchestrated resident preference fervor by "throwing the most vocal residents a bone" was later confirmed by a conversation (T. Spraker, Board Chair pers. comm.) If this were the strategy, it failed.

The interest of aircraft owners (those with the means to own personal aircraft) had been piqued by their invitation to participate in the failed management planning working group. These hunters were acutely aggrieved that their investments in and alleged approach to hunting plus their means of transport had been identified for discrimination. In response, they formed an organization called "Resident Hunters of Alaska" (RHAK). Enough money was raised to hire an Executive Director, and promote resident preference interests. Presently, the Board of Game deals with RHAK-driven proposals to disadvantage nonresidents hunting all species on a predictable basis (ADF&G 2007-2021).

Tension between local and non-local hunters (and their guides) has always existed, but the presence of RHAK in Alaska has exacerbated these tensions. RHAK seems to have diverted its interest away from the ban on aircraft use in Dall's ram hunting, and is presently focused more broadly on compromising nonresident hunting opportunity (and the guiding industry on which nonresidents depend).

Disease protection awareness overview

The effective focus of bighorn disease biologists on domestic sheep as causes of bighorn die-offs is broadly appreciated throughout North America. Bighorn die offs have always been interpreted in light of the existing knowledge base (Heimer 2002). Various "causes" for bighorn die off biology have enjoyed periods of predominant popularity over time. This progression began with blaming bighorn die offs on competition with domestic grazers, progressed through "the lungworm/pneumonia complex" era, the domestic sheep *Pasterellacae* period, the identification of *Mannheimia* and the discovery of leukotoxin effects (Heimer 2002). Today the focus is on *Mycoplasma ovipneumoniae (M. ovi)* (ADF&G 2017). Although no disease-related die offs resembling bighorn pneumonia have been recorded in Alaska, the present emphasis on *M. ovi.* among bighorns has affected Alaska. Both the Department of Fish and Game and the Alaska Chapter of the Wild Sheep Foundation plus domestic sheep advocates have been involved (Heimer. 2019).

Alaska's history with domestic sheep

Although various attempts to establish a domestic sheep industry in Alaska have occurred throughout the last 100 years, Alaska has no definable domestic sheep industry at this time. The attempts to establish a domestic sheep industry failed as consequences of location, weather, and marketing logistic constraints. Today, domestic sheep exist in Alaska as small "farm flocks" or student agriculture projects (Heimer, 2019).

Dating from the various gold rushes of the late 19th and early 20th centuries, thousands of domestic sheep have been introduced to Alaska. Hundreds were barged up the Yukon River, and thousands trailed through (but never ranged on) the heart of Dall's sheep habitat in the Central Alaska Range south of Fairbanks (ADF&G 2017). A University of Alaska (then called the College of Agriculture and Mining) project, in concert with the US Department of Agriculture, proposed (and experimented with) hybridizing captive Dall's sheep with domestics in 1930. Apparently hybrids were produced, survived, and became campus pet favorites. Nevertheless, the idea of producing weather-resistant hybridized wild/domestic sheep, where wild meat was plentiful, faded when confronted with economic realities. (Bunnell, 1930). Alaska currently has no industrial-scale domestic sheep industry. Nevertheless, protection of Alaska's Dall's sheep from small-flock domestic sheep-borne *M. ovi.* became controversial (Heimer 2019). Here's that story:

Contemporary efforts to protect Alaskan Dall's sheep from domestic diseases

Because of the focus on bighorn die-offs associated with *M. ovi.,* ADF&G initiated monitoring hunter-harvested Dall's sheep (and other species) for evidence of *M. ovi.* in Alaska. Ultimately, the ADF&G survey showed an apparently unique Alaskan strain of *M. ovi*. This strain is wide spread among caribou and Alaska's Dall's sheep, and its origin is uncertain (ADF&G 2019).

The Alaska Chapter of the Wild Sheep Foundation was initially unaware of that survey effort, and benightedly committed to creating *M. ovi.*-free domestic sheep, via administrative programs requiring mandatory testing and voluntary culling of domestic sheep and goats in Alaska, as the protective solution.

In an effort to effect its management goal, the Chapter acted to use the administrative mechanisms through the Alaska Board of Game (those it understood) to prohibit import of domestic sheep and goats that might carry *M. ovi.*

The Alaska Board of Game and the "clean list"

The Alaska Board of Game exists "... for purposes of the conservation and development of the game resources of the state." (Alaska Statute 16.05.221 (b)). Presumably as part of "conservation," and permitting efficiency, the Board has established a list of animals, for which it has statutory responsibility that may be imported to the state without a special permit. This list is called the "clean list." For unexplained reasons, the "clean list" expansively includes domestic animals like sheep and goats, even though import of domestic animals is beyond the purview of the Board of Game. The Board may only deal with critters defined as "game animals," not domestics.

The Alaska Chapter of the Wild Sheep Foundation, hoped to get the Board of Game to remove domestic sheep and goats from the Board's "clean list." The implicit assumption was that once domestic sheep and goats were off the "clean list," import regulations would be more restrictive. The Alaska Chapter did not inform domestic growers of this plan prior to going to the Board of Game. It simply proposed removal of domestic sheep and goats from the Board's "clean list," as well as some separation language.

When news of this proposal reached the domestic growers, they felt threatened, and acted through their own non-governmental organization (the Alaska Farm Bureau), to oppose the proposal by the Alaska Chapter of the Wild Sheep Foundation. Controversy developed, and initiated a rough-and-tumble administrative struggle between the two special-interest groups. The Board of Game and ADF&G were caught in the middle, with the Department of Environmental Conservation (DEC) dragged into the mix. Regulation of domestic animal health is the responsibility of DEC because the office of the Alaska State Veterinarian is presently within that Department.

Ultimately, the issue of regulating domestic animal import was ruled to be beyond the authority of the Board of Game. Through a complex nexus of stormy negotiations, a facilitated working group meeting, and management agency efforts to address the problem, the Department of Environmental Conservation and the Department of Fish and Game negotiated a draft set of revised regulations requiring *M. ovi.* testing prior to import of domestic sheep and goats. These, now final, regulations (18AAC 36.015) call for testing of domestic sheep and goats for the presumably pathogenic strain of domestic sheep/goat *M. ovi.* prior to import. They also define *M. ovi.* infection in domestic animals as a "reportable disease," and require permanent identification of all imported sheep and goats.

These regulations look very much like what the activist Alaska Chapter of the Wild Sheep Foundation wanted. However, politics being what they are, the draft regulations from DEC propose an exception for importation of domestic sheep and goats under the age of two months. This exception seems based on early-reported research from Washington State University (subsequently shown to be unrepeatable) that sheep and goats under two months of age do not carry *M. ovi.* That preliminary finding has recently been recognized as a mistaken preliminary finding, and efforts to correct that mistake are underway (AWCA, 2020).

SUMMARY

The facts that our present knowledge of *M. ovi* is evolving, while the social complications and animosities generated during the course of these events persist, suggest the proposed regulations may not be the ultimate mechanism protecting Dall's sheep from domestic animal disease. Still, it seems a rational first step where *M. ovi.*is concerned.

> <u>Author's note:</u> Surprisingly, to me as a participant in the facilitated M. ovi. working group, the domestic growers were agreeable to a zero-tolerance, lethally enforced separation policy. That policy would prescribe that any domestic grower who saw a Dall's sheep approaching his/her farmstead should shoot the interloping Dall's sheep on sight. The carcass would be forfeited to ADF&G for disease testing. That agreement on the part of domestic owners wasn't surprising. What was surprising was the reciprocal suggestion from the domestic growers. They insisted that to be effective, any domestic sheep or goat encroaching on Dall's sheep range be shot on sight as well, and the carcass forfeited to ADF&G for disease testing. This verbal agreement did not factor in pack goats closely attended by humans. The coordinated Alaska Chapter interests at the facilitated working group immediately dismissed this proposed solution as unworkable. Today, it exists only as a unique suggestion rejected by the Alaska Chapter of the Wild Sheep Foundation.

The progression of Dall's sheep management in Alaska over the last half-century appears both chaotic and directed. How it is seen as a matter of perspective. Management has evolved from benign neglect through arbitrary administration of use, and toward appreciation of Dall's sheep adaptations to environment. Trends in public involvement, and the influences of the broader wild sheep community, in disease protection have been recent influences. If management is to become more harmonious in the future, better communication between managers and users will be necessary. Special interest groups supporting management have been helpful. Special interest groups mistaking themselves for managers have not.

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Fast phenotypic change in a sexually selected trait: A new mechanism

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ABSTRACT: Intra- and intersexual selection on male secondary sexual traits generally confer increased reproductive success in bearers with the most prominent traits. Strong selective harvest pressure of such trophy males can lead to a negative selection for trait size, and, over time, favour males with slow horn growth (genetics). However, this view ignores the role of plasticity in phenotypes and behaviour, and its impact on accelerating or decelerating the expression of sexually selected traits. We argue that changes in selection pressures (e.g., predation, selective harvest) may cause a cascade of behavioural responses, and a rapid change in trait size. We propose that selective removal of individuals with the most prominent traits induces behavioural changes in the surviving males, and thus in trait size (phenotypic expression). To test this idea, we used an individual-based simulation, parameterized with empirical data of male bighorn sheep, *Ovis canadensis*. Our model shows that the expression (phenotype, not genotype) of the trait under selection (horn size) can be negatively affected, if the biggest, most dominant males in the population are removed. The selective removal of prime males opens up breeding opportunities for younger, smaller males, which we predict would come at the expense of growth and maintenance. Indeed, we observed a rapid decline in average male horn length in our model. This result is further supported by empirical evidence in alpine ibex, *Capra ibex*, which we will discuss. We argue that this nongenetic mechanism is important because it describes how heritable traits can rapidly change because of behavioural plasticity, before any genetic changes might be detectable.

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KEY WORDS: bighorn sheep, horn growth, selection pressure, sexual selection, theoretical model

Reintroducing and augmenting mountain goat populations in the north Cascades: Translocations from the Olympic Peninsula, 2018-2020

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ABSTRACT: In response to a long-term decline in abundance of mountain goats (*Oreamnos americanus*) in many parts of their historic range within Washington's Cascade Mountains, and taking advantage of Olympic National Park's desire to remove non-native goats, the Washington Department of Fish and Wildlife led an effort to restore goat populations via reintroductions sourced from the Olympic Peninsula during 2018-2020. Following analyses that suggested where goats were most needed and would likely fair best, 326 goats (182 ♀, 144 ♂) were released at 17 sites ($\bar{x}$ = 20.4 goats, minimum = 5, maximum = 49) over the course of 4 summer-time bouts; 262 were equipped with GPS collars allowing monitoring of survival and movements. Because most goats moved considerably after release, we found it useful to view them as having formed 6 population clusters ($\bar{x}$ = 54.3 goats released/cluster). We analyzed adult (age 1+) survival and associated covariates at 3 temporal scales 1) 150 days, which we considered the acclimation period, 2) 150 days to 1 year, and 3) after 1 year. Overall annualized adult (age 1+) survival was 0.53 for females and 0.58 for males; survival was slightly lower during the initial acclimation period, but at ~ 0.8-0.9 approached rates needed for population growth among those surviving a year in some population clusters. Adult females with higher body condition score survived better than those with lower scores. Kids were always abandoned by their mothers upon release, but at 0.25, estimated survival of orphans we monitored was higher than expected. The degree to which the translocation program succeeded in restoring inter-connected mountain goat populations in Washington's Cascade mountains will not be known for a few more years.

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KEY WORDS: mountain goat, north Cascades, *Oreamnos americanus*, reintroduction

INTRODUCTION

Mountain goats (*Oreamnos americanus*), native to the entire Cascade Range of Washington, declined considerably during 1940s-1980s (Johnson 1983), at least in part due to excessive legal recreational harvest (Rice and Gay 2010, Rice 2012). Throughout western North America most jurisdictions with mountain goats misunderstood goat biology during those earlier decades (Toweill *et al.* 2004), typically offered greater harvest opportunities than populations could withstand (Kuck 1977, Hamel *et al.* 2006), and most native populations experienced reductions (Decesare and Smith 2018). Beginning about 2000, the Washington Department of Fish and Wildlife (WDFW) has managed recreational goat harvest conservatively, and goats in some areas of the North Cascades have recovered (WDFW 2015). However, recovery in other portions of the North Cascades was very slow or absent. Rice (2012) combined rigorous estimates with educated guesses in postulating a total mountain goat population in Washington State during the 2004-2007 period at 2,400–3,200 animals. This estimate incorporated national parks (including the introduced goats in Olympic National Park) and illuminated marked heterogeneity in the status of populations managed by WDFW. By 2011, based on aerial surveys indicating specific sections of Washington's Cascades either avoided the general decline or recovered naturally, WDFW began offering limited (lottery permit-only) licenses within 10 hunting districts in the Cascade Mountains. However, excluding these hunting districts and national parks, estimates by Rice (2012) suggested only 530-930 mountain goats remained, scattered within the remainder of Cascade Range in Washington from the British Columbia boundary in the north to Mt. St. Helens in the south.

Genetic diversity among goats in the Washington Cascades also was a concern. Heterozygosity and allelic diversity were lower among a small sample of these goats than larger, more connected populations in Alberta and British Columbia (Shafer *et al.* 2011), with genetic diversity within Washington declining from north to south (Parks *et al.* 2015). Cowan and McCrory (1970) noted that skulls from three Washington mountain goats were missing the first two molars on one or more tooth rows and suggested the possibility of a genetic mechanism for these abnormalities. However, if so, this was unlikely to be a selective adaptation; it seems more likely an expression of deleterious alleles. Parks *et al.* (2015) suggested that geographic and topographic characteristics limited gene flow among goat groups at a fine geographic scale. Additionally, Interstate Highway 90 was identified as an impediment to gene flow between northern and southern portions of the Washington Cascade Range (Shirk *et al.* 2010, Parks *et al.* 2015).

For these reasons, WDFW has long considered translocation an appropriate tool to restore this valuable component of the alpine ecosystem to its historic abundance (WDFW 2015), an objective shared and supported by the consortium of Native American tribes in the region (co-managers and signatories to the Point Elliott Treaty of 1855). Because the abundant mountain goats on the Olympia Peninsula (OP), particularly within Olympic National Park (ONP) were not native (introduced in the 1920s, Houston *et al.* 1994), when the opportunity arose to procure goats to replenish depleted populations in the Cascades, WDFW entered into a cooperative agreement with the National Park Service and the U.S. Forest Service. National Park Service (2018) provides additional details on the rationale for removing mountain goats from the OP, as well as the work conducted during 2018-2020 to provide animals for this translocation.

Considerations regarding source goats for translocation

Disease

Mountain goats can have diseases and parasites that cause morbidity and mortality for individuals. Until recently, when pneumonia associated with the bacterium *Mycoplasma ovipneumoniae* was implicated in a local die-off in Nevada (Wolff *et al.* 2014, 2016), neither diseases nor parasites were considered major mortality factors with population-level consequences (Côté and Festa-Bianchet 2003). We were unable to perform a thorough screening of the source population prior to translocations, but reasoned that whatever diseases and parasites may have affected OP goats failed to preclude marked population growth. Additionally, we had no reason to suspect that OP goats carried diseases or parasites not already present among resident animals in the Cascades because i) from 1972 to 1985, ONP conducted 7 translocations of mountain goats into the Washington Cascades (totaling 149 animals), so any diseases and parasites OP goats carried had long-since been introduced, and ii) work by Johnson (1983) and Foreyt (1989) quantified that parasites present in ONP goats were always present (and often in higher prevalence than on the OP) among native Cascade goats.

Nonetheless, our processing protocols included examining all goats at capture for evidence of disease, and testing all kids captured for genetic evidence of *Cryptosporidium* and *Giardia* sp., as well as Johne's disease (*Mycobacterium paratuberculosis*; Williams *et al.* 1979) and *M. ovipneumoniae* (present in mountain goats outside Washington State). The decision to translocate or euthanize individuals was made by project veterinarians on-site.

Genetics

We expected that augmenting Cascades populations with OP goats could restore missing alleles that may have been lost to drift and could reduce the probability of inbreeding. Although no subspecies of mountain goats are recognized (Côté and Festa-Bianchet 2003), OP goats were derived from Alaskan and British Columbia founders, and were differentiable from native Cascades goats at the molecular level (Shirk 2009). Thus, we considered possible adverse consequences if any local adaptations in Cascades goats were susceptible to being swamped or overridden by maladaptive traits among OP mountain goats. Balancing these two unknowns, we concluded that the probable genetic benefits outweighed the potential risks associated with outbreeding depression (National Park Service 2018: J-21).

Habituation, salt conditioning, and aggressiveness

National Park Service (2018) identified issues of mountain goats being habituated to humans on foot, conditioned to seeking salt, or being aggressive to people within ONP and potentially after being translocated. Because ONP could not identify the habituation or salt-conditioning status of each mountain goat prior to the project, goats residing in areas known to have high human visitation and a history of containing habituated goats were classified as "habituated"; all others were classified "non-habituated". Translocation protocols called for "habituated" goats to be released only in remote areas, and for subsequent monitoring in light of each individual's pre-translocation habituation characterization. In addition, any goat considered by NPS staff to be "aggressive" (having direct contact with a person) would be euthanized rather than translocated.

Selection of release sites

Simply knowing that large-scale declines occurred within broad sections of the North Cascades constituted only the starting point in our assessment of optimal sites for field releases. Analyses of previous mountain goat translocations into native habitat (Harris and Steele 2014) showed that long-term success was likely only if each selected area could receive at least 30 adult females and 15 adult males (we expected fewer than 400 goats). Consequently, we attempted to prioritize the top ~12 sites within the project area to function as presumptive population nuclei. To identify suitable sites for mountain goat translocation, we evaluated habitat suitability, connectivity, historic harvest, potential population density, whether the polygon containing the site was occupied by mountain goats, an extrapolated assessment of forage abundance and quality based on geological characteristics, and finally, the logistics of getting goats to the site (details in Harris and Rice 2018).

Occupied or unoccupied

We classified patches as occupied (estimated population >25% of potential population) or unoccupied (all others) by comparing the estimated densities from Rice (2012) with the potential densities (see below). We also sub-classified occupied patches as 25-50% of their potential population and >50%. Unoccupied patches were sub-classified as either 10-25% or <10% of their potential population size.

Habitat and identification of habitat polygons containing potential sites

We defined summer mountain goat habitat based on the raster map of mountain goat habitat developed by Wells *et al.* (2011). At a broad scale, we aggregated the habitat pixels to 125 × 125 m using the median value of the 25 original cells. The aggregated pixels were grouped (using 8 adjacent cells) to identify habitat pixels adjacent to one another. The grouped pixels were converted to a polygon shapefile. The resulting shapefile contained 13,592 polygons of mountain goat summer habitat. Most of these were small, so to concentrate on main areas of habitat we removed all that were <0.25 km^2 (0.1 mi^2) in area. This resulted in 36 habitat polygons with areas ranging from 0.25 to 185 km^2 (0.1 to 71.4 mi^2).

Connectivity

Many of the resultant 36 habitat polygons were near others. Because mountain goats cross unsuitable habitat to access nearby patches (Côté and Festa-Bianchet 2003, Rice 2008), we evaluated connectivity of the habitat polygons. We used Least Cost Path analysis to determine resistance to movement between polygons based on the isolation-by-resistance model of Shirk *et al.* (2010). We removed 4 polygons from consideration because they were in unsuitable locations. Among the 32 remaining patches, 10 were occupied and 22 were unoccupied. Connectivity was assessed for every pair of these 32 patches using Linkage Mapper Connectivity Analysis Software (McRae and Kavanagh 2011). Linkage Mapper produced a table of the least cost path movement costs for each patch pair.

In addition to dispersal resistance to other patches, we considered the amount of habitat or the expected mountain goat population in other patches, and whether the connection was to another unoccupied patch or an occupied patch (i.e., connections between patches with large potential populations were considered better than between patches with small population potential). Also, a patch highly connected to an occupied patch would not be a high priority for translocation. Potential natural dispersal to that patch by our released goats could compete with potential natural dispersal and colonization. To quantify these considerations, we calculated an inter-patch connectivity score as follows:

$$ConIndex = \frac{PopEstA + PopEstB}{KmEq}\begin{pmatrix} UnoccupiedA \wedge UnoccupiedB \rightarrow 1 \\ OccupiedA \vee OccupiedB \rightarrow -1 \end{pmatrix}$$

where: *ConIndex* = the connectivity index
KmEq = *A* to *B* isolation kilometer equivalents
PopEstA and *PopEstB* = estimated population potential for patches *A* and *B*
Unoccupied, Occupied = whether patches *A* and *B* were occupied.

Values of ConIndex were near zero when patches were separated by large distances (e.g., >100 km), especially if the potential population sizes were small (e.g., estimated at < 25 individuals). Large potential populations connected by small distances had a high index value if both were unoccupied, but a highly negative index if either was occupied. The score applied to each patch was the median ConIndex from it to all other unoccupied patches.

Historic harvest

We enumerated the historic harvest for each area as an indicator of prior abundance (subject to interpretations we added about hunter accessibility and popularity). From 1947 through 1970, hunters reported mountain goat kills by providing a place name and drainage (n = 4,373 records).

Potential population size

We matched population estimates by Rice (2012) with habitat polygons, and those considered depressed populations were removed from analysis. We estimated the density (mountain goats/km^2 of habitat) for each polygon. Because the distribution of these densities was highly skewed, we log-transformed the data. Log-densities were not significantly different between surveyed and expert-estimated areas ($F_{1,24}$ = 1.278, P = 0.2695), so we used the overall mean log-density of 0.871 (SE = 0.253, n = 26; i.e., 2.3 mountain goats/km^2, 95% CI = 1.3-3.9). We then estimated the population potential of each habitat patch by multiplying its area by mean population density. Because mountain goat translocations ideally focus on areas with significant population potential, we selected all patches with a population potential of >25 mountain goats. However, 6 patches were added because it appeared, based on personal knowledge of those areas and the number of mountain goats within them, that the habitat model under-represented the area, and hence population potential in those patches. Each of these 32 patches was named based on the geographic features it contained.

Extrapolation of forage suitability based on geological substrate

Preliminary observations indicated that areas that had adequate escape terrain, but historically low density mountain goat populations (particularly in and around North Cascades National Park), were characterized by predominately plutonic geological formations. Therefore, we examined our hypothesis that geological substrate could serve as an additional indicator of mountain goat habitat quality, and thus indirectly predict long-term carrying capacity for goats. Based on these results

(Harris *et al.* 2017) the proportion of overlaying geological substrates positively (volcanic, sedimentary, and shale), and negatively (plutonic, metasedimentary, schist, gneiss, potassium-feldspar, and sodium-rich igneous rocks) associated with preferred mountain goat forage were added to each candidate translocation patch. Each patch was assigned a geological score defined as the sum of the proportions of areas with positive associations minus the sum of the proportions with negative associations.

Ranking of candidate habitat patches

Having aggregated all available biological and social criteria describing each patch, we concluded that further attempts to systemize ranking via a numerical scheme was counterproductive. We found no satisfactory way to objectively weight biological measures with one another (e.g., patch size vs. patch connectivity), nor to objectively merge quantified biological characteristics with unquantifiable ones (or social considerations). We thus circulated a summary of all 32 patches to the interdisciplinary team (e.g., Tribal biologists, Forest Service, biologists, university researchers), and ultimately selected a consensus ranking of the patches.

Field logistics

WDFW staff accessed each site by helicopter (landing where permissible, outside designated wilderness) in July 2016. We identified potential landing sites and measured the distances from these to the nearest road access, rejecting sites with distances > ~11.3 km (7 miles) to reduce the ferry time needed to transport goats.

Based on these site visits, the number of candidate patches was reduced to 12, and exact sites for goat release and staging areas were identified (Olympic, Mt. Baker-Snoqualmie, and Okanogan-Wenatchee National Forests, 2018). To provide options during poor flying weather, we added 5 nearby substitutes (including some accessible by road when weather precluded any flying) (Figure 1).

METHODS

Pilot study

In preparation for translocating animals from the Olympic Peninsula, WDFW and the Muckleshoot Tribe conducted a pilot translocation of mountain goats from the Elkhorn Mountains of eastern Oregon, near Baker City in July 2016 (Harris 2016). This was accomplished with close cooperation and invaluable assistance from the

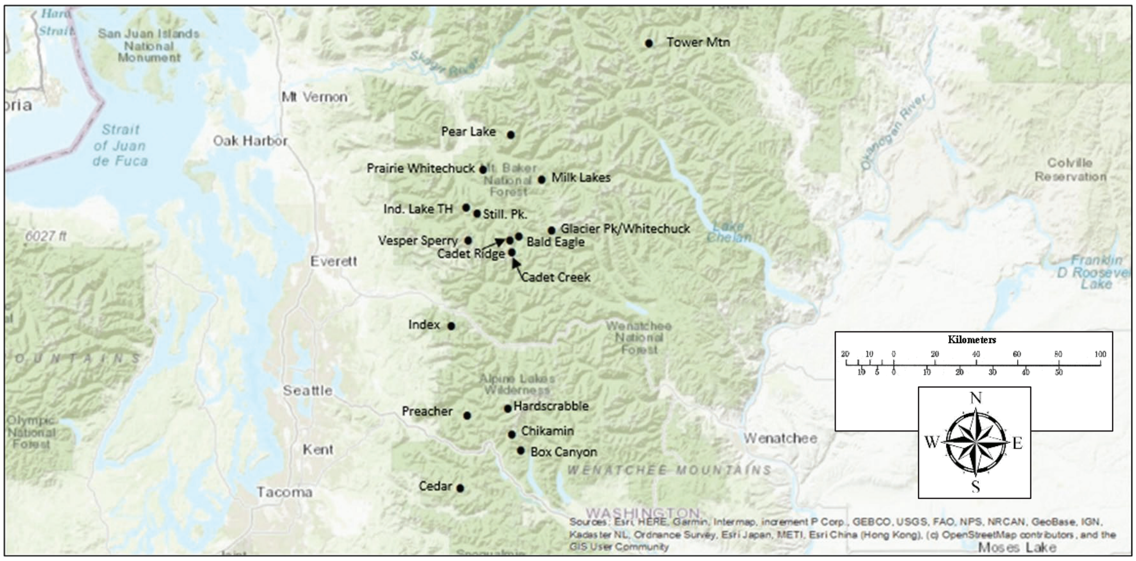

Figure 1. Release sites for translocating mountain goats in Washington State, 2018-2020.

Oregon Department of Fish and Wildlife and Seattle Public Utilities. Six goats (3 adult ♀, 2 subadult ♀, 1 subadult ♂) were captured with a fixed tangle net (Myatt *et al.* 2010), transported by vehicle and helicopter to a site in the Cedar River Watershed, and released (detailed methods below on transport and release). The remainder of this report deals only with goats obtained during the cooperative project with Olympic National Park and the U.S. Forest Service during 2018-2020.

Capture and handling

Happe *et al.* (2020) describe effort and methods to capture mountain goats. Generally, each goat was evaluated by staff veterinarians for emergency medical conditions and treated if necessary. In addition to sex and age, body mass, condition score (Iowa State University 2011), horn dimensions, body measurements, and lactation status were recorded. Nasal swabs, tissue for DNA analysis (facilitating subsequent analysis of translocation success), blood, hair, and fecal samples were collected. All goats were given BoSe® (selenium and Vitamin E to reduce muscle damage associated with capture myopathy), fluxinin (nonsteroidal anti-inflammatory and analgesic), ivermectin (anti-parasitic), and oxytetracycline (antibiotic). All adults and yearlings were administered midazolam (35 mg for adults, 15 mg for yearlings) and 20 mg haloperidol (Hofmeyr 1981, Wolfe and Miller 2014) to help maintain tranquility. In addition, most received 1 L fluids subcutaneously to reduce the potential for dehydration during transport. Body temperature, respiration, and capillary refill time were monitored throughout the process. Each animal received an ear tag with a unique number corresponding to the animal number in the records.

After processing, goats were moved into individual transport crates (Figure 2) kept in a secluded and shaded area until loaded into the transport trucks. All adults and large-sized yearlings (except 3 goats that ONP previously equipped with VHF collars) were fitted with Vectronics Survey GPS collars. Vectronics "mini-GPS" collars were used on selected kids and yearlings in 2019. These collars were small, lightweight, and could safely be placed on small, growing animals because they stretch as the neck grows. When stretched maximally, they break off the animal to avoid harm. Goats with injuries sufficiently severe to compromise survival probability post-release were euthanized, as were a few individuals suspected of infection (see results).

Figure 2. Crates with goats. Left crate has a "howdy door" allowing mother and kid to see and smell each other during transport; right crate has a normal door.

Mountain goats were transported in refrigerator trucks that carried up to 9 goats in each truck, or by pick-up trucks carrying up to two goats. Pick-up trucks were used only when ambient temperatures were cool enough (typically <10°C) to allow safe transport without additional controlled cooling. Communication between capture and release crews was accomplished with personal cellular phones as well as InReach® GPS units (Garmin Ltd, Olathe, KS). Crated goats were off loaded and prepared for helicopter transport to high elevation release sites either early the following morning (n = 323) or, when time allowed, late the afternoon of their capture date (n = 23).

At helicopter-accessed release sites, we first confirmed that it was safe to land. We then flew to the staging area to confirm plans with the crews tending the goats overnight. We ferried the release crews and field gear to the release sites prior to slinging in the crated goats. In 2018 we used a Bell Jet Ranger that can safely accommodate 3 passengers, thus requiring 2 round-trips for personnel. In 2019 and 2020 we used a Bell 407 that allowed a single trip. All helicopter services were provided by HiLine Helicopters, Darrington, WA. See Harris *et al.* (2019) for additional details on methods used to transport and release mountain goats.

Analyses

Survival

Annualized survival rates were estimated as the reciprocal of the sum of mortalities divided by the sum of exposure days, raised to the 365th power. We used Cox Regression, implemented in R ("res.cox" within the Survival library) to assess if selected attributes of goats (or their handling) hypothesized to effect survival, were significantly associated with the number of days until death. We broadly categorized hypotheses explaining risk of mortality into 3 groups: i) factors theoretically under our control (or influence) during the capture and handling on the OP, ii) factors theoretically under our control during the transport and release of the goats (in the north Cascades), and iii) factors inherent to the goats themselves over which we had no control. In models under the first group, we examined the capture method (darting vs. netting), whether goats were injured on arrival at the processing site, and the time taken to process the animal before it entered the crate. In the second group, we examined models including the time in transport (between crating and releasing), whether there was an overnight wait before release, whether transportation to the release site was by helicopter or vehicle, whether the release site was in designated wilderness, and finally, the specific location of release. In the third group, we examined potential covariates of mortality risk including gender, age at capture, whether habituated, body condition index, and if female, whether lactating or had a kid with her at capture. We examined 2-way interactions where main effects were significant or where a cross-over effect was possible.

Climate

White *et al.* (2011:1739) found that survival of most sex/age classes of mountain goats was related

Table 1. Mountain goats from the Olympic Peninsula released[1] in the north Cascades, 2018-2020 (aggregated release sites, Harris *et al.* 2019).

Population Cluster	Release site	Nanny	Billy	Female yearling	Male yearling	Female kid	Male kid	Total females	Total males	Total
Cedar	Cedar River	**11**	**6**	**0**	**1**	**0**	**1**	**11**	**8**	**19**
Alpine Lake South	Chikamin	5	8	1	0	0	2	*6*	*10*	**16**
	Box Canyon	13	7	0	3	0	1	*13*	*11*	**24**
	Preacher	1	3	1	1	0	0	*2*	*4*	**6**
	Cluster Total	**19**	**18**	**2**	**4**	**0**	**3**	**21**	**25**	**46**
Suak River South	Stillaguamish Peak	9	2	0	1	2	0	*11*	*3*	**14**
	Independence Lake	4	0	2	0	0	1	*6*	*1*	**7**
	Vesper-Sperry	20	6	7	9	2	2	*29*	*17*	**46**
	Cadet Ridge/Creek	9	15	2	3	0	3	*11*	*21*	**32**
	Bald Eagle Trailhead	4	1	0	1	0	0	*4*	*2*	**6**
	Cluster Total	**46**	**24**	**11**	**14**	**4**	**6**	**61**	**44**	**105**
Alpine Lakes North	Index	7	6	2	1	2	1	*11*	*8*	**19**
	Hardscrabble	1	6	0	0	0	1	*1*	*7*	**8**
	Cluster Total	**8**	**12**	**2**	**1**	**2**	**2**	**12**	**15**	**27**
Glacier Peak/Sauk North	Glacier Pk Upper Whitechuck	4	0	0	0	0	1	*4*	*1*	**5**
	Milk Lake	15	11	3	3	0	4	*18*	*18*	**36**
	Prairie Mtn-Whitechuck[2]	11	5	1	1	3	3	*15*	*9*	**25**
	Pear Lake	7	5	0	1	0	1	*7*	*7*	**14**
	Cluster Total	**37**	**21**	**4**	**5**	**3**	**9**	**44**	**35**	**80**
Upper Methow	Tower Mtn	**24**	**7**	**5**	**1**	**5**	**7**	**34**	**15**	**49**
Total		**145**	**88**	**24**	**26**	**14**	**28**	**183**	**142**	**326**

[1] Sixteen kids were transferred to accredited zoological institutions

[2] Total includes one intersex (pseudohermaphrodite) animal

negatively to the yearly accumulation of snow. We thus queried USDA websites for snow water equivalent records in the translocation region during 2018-2020 and considered survival of translocated goats in this context.

RESULTS

Releases: animals and locations

We released 326 goats (Table 1) during 4 periods over 3 years (98 in September 2018, 76 in July 2019, 102 in August 2019, and 50 in July/August 2020; including one goat captured in August 2019 near North Bend, WA that does not appear in ONP progress reports). We translocated more females (183) than males (142). One translocated animal was categorized as "intersex" (pseudohermaphrodite), possessing phenotypic characteristics of both genders (see Harris *et al.* 2019 for details). Of the 326 goats, 42 were kids (14♀, 28 ♂), 50 yearlings (24♀, 26 ♂), and the remainder were >1 year-old adults (145♀, 88 ♂, 1 intersex).

There was no evidence of *M. ovipneumoniae, Cryptosporidium*, *Giardia*, or Johne's disease in any of the 35 goats tested. However, processing crews euthanized 3 goats because of disease concerns: 1) a nanny with severe hoof lesions in case she might have, or spread *Treponema* bacteria. She was subsequently diagnosed as having non-treponeme bacterial dermatitis; 2) two kids assessed with potential contagious ecthyma (orf). In addition, 1 adult billy was euthanized due to a history of aggressive interaction with humans (additional details in Happe *et al.* 2020).

We monitored 262 of the 326 goats via GPS or VHF telemetry. Due to their small size or concerns about subsequent growth causing problems with fitness, some kids and yearlings were not equipped with radio collars. Analyses refer to this sub-sample of 262 animals. In summer 2020, Covid19-related restrictions precluded us from conducting telemetry flights to confirm the reproductive or survival status of non GPS-monitored mountain goats however a partial survey to document reproduction was accomplished in early September 2021.

Most monitored goats were in the prime ages of 3 to 7 years. The oldest documented animal was a 12-year old billy; we also monitored 2 10-year old nannies. Mean body condition indices were higher for males than females (Figure 3, Table 2). For both sexes, condition index was positively associated

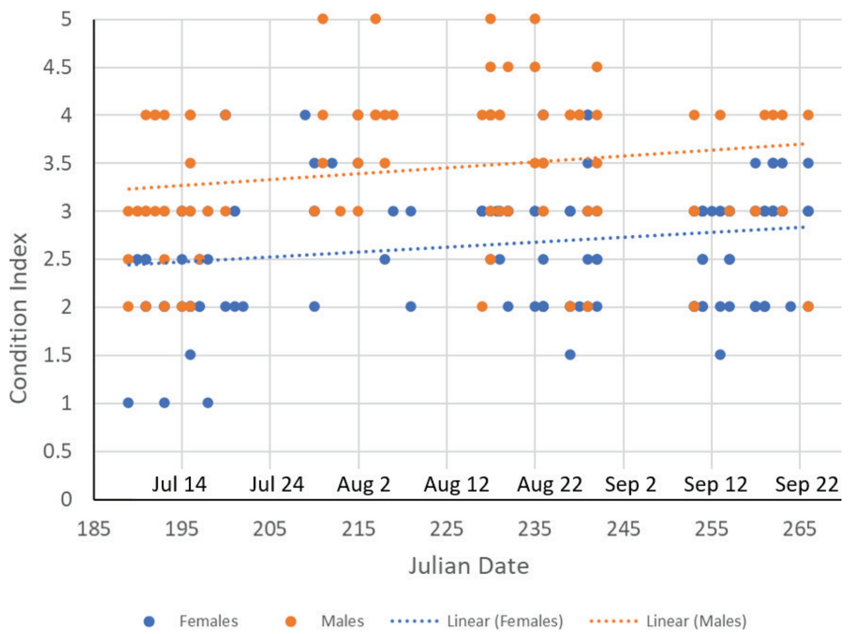

Figure 3. Body condition index as a function of Julian date. For adult males, condition index = Julian date X 0.00587, SE = 0.0035; $z = 1.679$, $P = 0.0965$. For adult females, condition index = Julian date X 0.00502, SE = 0.0021, $z = 2.346$, $P = 0.0203$.

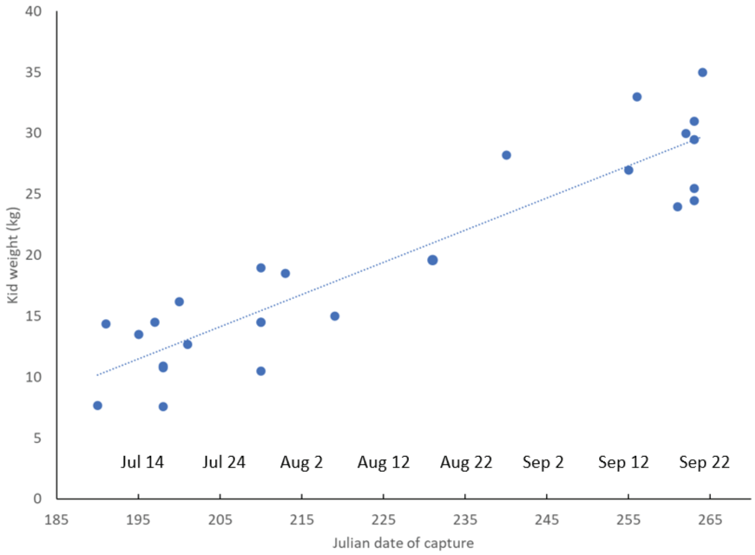

Figure 4. Kid body mass (e.g., weight) when captured as a function of capture date. Linear fit: -39.9 + 0.2637 X Julian date; $t = 11.26$, $P < 0.0001$. Neither gender, nor the gender X Julian date interaction were significant predictors.

with Julian date (i.e., goats captured later in the year tended to be in better condition than those earlier in the year). Kids generally were not scored for body condition index. However, as expected, kid body mass was heavier when captured later in the year (Figure 4).

Climate

Snow accumulation was generally about 85-90% of normal during early winter 2018 and considerably lower than normal (~ 60-70%) during March 2019. Snow accumulation was very low (<60%) in December 2019, but approached average by March 2020. Snow accumulation was slightly below normal in December 2020, but considerably above normal (~ 116-137%) by March 2021 (Figure 5).

Survival

We monitored adult (aged 1+) female mountain goats for 53,176 cumulative days post-release, producing an overall estimated annual survival of 0.53 (SE = 0.04). We monitored adult (aged 1+) male mountain goats for 34,019 days post-release, producing an overall estimated annual survival of 0.58 (SE = 0.04). Both survival rates were slightly higher than the initial 365-days post-release period, during which approximately 51% of adult females and 55% of adult males survived. We monitored kids for 3,963 days (censored for times during which we were unable to discriminate mortality from collar drop), generating an estimated annual kid survival rate of 0.25 (SE = 0.10).

Based on qualitative visual inspection (Figure 6), we identified 3 periods for further analyses of survival patterns: i) 150 days post-release, during which survival was low although seasonal conditions (roughly July through December) were expected to be best for goats (and thus we hypothesized survival may be affected largely by capture, translocation, and the stress of adapting to a new area); ii) the following ~ 200 days, which roughly coincided with the typically high mortality months of January through May; and iii) beginning a year after release, which we hypothesized sex/age-specific survival probability would largely reflect environmental conditions at the newly colonized sites.

Male and female survival was initially similar, but quickly diverged, with male survival notably higher than female survival between about 50 and 150 days post-release. Male survival declined more than female survival in late winter/early spring, and by 1-year post-release, male and female survival rates were similar (Figure 6).

Table 2. Released mountain goats alive or dead 150 days post-release, and alive or dead as of late March 2021. See text for details.

	Released	Alive at 150 days	Dead at 150 days	Alive March 2021	Dead March 2021
Adult Males	88	75	13	39	49
Adult Females	140	114	26	50	90
Adult Intersex	1	1	0	0	1
Kids	12	7	5	2	10
Yearlings	21	15	6	10	11
Total	262	212	50	101	161
$\bar{x}$ male age	4.17	4.34	3.45	4.04	4.26
SE	0.24	0.24	0.74	0.32	0.55
$\bar{x}$ female age	3.71	3.71	3.69	3.60	3.77
SE	0.14	0.15	0.69	0.23	0.18
Captured using					
Net gun	188	148	40	74	114
Dart gun	71	54	17	26	45
Released					
Same day	21	19	2	15	6
Next day	241	185	56	86	155
Goats considered					
Habituated	78	65	13	35	43
Not Habituated	178	135	43	63	115
Proportion Injured during capture	0.40	0.39	0.46	0.45	0.38
Male Condition Index	3.38	3.43	3.14	3.48	3.30
SE	0.08	0.09	0.21	0.13	0.42
Female Condition Index	2.65	2.73	2.29	2.79	2.56
SE	0.05	0.06	0.42	0.09	0.07

For goats surviving past the initial 150-day period, monthly mortality rates (assessed across all 3 years) increased through late winter, peaking in March before declining again through summer and autumn (Figure 7).

Translocated males were typically slightly older ($\bar{x}$ = 4.17, SE = 0.24) than females ($\bar{x}$ = 3.71, SE = 0.14; Table 2). More goats were captured with net gun than dart gun, most were released after an overnight stay, and most came from areas where goats were considered not habituated (Table 2). Additional insight into effects each of these may have had on short (150-day) and long-term (entire period) survival should be interpreted cautiously because raw numbers do not account for differences in the durations that individual goats were exposed to risk of death.

The strength of influences on survival is better provided by Cox Proportional Hazard modelling. In these analyses, negative coefficients (β values) indicate continuous variables negatively associated with the hazard (i.e., risk of death during the time period declined as the value of this variable increased). Odds ratios greater than 1.0 indicate categorical variables that were positively associated with the hazard (i.e., risk of death was greater than for the reference category).

We found no evidence that variables related to capture, handling, and transporting adult (aged 1+) goats (e.g., type of capture, whether injured, length of processing time, length of transport time) affected survival of translocated goats during the monitoring period, or during any of the sub-sections of the monitoring period (all $P > 0.10$, results not

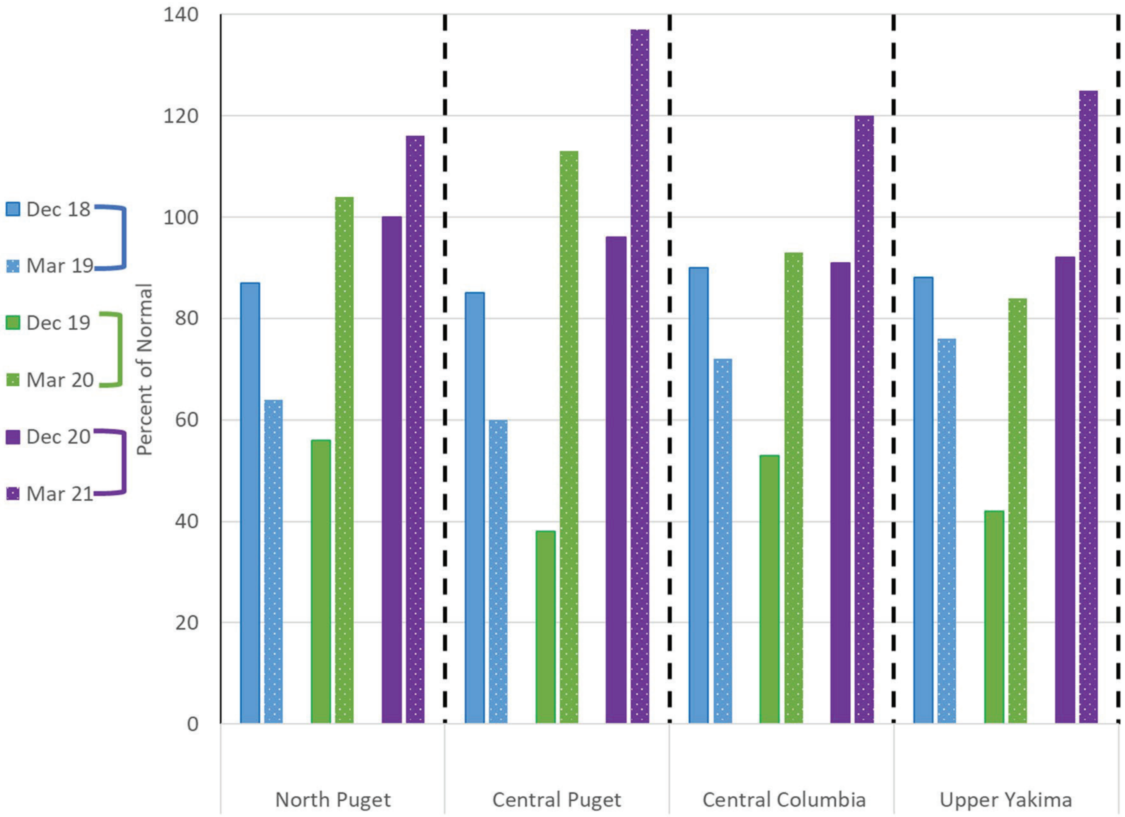

Figure 5. Snow-water equivalents as percentages of 30-year normal for 4 geographic subdivisions of northwestern Washington during the 3 winters of translocated mountain goat monitoring. Blue: winter 2018-19, Green: winter 2019-20; Purple: winter 2020-21; hatched: December, solid: March. Dashed line indicates 30-year average. Source: USDA NRCS National Water and Climate Center.

shown). However, we found a strong relationship between body condition score and subsequent survival of adult females: female goats with higher body condition scores survived better than those in poorer condition (Table 3; neither female body weight nor its interaction with body condition were significant). No relationships involving body condition, weight, or age were observed among adult males. Survival among adults during 2019 and 2020 was marginally lower than during 2018 (the reference year, Table 3). Among kids, both weight and date captured were significant predictors of survival (heavier kids were more likely to survive than lighter kids). As noted above, kid weight was not independent of capture date (kids captured later in each year being heavier; Figure 4). One additional variable was close to being significant at α = 0.10 level: nannies caring for a kid when

Table 3. Significant predictors of adult (age 1+) and kid mountain goat mortality hazard for the entire monitoring period, Cox proportional hazards models. For each, *n* = sample size, *z* = test statistic, *P* = probability, *β* = slope, SE = standard error of slope. Odds ratio statistics shown for categorical variables.

Variable	***n***	***β***	***SE***	***z***	***P***
Adult females only					
body condition	150	-0.429	0.160	-2.675	0.007
Kids only					
weight	26	-0.103	0.044	-2.324	0.020
capture date	28	-0.024	0.012	-2.018	0.044
Variable	***Odds ratio***	***Lower 95%***	***Upper 95%***	***z***	***P***
2019	1.357	0.934	1.973	1.601	0.109
2020	1.643	0.900	3.002	1.616	0.106

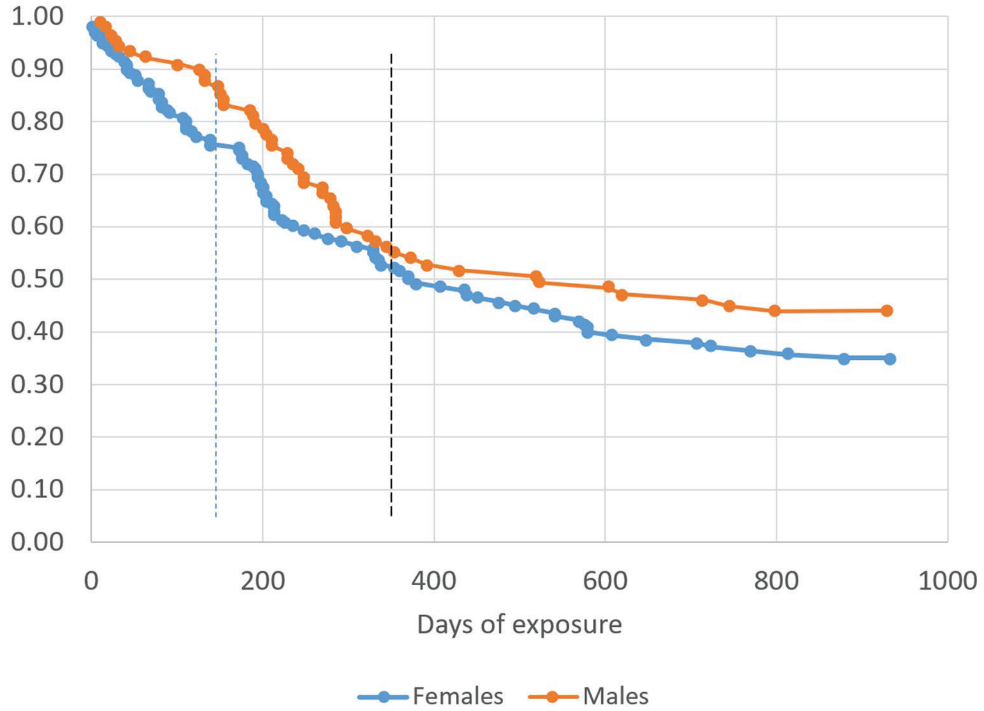

Figure 6. Kaplan-Meier type survival curve of adult (age 1+) mountain goats released in the north Cascades. We selected 150 days (short dashed vertical line) as a reasonable approximation of the time at which survival was decreasingly a function of capture and transportation effects, and increasingly a function of release site and adjacent areas. Mortality subsequently increased, but this coincided with late winter/early spring, when survival was at its lowest seasonal ebb (see Figure 7). Long-dashed vertical line indicates approximately 1-year post release.

captured were marginally more likely to die than other nannies.

In examining mortality hazards during only the initial 150-day period, poor body condition was again strongly predictive of low survival among adult females ($\beta_{condition}$ = -2.985, SE = 0.884, z = -3.377, P < 0.001; Figure 8), but this effect was conditional on adult female weight (β_{weight} = -0.074, SE = 0.039, z = -1.913, P = 0.056; $\beta_{weight*condition}$ = 0.029, SE = 0.012, z = 2.389, P = 0.017). As with the analyses of the full duration, no similar relationships were observed among adult males. Adult mountain goats released in designated wilderness areas were somewhat more likely to survive the initial period than those released in non-wilderness areas (odds ratio 0.535, 95% CI = 0.271-1.056, z = 1.802, P = 0.072). During the period between 150 days and 1-year post-release, the only significant categorical variable predicting mortality

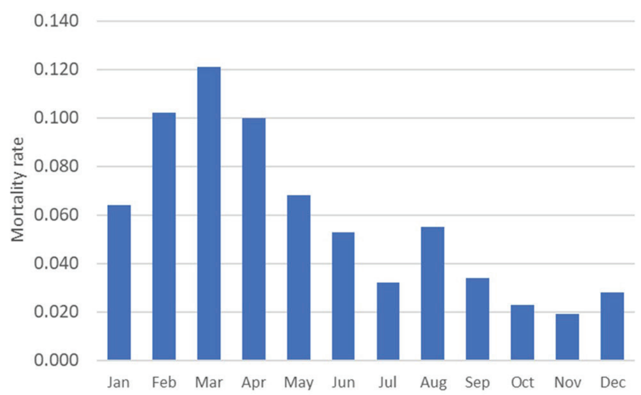

Figure 7. Monthly mortality rate of adult (age 1+) mountain goats released in the north Cascades that survived at least 150 days (thus reducing the effects of translocation on mortality and clarifying long-term seasonal dynamics, n = 205).

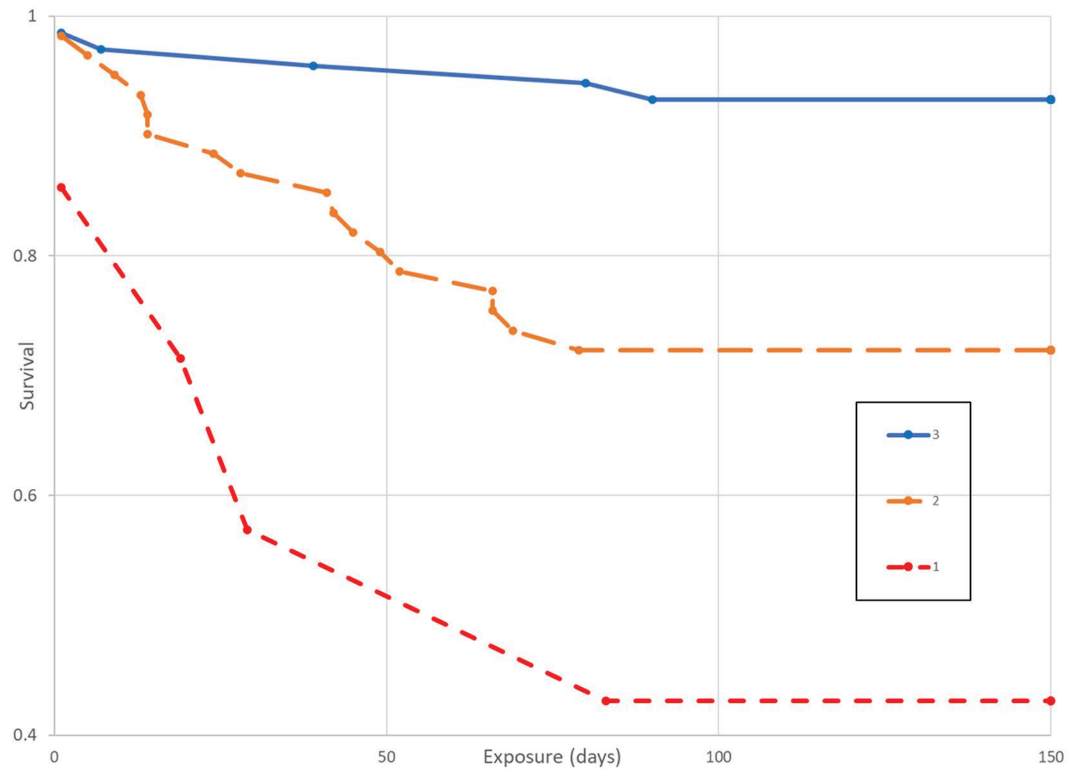

Figure 8. Kaplan-Meier type survival curves of adult female mountain goats released during 2018-2020 during their initial 150 days post-release, by body condition scores 1-3 (n = 7, 61, and 72, respectively) (sample sizes of females with body condition scores of 4 were too small for meaningful representation).

hazard was that adults released in 2019 were more likely to die than those released in the reference year of 2018 (odds ratio 2.345, 95% CI = 1.275-4.315 z = 2.738, P = 0.006). For adults surviving at least one year, mortality hazard was predicted by whether the release occurred in a designated wilderness area (odds ratio = 0.224, 95% CI = 0.113-0.977, z = -2.003, P = 0.045).

Survival was higher among goats released in the Alpine Lakes South, Cedar, and Glacier Peak clusters than those released in the Alpine Lakes North cluster (Table 4). Among adults that survived their first year, we found no evidence that subsequent survival was related to release site. However, when considered by aggregating sites into population clusters (more closely reflecting where animals ultimately settled, Harris *et al.* 2019): adult goats released at sites within the Glacier Peak zone had higher survival than those released in the Alpine Lakes North zone.

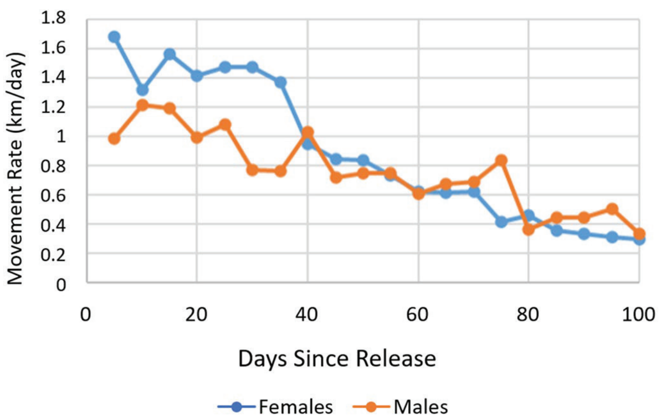

Figure 9. Movement rate (km/day) of translocated mountain goats by 5-day periods after release. Movement rates are underestimated because most collars provided locations only every 23 hours.

Table 4. Annualized survival of adult (age 1+) mountain goats released at each site (and aggregated into population clusters, Harris *et al.* 2019). For each category: Left column shows annualized survival for all goats (including those succumbing early when we hypothesize capture/transportation effects dominated), middle column shows survival for goats surviving the initial period to 150 days, and right column shows survival for goats surviving at least one year after release. Analyses of survival rate differences after 1 year had less power to detect true differences than others because of small sample sizes. Some goats moved away from the population cluster in which they were released; thus their fate depended in part on where they ultimately spent time.

Release site	Entire period	After 150 days	After 1 year
Hardscrabble Ridge	0.21	0.06	-
Index	0.29	0.31	0.35
Box Canyon	0.57	0.55	0.80
Chikamin	0.72[a]	0.67	0.84
Preacher	0.75	0.64	0.55
Cedar	0.78[a]	0.79[a]	0.71
Bald Eagle	0.76	0.65	0.61
Milk Lakes	0.66[a]	0.55	1.00
Pear Lake	0.75[a]	0.90	1.00
Prairie-Whitechuck	0.44	0.40	1.00
Whitechuck-Glacier	0.33	0.49	1.00
Cadet Creek	0.44	0.24	0.53
Cadet Ridge	0.72	0.71	1.00
Independence Lake	0.82	0.75	1.00
Stillaguamish Peak	0.48	0.78	0.67
Vesper Sperry	0.38	0.34	0.30
Tower Mountain	0.57	0.56	0.66

Release population cluster	Entire period	After 150 days	After 1 year
Alpine Lakes North	0.27	0.23	0.35
Alpine Lakes South	0.64[b]	0.60[b]	0.79
Cedar	0.78[b]	0.79[b]	0.71
Glacier Peak	0.62[b]	0.61[b]	0.92[b]
Sauk River South	0.48	0.44[b]	0.53
Upper Methow	0.57	0.56[b]	0.66
All	0.57	0.55	0.66

[a] *Higher than reference area Index (lowest survival with adequate sample size), $P < 0.05$*
[b] *Higher than reference area Alpine Lake North (lowest survival), $P < 0.05$*

Annualized survival rates of adults increased among goats that survived the early hazards; in some areas, survival rates approached those generally required for a sustainable population (Table 4).

Movements of translocated adults

Post-release movements

Immediately post-release, female goats moved more on average on a daily basis than males for the first ~ 40 days, after which movements rates were similar for the sexes (Figure 9). Considerable individual variability characterized movement patterns (Harris *et al.* 2019). Mean daily movement rates declined with time after release, although how much that reflected "settling down" and how much reflected the onset of winter (when movement of resident goats generally declines) cannot be distinguished with these data (Figure 10).

Seasonal elevational migrations

As expected, goats descended to lower elevations beginning in October, averaging about ~ 300 m feet lower during mid-winter than mid-summer (Figure 11). Similarly to findings of Rice (2008), translocated mountain goat females began their upward elevational movement in summer

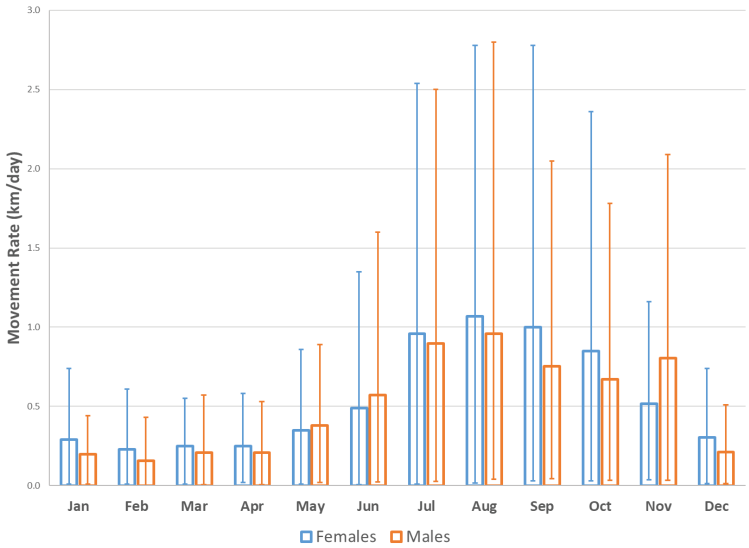

Figure 10. Mean (histogram) and 90% percentiles (error bars) of daily movement rates of mountain goats fitted with GPS collars.

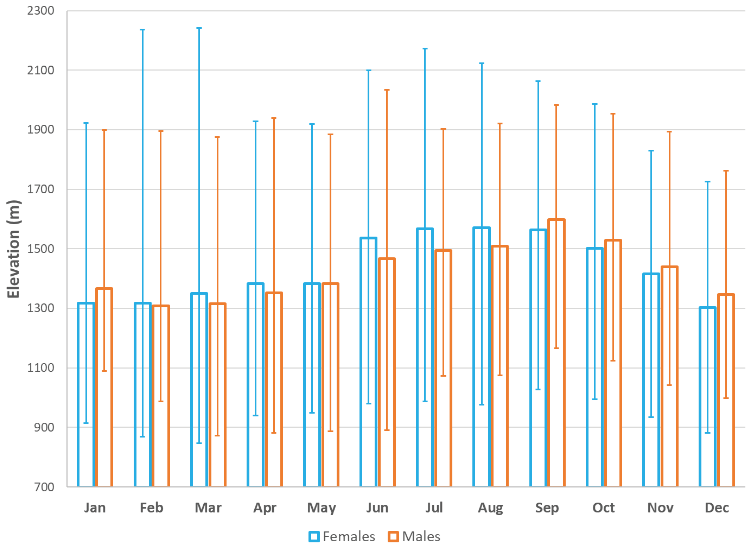

Figure 11. Mean (histogram) and 90% percentiles (error bars) of elevations of mountain goats fitted with GPS collars.

earlier than males, and spent more time at relatively low elevations than in the alpine.

Movements of translocated kid/nanny pairs

We found no evidence that nannies and kids (captured, transported, and released together) remained together for more than a day or two (see Figure 12). All kids released were effectively orphaned (although about 25% survived past the age of 1 year).

Locations used by mountain goats

As reported in Happe and Harris (2018), most goats moved considerably after release, adopting various patterns (Harris *et al.* 2019). Although the goats used a variety of habitats and elevations, we observed no movements suggestive of homing, nor of attraction to humans or human infrastructure (Harris *et al.*, in prep).

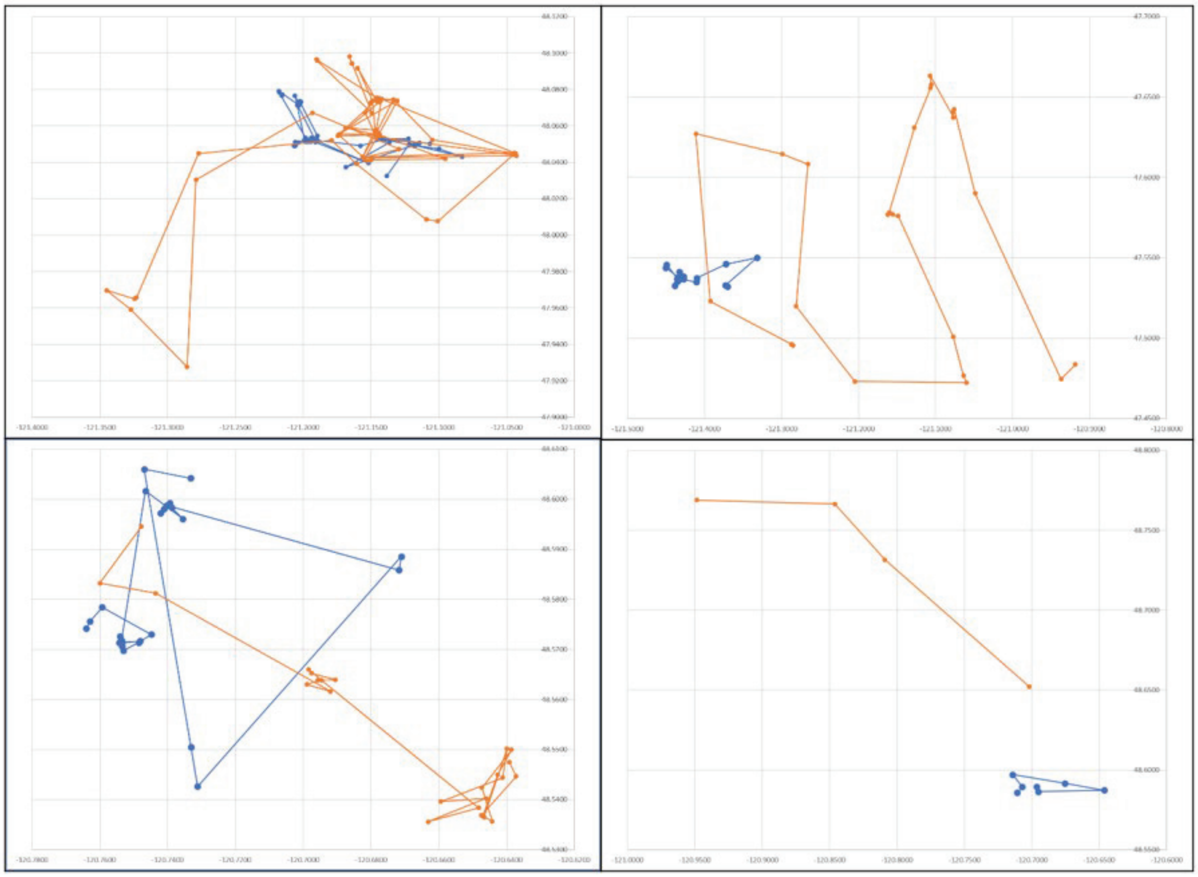

Figure 12. Post-translocation movements of nanny-kid pairs; nanny (orange), kid (blue). Upper left: nanny 5009, kid 5032, released at Tower Mountain, 7/28/20; upper right: nanny 5285, kid 5255, released at Hardscrabble Ridge, 8/28/19; lower left: nanny 5155, kid 5170, released at Upper Whitechuck, 7/20/19; lower right: nanny 5069, kid 5061, released at Tower Mountain, 7/28/20. Axes are latitude and longitude (decimal degrees). Durations and spatial scales differ.

Reproduction by translocated nannies

Because only 14 of the 98 goats released in September 2018 were adult billies, and because they had relatively little time to adapt to their new surroundings, we did not expect much reproduction from translocated nannies in spring 2019. Further, our monitoring budget was sufficient to allow visual confirmation of reproductive status of a selected handful of nannies. In summer 2019, teams of students from Western Washington University made 14 backpacking trips to observe selected nannies that could have produced kids and that were accessible within time constraints. The teams observed 8 of 18 candidate nannies. Of these, 3 were confirmed to have kids (Figure 13). Muckleshoot tribal biologists also confirmed kids with 3 of 6 nannies they visually identified in August 2019. Through radio-tracking, we observed an additional kid with the only nanny released in 2018 that we attempted to observe. Thus, we accounted for 7 kids born to nannies released in 2018 (out of 15 for which we had information). Covid-19 restrictions precluded field surveys for reproduction in summer 2020. On September 2 and 3, 2021, WDFW staff used aerial radio-tracking to observe 18 nannies (estimated ages 3–9, $\bar{x}$ = 6.0), confirming kids produced by 7 (one of which had twins, total of 8 kids from 18 females).

Figure 13. Translocated nanny (left) with recent kid, summer 2019.

DISCUSSION

We faced considerable logistical difficulties in moving goats to the best possible places. Choosing which release site to use for a given release was a complex decision, involving our knowledge of the number and sex/age composition of goats previously moved, the number and sex/age composition of goats *en* route, as well as weather and logistics. In year 2020, efforts were further compromised by the need to reduce the risk of staff contracting COVID-19.

We were not surprised to find that summer body condition was better among males than females, and that condition in both sexes generally improved over summer, or that kids were heavier when captured later. We would generally expect females (many encumbered by pregnancy and lactation) to recover condition later than males through the summer months (when forage nutrition is optimal).

The body condition index at capture was the strongest and most consistent predictor of survival. Body condition, in turn, is typically a complex function of nutrition and energetic demands. Numerous studies on ungulates demonstrate that pregnancy and lactation are the single largest determinants of female body condition: Our data are consistent with these findings. We hypothesize that the stress of capture, transport, and learning how to find needed resources in a new place often manifested in lower survival, particularly in individuals already vulnerable. Similarly, we interpret the lower survival of females (particularly during the acclimation period) – the reverse of patterns typically seen among resident ungulates – as an additional signal that body condition at capture (lower among females than males) was an important influence on survival.

We made no attempt to quantify body condition among kids. We were not surprised to document higher survival among kids captured later in the summer, when they were larger and fully weaned. Indeed, our original intention – though not always realized – was to prioritize the youngest kids for captive placement precisely because we expected these individuals to face the longest odds of survival. As reported in more detail (Harris *et al.* 2019), our efforts to encourage nannies and kids to stay together post-release seemed unsuccessful as all released kids were effectively orphaned within days after release (see Olson *et al.* 2010). Consequently, the 25% annual kid survival was greater than expected (and some evidently survived their 2nd year). Festa-Bianchet and Côté (2008) reported 64% average first year survival for mountain goat kids accompanied by their nannies. Although we were unable to monitor kids closely in 2020, earlier monitoring indicated that some orphaned kids found and began travelling with other goats (both translocated and resident; Harris *et al.* 2019).

In planning this large and complex project, we gave considerable thought to the optimum timing for capture and release of goats. An overriding constraint was weather. Anticipating that most releases (and all captures) would require helicopter support, we prioritized a time window in which weather conditions – not known for clear skies in this part of the world – would most likely be safest for flying. We faced challenging weather conditions during all 4 field programs. In retrospect, knowing that survival was higher for goats in better body condition and that body condition in turn gradually increased through the summer months, a reasonable question arises as to whether released goats would have survived better if all field work occurred later during the snow-free months. Our analyses suggest they would, but we caution against a straight-forward conclusion. Goats translocated in September 2018 fared best, but also happened to face the least challenging weather conditions during their first winter at their new locations.

After accounting for the anticipated acclimation period, seasonal patterns of survival were broadly consistent with our expectations from native mountain goat populations. Mortality peaked in late winter/early spring, when animals were at their most susceptible. It is intriguing that survival was lower for goats whose first winters in their new environments were more severe than those whose first winter was the relatively mild one of 2018. However, other factors (such as timing of release, types of animals moved, and selection or release sites) may have played a role in the year-specific differences in survival probability.

Our finding that mountain goats released in designated wilderness fared better than those released in non-wilderness merits some scrutiny. We caution against adopting the intuitive but potentially misleading interpretation that isolation from motorized humans was the primary factor. We found no differences in survival between goats released in accessible areas and those released in remote areas. Although all release sites in designated wilderness were, by definition, remote from humans, our non-wilderness helicopter sites also were in remote areas, far from motorized access. We hypothesize that the strength of the categorical variable "wilderness" was associated with larger sample size inherent in comparing a simple, binary variable (in or out) than provided for in site-specific categorical analyses, and that it masked more subtle differences in survival among various release sites.

We documented proximate cause of death for a small minority of mortalities. Almost all deaths occurred in steep and remote terrain where accessing carcasses rapidly enough to diagnose cause of death was not feasible. Many mortalities occurred within designated wilderness, where our legal (USFS permitted) access using a helicopter was restricted to releasing goats and did not extend to retrieving carcasses or collars. No translocated goats were harvested by hunters permitted by WDFW during 2018-2020 (few translocated goats spent any time within designated goat hunt units), and we are not aware of any translocated goats taken under Tribal hunting programs. In the few cases where cause of death was determined, it was largely predation by cougar (*Puma concolor*).

From the outset, we anticipated that survival of translocated goats would be lower than that expected among comparable classes of goats unexposed to the stress of capture, transport, and a new environment. The overall annualized survival of 0.53 for females and 0.58 for males was, nonetheless, a disappointment. However, we are encouraged that annualized survival of goats past the initial 150-day acclimation period, and particularly those living at least 1 year, was approaching survivorship (~ 0.90) we would expect from a stable or increasing goat population. We also found it reassuring that any factors related to capture or transport were not significantly associated with mortality.

It appears that our objective of providing the seeds of populations that would display spatial integrity and facilitate breeding aggregations has been only partly successful. Thus far, most surviving mountain goats have spread surprisingly uniformly throughout the entire translocation area (see also Jorgenson and Quinlan 1996). Additionally, about 1/3 of the goats displayed impressive abilities to find other goats with which to form groups. Our initial interpretation suggests that some population clusters were better than others at attracting goats, and/or providing better conditions for survival. Consequently, site-specific differences in survival to date may reflect true differences in aspects of habitat quality that affect survival (but not necessarily reproduction, which we were able to quantify only partially).

In addition to site characteristics that potentially affect vital rates in a bottom-up manner (e.g., forage quality), we speculate the presence of geographic heterogeneity in the strength of top-down forces, i.e., predation. We anticipated that newly arrived mountain goats, naïve to local conditions, would be more susceptible to predation (particularly by cougars) than resident goats. That even a year after release the overall survival rate remained below that needed for population growth (particularly in some zones) suggests the possibility that experienced goats may also face unsustainable predation rates. Although cougars most commonly subsist on deer (*Odocoileus* spp.), the ability of specialist cougars to limit growth or induce declines in small, isolated, or reintroduced bighorn sheep (*Ovis canadensis*) populations is well known (Rominger *et al.* 2004, Festa-Bianchet *et al.* 2006). Cougar predation has also been implicated as a substantial mortality cause in a small, isolated, non-native mountain goat population (Lehman *et al.* 2020). Mountain goat populations are not typically considered predation-limited, with most predation coming from grizzly bears (*Ursus arctos*), occasionally wolves (*Canis lupus*), and – on young kids – golden eagles (*Aquila chrysaetos*; Festa-Bianchet and Côté 2008). Where dominant grizzly bears and wolves were eliminated or greatly reduced, cougars have sometimes expanded not only in abundance but in their trophic niche, adapting to use prey species other than the deer that fundamentally sustain their populations (Rominger 2017, Lehman *et al.* 2020). Limitations of our data preclude us from inferring whether such a dynamic played a role in this case, but we note that if it did, mountain goat populations in the Cascades may respond positively if grizzly bears and wolves ultimately return and reduce cougar abundance (Rominger 2017).

Periodic updates of survival among those goats still wearing GPS collars would be useful to confirm or alter these preliminary conclusions. As well, when schedules and COVID protocols allow, aerial monitoring to obtain rough estimates of reproductive rate among translocated nannies would add valuable insight into the prospects for long-term success of the translocation program.

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Removing non-native mountain goats from the Olympic Peninsula

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ABSTRACT: In 2018 the National Park Service (NPS), in cooperation with Washington Department of Fish and Wildlife (WDFW) and the U.S. Forest Service (USFS), initiated a project to remove all non-native mountain goats from Olympic National Park and contiguous habitat in Olympic National Forest. The first step of the two-part plan was capture and translocation. From September 2018 through August 2020, we conducted 4 two-week long aerial capture sessions. During those operations we removed 381 of the estimated 725 goats from the Olympic Peninsula (OP), of which 325 were translocated to the Cascade mountain range in Washington State, and 16 kids were distributed to zoos. Operations halted at the end of the 4th session when goats became increasingly hard to catch and capture mortality exceeded 10%. The remaining goats will be removed through lethal means.

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KEY WORDS: mountain goat, non-native, Olympic Peninsula, *Oreamnos americanus,* removal

INTRODUCTION

Although native to western North America, mountain goats (*Oreamnos americanus*) in addition to several other alpine species, are not native to the isolated Olympic Mountain range in northwestern Washington State, USA (Figure 1). Mountain goats were introduced in the Olympic Mountains during the 1920s prior to the establishment of Olympic National Park (ONP) in 1938 (Scheffer 1993, Houston *et al.* 1994, Noss *et al.* 2000). Over the succeeding decades, the population increased in size and expanded throughout the Olympic Mountains. By the mid-1970s evidence accumulated of negative effects of overabundant mountain goats on soils and endemic plants in ONP's high-elevation plant communities (National Park Service 1995). Despite the desire to minimize negative effects on sensitive alpine resources, mountain goats remained charismatic and popular with the public. In fact, the question of what to do with this introduced herbivore is among the most hotly contested in the ecological literature regarding invasive species (Jessup 1992, Scheffer 1993, Houston *et al.* 1994, Hutchins 1995, Wagenvoord 1995, Noss *et al.* 2000). This controversy resulted in an unfinished mountain goat management planning process in the mid-1990s (NPS 1995) and Congressional action to stop a lethal removal project in 1997 (Associated Press 1997). In 1983, ONP conducted the first aerial survey to estimate mountain goat population size throughout the Olympic Mountains (Houston *et al.*1986), returning an estimate of 1,175 (SE = 71). During the early 1980s, the NPS, working with WDFW, captured and transplanted mountain goats from ONP to other ranges throughout several western states to reduce the population (Houston *et al.* 1991). From 1981 through 1989, 407 mountain goats were captured and removed from the park (Houston *et al.* 1994). An additional 119 mountain

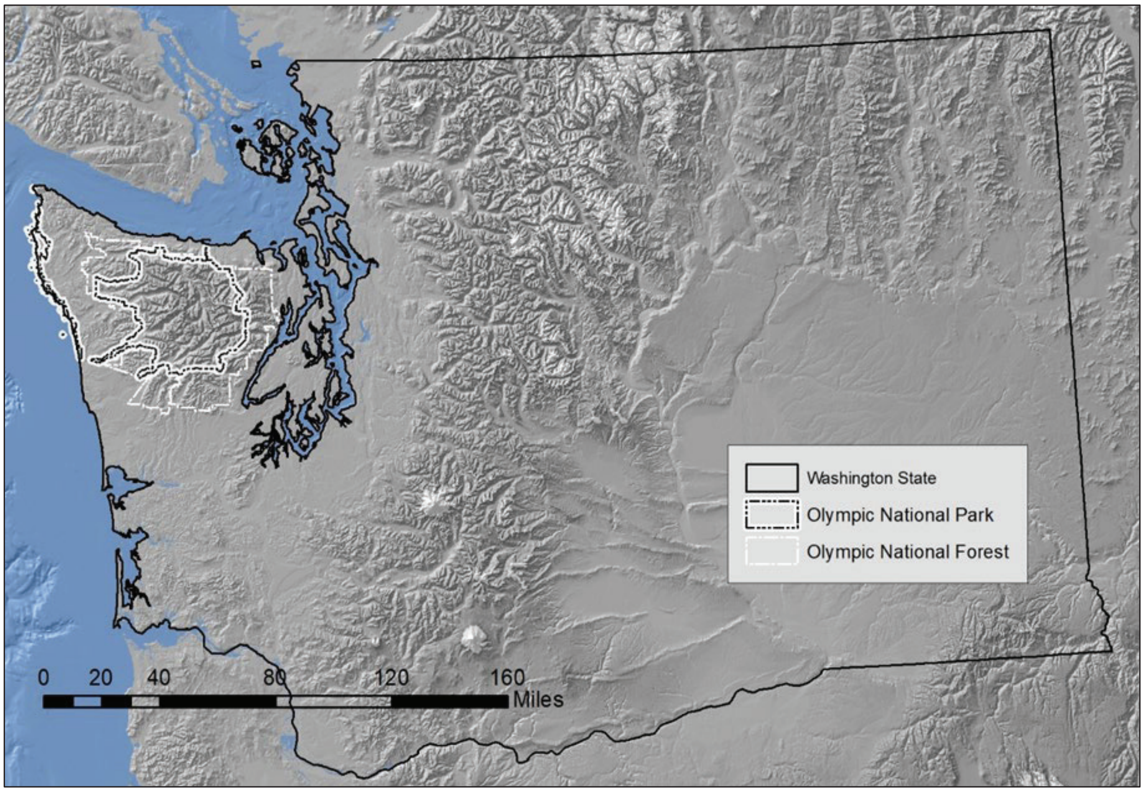

Figure 1. Olympic National Park and the surrounding Olympic National Forest, Washington.

goats were killed legally during sport hunting seasons outside the park, and three known illegal kills occurred within ONP during 1983–1997. The aerial capture and removal program was halted in 1990 due to human safety concerns associated with aerial capture operations (Houston *et al.* 1994). No mountain goats were transplanted from the Olympic Mountains during 1990-2018.

A second mountain goat survey, conducted in July 1990 following the cessation of initial capture and transplant operations, produced an estimate of 389 (SE = 106; Houston *et al.* 1991). Subsequent surveys conducted in 1994, 1997, and 2004 produced estimates near 300, but a significant increase in the population was detected by the survey work conducted in 2011 (Jenkins *et al.* 2012). Along with the increase in the goat population came increasing levels of habituation of goats to human visitors and conditioning to human-derived salts. Some goats became aggressive in their salt-seeking behavior, resulting in a human fatality in 2010. The most recent rigorous estimate, conducted in 2016, indicated that the population, estimated at 623 (SE = 43), increased approximately 8% annually since 2004 (Jenkins *et al.* 2016), raising concerns anew about additional increases (and associated resource damage and visitor safety) before a new reduction effort could begin. If this rate of increase continued, NPS estimated ~725 animals in the population by 2018.

On June 18, 2018, after years of planning and extensive public review, a Record of Decision was signed, authorizing a plan to remove mountain goats from ONP. The declared purpose of the plan was to "…reduce or eliminate impacts on park resources from exotic mountain goats while reducing public safety issues associated with the presence of mountain goats in the park" (NPS 2018: 1). Its objectives included to "…work cooperatively with co-managers of mountain goats or habitats in Washington State" and to "…provide opportunities to reestablish or augment sustainable native mountain goat populations in suitable mountain goat habitat…" The WDFW and USFS were cooperating agencies in the planning process, and consequently the plan covered Olympic National Forest lands adjacent to the park, as well as state and USFS lands in the Washington Cascade mountain range. The approved plan included two phases: a 5-year initial management phase and a subsequent 15-year maintenance phase. The goal of the initial management phase was to remove at least 90% of the goat population from the Olympic Peninsula (on both NPS and USFS lands), first through capture and translocation and later by lethal removal when capture operations were deemed no longer safe or feasible. WDFW had responsibility for translocating mountain goats (National Park Service 2018, Harris *et al.* 2020).

Herein, we describe capture efforts and accomplishments during the first 3 years of the initial management phase. We cover efforts that took place during 4 capture sessions (September 2018, July 2019, August 2019, and July/August 2020). Details on capture logistics and planning, including rationales for choice of dates for operations and locations of operation bases, are provided in National Park Service (2018), Happe and Harris (2018), and Harris *et al.* (2019). The lethal removal phase is ongoing and data will be provided in subsequent documents. Planning and implementation of the reintroduction and augmentation component in the North Cascades are provided in Harris *et al.* (2020).

METHODS

Field capture

Capture teams consisted of 3-5 crewmembers and the pilot. All crewmembers were experienced and qualified in the use of remote chemical immobilization. The capture team caught goats by net gun, chemical immobilizing dart, or a combination of both. Details of chemical immobilization are provided in Appendix 1. After securing a goat, the capture team immediately reversed the capture drug (if one was used) and all adult goats were to receive the sedative midazolam in the field to reduce stress during the transport flight. Captured goats were hobbled, blindfolded, and secured in specialty sling bags until they were ready for transport (Figure 2). Field capture datasheets and horn guards were attached to each goat prior to transport.

Captured goats were transported via sling load to the closest helicopter base, where they were secured, placed in a sternal position, and given a quick evaluation. Goat sling load size ranged from 1 to 5, with an average of 2 goats per load (loads with larger numbers of goats included kids accompanying their mother). Very active goats were given an additional dose of midazolam at the helicopter base, and those that were hot (see below) were immediately cooled with water. In 2020 a few goats appeared overly sedated upon delivery, to the point where it was difficult for them to keep their head up and maintain their airway during the transport flight (this issue was not observed in 2018 or 2019). Midway through the 2020 capture operation, after consulting with the veterinarians and the capture team, we ceased administering midazolam in the field, and instead gave it by hand injection to all adult and yearling goats after they were delivered to the helicopter base.

Mountain goat processing

After delivery to the helicopter base, each goat was transported to the processing area to be weighed and then taken to one of 3 processing teams (Figure 3). Processing teams were led by a veterinarian or an experienced vet tech and consisted of 2-3 staff experienced with working with immobilized ungulates, 1-2 trainees, and a designated data recorder. Information from the capture team or the helicopter base staff regarding potential injuries or other concerns about animal condition were conveyed to the processing team. Staff veterinarians evaluated each goat for emergency medical conditions and treated, if necessary. Animals were placed in a sternal position (often supported by sandbags), and vital signs (temperature, respiration, heart rate) monitored and recorded. Cotton ear plugs were inserted, eyes were checked and flushed with sterile eye wash if necessary, and sterile ophthalmic

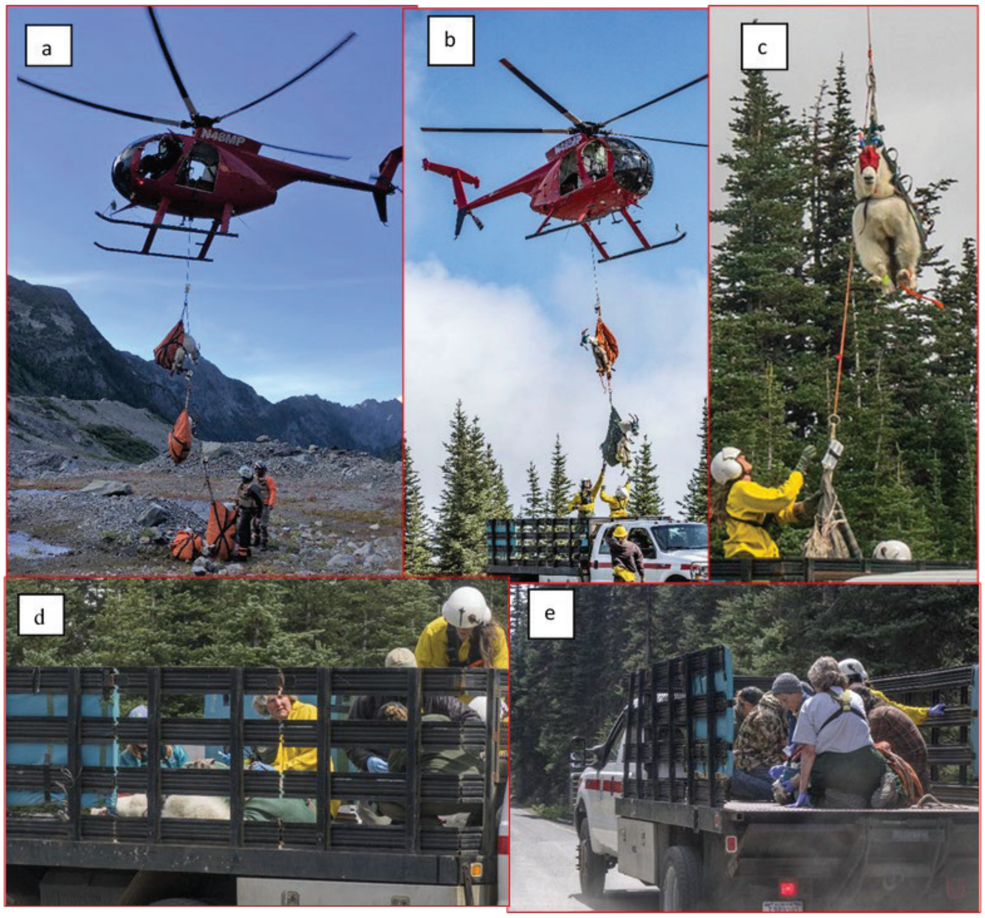

Figure 2. Captured goats attached to sling load in the field (a), delivered to the transport truck (b,c), evaluated prior to transport to the processing area (d), transported to the processing area (e). Photo credits: Leading Edge Aviation (a), Darryn Epp (b), John Gussman (c,d,e).

ointment applied. Horn guards, hobbles, blindfold, and earplugs remained in place throughout the processing.

In addition to sex and age, body mass, horn dimensions, body measurements, and lactation status were recorded. Samples taken included nasal swabs, tissue for DNA extraction, blood, hair, and fecal samples. After evaluation by a veterinarian, each goat was assigned a body condition score of 1 to 5, where 1 was very poor and 5 was very good, and largely reflected the fat layer depth over the vertebrae and ribs (Iowa State University 2011). All goats were given BoSe® (3 ml/45kg) and Vitamin E-300® (5 ml/45kg) to mitigate oxidative cellular stress, fluxinin meglumine (1.1 mg/kg, a nonsteroidal anti-inflammatory and analgesic), ivermectin (0.2 mg/kg, an anti-parasitic), and oxytetracycline (10mg/kg, an antibiotic). In 2019 we added the anthelmintic albendazol (10mg/kg). In addition, all adult goats and yearlings were given 0.3mg/kg of long-acting tranquilizer haloperidol (Hofmeyr 1981, Wolfe and Miller 2014) in recognition of the upcoming ~ 24 hours in transport. In addition, most received 1 L buffered isotonic fluids subcutaneously to prevent dehydration. Each animal was given an ear tag with the unique number corresponding to the animal number in the records. Photographs were taken of the horns and teeth of each animal in 2018. All adults were equipped with a radio-collar; all but 3 were GPS collars. Kids that were released also received breakaway VHF collars in 2018, and breakaway GPS collars thereafter.

Mountain goats are sensitive to intra-group hierarchical relationships, and typically maintain

Figure 3. Mountain goats in the processing area. Upper left: weighing. Upper right: overview of processing area. Lower left: A processing team. Lower right: Loading into crate.

social relations via aggressive interactions (Geist 1967). In a stressful, unnatural situation (such as capture and retention in captivity), we considered the goats would likely engage in considerable aggression if housed in groups. Mountain goats also are sensitive to stress, warm temperatures, and capture myopathy (Hebert *et al.* 1980, Blood 2001). Blood (2001) reported that transplant-caused mortality rates for mountain goats in British Columbia during 1980-2000 were higher (10.6%) than for other translocated ungulates. Thus, we elected to transport mountain goats from the OP to release sites using individual crates (ODFW and CTWSR 2010) built (*n* = 50) specifically for the program. Crate design was modified from those developed by the Oregon Department of Fish and Wildlife (ODFW); crates constructed of heavy-duty plywood with metal frames and vertically sliding doors were approximately 144 cm long, 47 cm wide, and 108 cm high, and were equipped to facilitate moving by hand and slinging by helicopter. Three horizontal rows of holes (1 to 4 cm diameter) drilled into the sides of each crate ensured adequate ventilation during transport. After processing, each goat was moved directly into a transport crate (Figure 3). The crates were kept in a secluded and shaded area, away from noise and disturbance, until they were ready to be loaded into the transport trucks. If individual goat rectal temperature remained elevated (>38.5°C (101.5°F)) or ambient temperatures rose to a point where over-heating in the crate was a concern (as indicated by panting goats), block ice was placed in the crate and the crate area was cooled by fans and/or a water misting system, or crated goats were placed in refrigerator trucks where the ambient temperature was adjusted to approximately 10° C (50° F).

Mountain goat kids for captive facilities

Because we anticipated low survival of translocated kids (Olson *et al.* 2010), and it was difficult to pair all kids with their mother, we made efforts to place as many kids as possible with accredited captive facilities. As per a Memorandum of Understanding between WDFW and Northwest Trek Wildlife Park (NWT, associated with Port Defiance Zoo and Aquarium, Tacoma, Washington, accredited by the Association of Zoos and Aquariums, AZA), kids captured without their mothers were donated to NWT to care for until qualified zoological parks with interest could adopt them.

RESULTS

Over the 4 removal sessions, the helicopter flew 270 hours during 41 days (Table 1). We removed 381 goats from various sections of the OP (Figure 4), of which 325 were transported to the Cascade Range on the mainland for release (Harris *et al.* 2020). The difference between removed and released totals are discussed below.

Although the 2018 capture session was constrained by challenging weather (4 of 14 days were unsafe for helicopter flights, and capture work was cut short due to imminent inclement weather during 7 of the remaining days) and we were restricted to areas near 1 helicopter base, we were able to remove 115 goats. This is largely due to proximity of Klahhane ridge, which was adjacent to the helicopter base (cluster of 2018 captures just north of the Hurricane helicopter base, Figure 4). This area contained ~50 goats and 31 were removed.

Two large males (>110 kg) died during transport on the first day of our capture operation in 2018, most likely due to the small size of the transport crate relative to their body mass. We consequently stopped catching adult males until 2 larger crates, previously used for bighorn sheep (*Ovis canadensis*) rams, could be brought to the site. We then restricted male captures to accommodate what we could transport with the

Table 1. Helicopter use and goats captured on Olympic Peninsula, Washington, 2018-2020

Year	Capture month	Days/ session	Flight hours/day			Number goats caught/ day			Number of goats	
			Min	Max	Total hours	Min	Max	$\bar{x}$	Removed	Released
2018	Sept	10	1.6	8	61.1	4	16	11.5	115	98
2019	July	10	2.5	8	61.7	3	15	8.9	89	76
2019	Aug	11	5.9	8	80.3	2	16	11.1	122	101
2020	Jul/Aug	10	3.2	8	66.8	3	15	5.5	55	50
Total		**41**			**269.9**				**381**	**325**

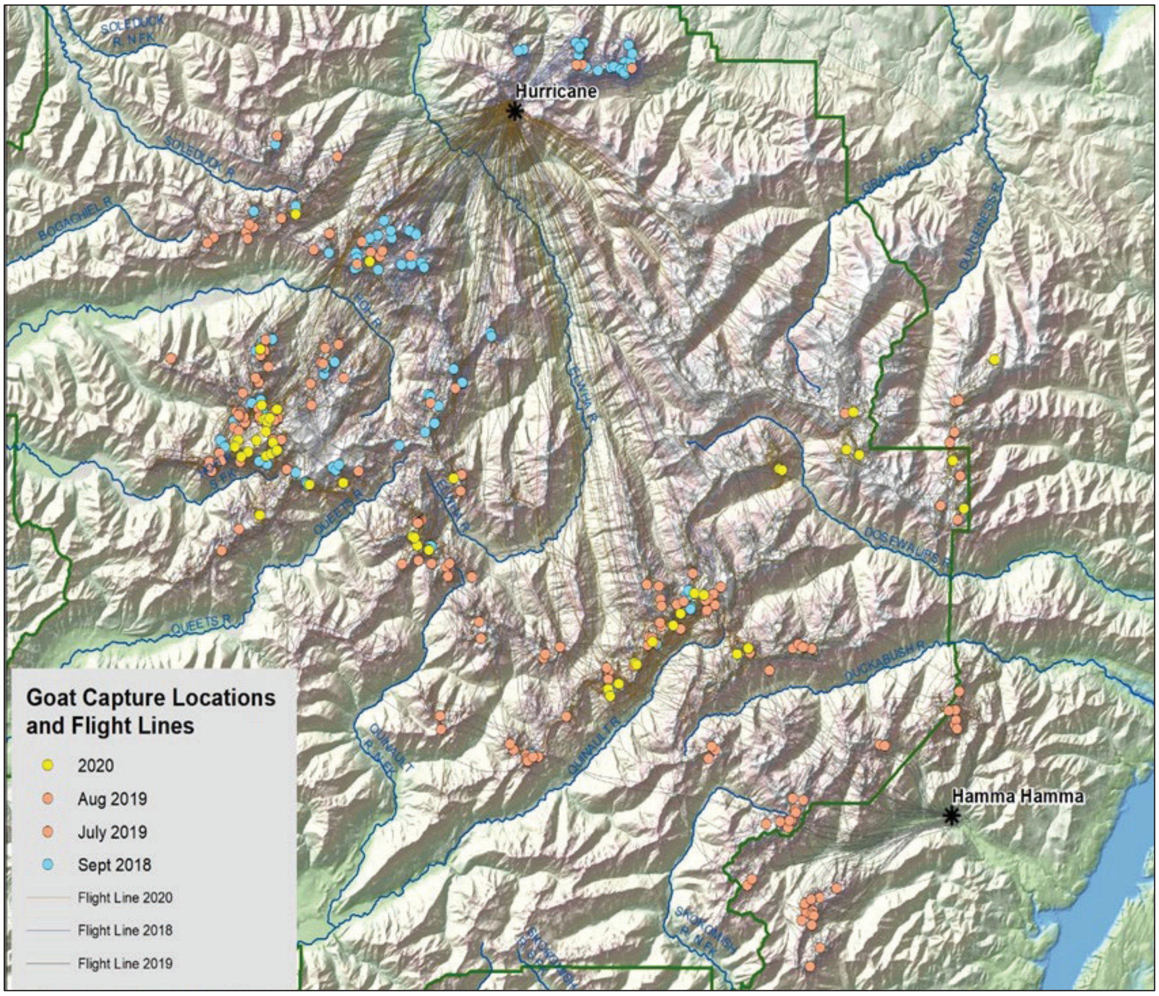

Figure 4. Staging areas, goat capture sites, and helicopter flight lines, 2018-2020. Green line shows the boundary of Olympic National Park.

crates on hand. In addition, in order to improve ventilation, we drilled two additional rows of holes in the crates (they originally had just one). After that change, we lost no more males during transport. After the 2018 capture season, volunteers constructed 10 additional crates with dimensions approximately 164 cm long, 67 cm wide, and 108 cm high that we used for males >110 kg.

During 2019 we removed 211 goats (Table 1). We encountered weather issues in July but made up for the lost capture days in August. Although only 4 additional goats were removed from Klahhane Ridge, capture efficiency remained high due to using a second helicopter base in the southeastern Olympic Mountains at Hamma Hamma (Figure 4). During the 2020 capture session (operated only from Hurricane due to COVID-19 limitations) we removed only 55 goats. Although the weather was more cooperative, goats proved harder to find and harder to capture.

The percentage of goats caught by nets increased over the operation from 59% in 2018 to 75% in 2020 (Figure 5). Mean time-to-restraint (from deploying the net or dart until the animal was tractable) was shorter with nets than darts. In addition, time-to-restraint for darted goats decreased during the operation; the most notable change occurred in 2019 when we switched immobilizing agents from carfentanil to thiafentanil (Figure 5). Mean time between darting and delivery to the helicopter base averaged 36 minutes and was similar across all years. Minimum times ranged

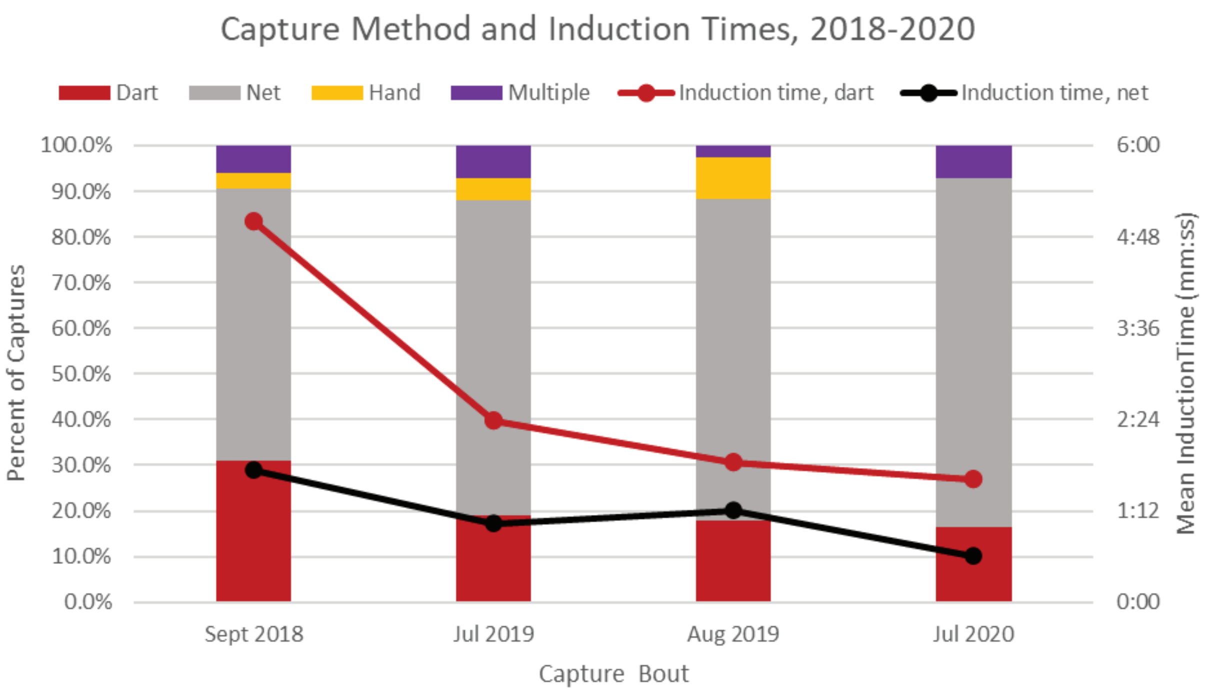

Figure 5. Capture method and time to restraint for mountain goats in the Olympic Mountains, 2018-2020. Times are for when only one capture method was used. Multiple = more than one method employed on a goat, such as a dart followed by a net, or 2 darts.

from 3 minutes in 2018 to 17 minutes in 2020, and maximum times ranged from 1:09 in 2019 to 1:39 in 2018. As anticipated (National Park Service 2018), goats became scarcer and more elusive, and capture efficiency (goats captured per flight hour) decreased as capture operations progressed (Table 2).

Capture mortality rates also increased as the operation continued, primarily due to remaining goats residing in steeper terrain, and injuries associated with falls. The exception to the trend occurred in August 2019, when capture efficiency rates and mortality rates improved slightly from that experienced the previous month due to availability of goats in relatively accessible Mt. Elinor area. August 2019 was the only time that the area was available for capture; it had a moderately high density of goats and was close to the southern staging area (Figure 6).

Adult females comprised the largest sex/age group among goats removed, followed by adult males (Table 3). The higher number of adult females was a result of our avoidance of males during the 2018 capture. One animal was

Table 2. Capture efficiency and goat mortality, Olympic Peninsula, Washington, 2018-2020.

Year	Capture month	Goats removed/hour	Goats translocated/hour	Capture Mortality
2018	Sept	1.88	1.78	5.2%
2019	July	1.44	1.30	7.3%
2019	Aug	1.52	1.38	5.9%
2020	Jul/Aug	0.82	0.76	9.1%

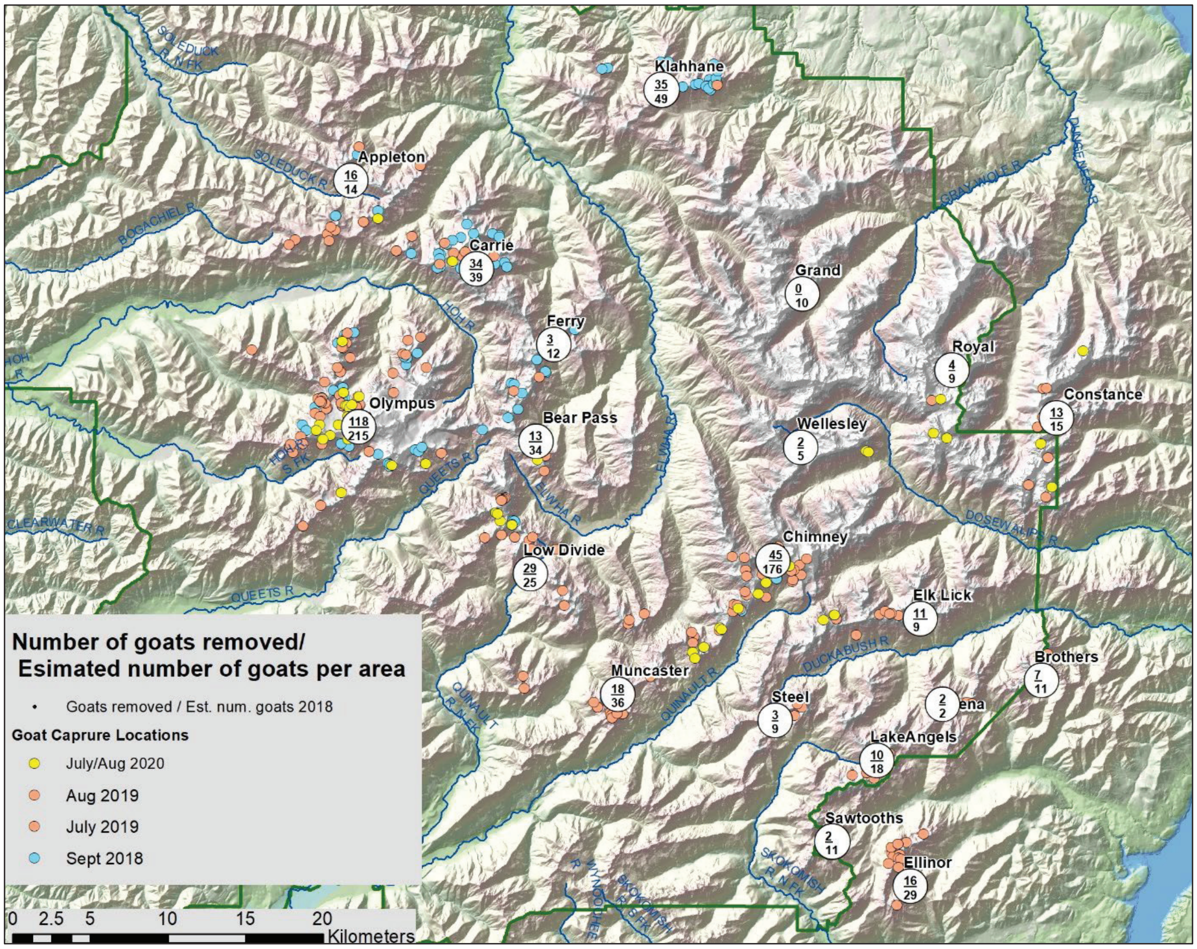

Figure 6. Total number of goats removed (upper number) and the estimated number of goats present (lower number) at the onset of capture operations in 2018. Also shown are capture locations, by year.

considered "intersex" (pseudohermaphrodite), possessing phenotypic characteristics of both genders (see Harris *et al.* 2019 for details). Numbers of goats removed roughly aligned with estimated abundances in 2016 (Jenkins *et al.* 2016), with the largest number coming from the Mt. Olympus area (Figure 6). Twenty-two animals intended for translocation died due to capture injuries (Table 4). Six goats were euthanized: Three with suspected disease, two in condition too poor for transport, and one with a history of aggressive behavior and classified as unsuitable for translocation. Eight additional goats were removed lethally by capture crews because live capture was deemed dangerous or unfeasible. Four died during transport, although only 2 deaths were attributed to the transportation process. Our protocols called for all goats to be awake during processing.

They were mildly sedated with midazolam in the field or at the helicopter base, and later haloperidol during the processing. If an animal was too active, an additional dose of midazolam was administered at the discretion of the attending veterinarian (see Appendix 1). Most goats fared well with our treatment protocols. The primary problems were capture injuries (falls). All injuries were evaluated by project veterinarians to determine survivability; four deaths attributed to capture mortality were goats euthanized due to capture injuries. In general, if the attending veterinarians thought that the goat had a reasonable likelihood of survival based on clinical evaluation

Table 3. Goats removed from the Olympic Peninsula, Washington, 2018-2020.

Sex	Age	Klahhane	Appleton	Bear Pass	Carrie /Ferry	Chimney	Constance	Elk Lick/steel	Low Divide	Olympus	Lake Angels	Muncaster	Royal/ Wellesley	Elinor/Sawt.	Lena/Brothers	Total
Female	Adult	14	9	6	14	19	3	5	8	54	3	6	1	7	1	**150**
Female	Yearling	2	0	0	2	3	1	2	3	8	2	3	1	1	1	**29**
Female	Kid	1	2	1	1	5	0	0	3	8	0	3	0	0	1	**25**
Male	Adult	10	3	5	14	13	6	5	6	26	4	3	4	5	6	**110**
Male	Yearling	2	1	1	3	2	1	1	6	8	0	1	0	2	0	**28**
Male	Kid	5	1	0	3	1	2	1	2	12	1	2	0	3	0	**33**
Intersex	Adult	0	0	0	0	0	0	0	0	1	0	0	0	0	0	**1**
Unknown		1	0	0	0	2	0	0	1	1	0	0	0	0	0	**5**
Total		35	16	13	37	45	13	14	29	118	10	18	6	18	9	**381**

Table 4. Fate of captured mountain goats, Olympic Peninsula, Washington, 2018-2020.

Date	Total Removed	Lethal Removal	Capture Mortality	Euthanized	Zoo	Trans-located	Transport Mortality	Released
Sept. 2018	**115**	0	6	3	6	100	2	**98**
July 2019	**89**	4	6	3	0	76	(1)*	**76**
Aug 2019	**122**	4	7	0	10	101	0	**101**
July 2020	**55**	0	5	0	0	50	(1)**	**50**
Total	**381**	8	24	6	16	327	2	**325**

**1 female in very poor condition died in transport; she would have been euthanized except she had a kid at heel being transported and we tried to keep them together.*

***One succumbed during transport to capture injuries. Death attributed to capture injury, not transportation.*

it was treated and prepped for release. Transport and release crew were notified of animals requiring particularly close attention. Of these, 1 died in transport (Table 4). Other problems included goats that were either hypothermic (<36.7 °C (98°F)) or hyperthermic (>40°C (104°F)). If the capture team encountered a goat that was too hot in the field (~>39ºC (103° F)), the goat was partially dipped in a mountain lake while in the sling bag. Some of these animals became over-cooled during the flight to the helicopter base; they were treated with chemical warmers, blankets, hot water bottles, and warm buffered isotonic fluids. The few goats that arrived hyperthermic were cooled immediately with water at the helicopter base, and then treated with ice, water, and in some cases a cold-water enema at the processing table.

Sixteen kids (9 ♀, 7 ♂) were transferred to Northwest Trek in 2018 and 2019, and eventually found homes at the Cheyenne Mountain Zoo

(Colorado), Hempker Zoo (Minnesota), Oregon Zoo (Oregon), Wildwood Park Zoo (Wisconsin), or Woodland Park Zoo (Washington), as well as Northwest Trek. No kids were sent to captive facilities in 2020, due to COVID-19 restrictions and no partners in the zoo community that needed more goat kids.

Across all sessions, weights of kids and yearlings increased with capture date (8 July through 20 September), with little difference between males and females (Figure 7). Mean weight of adult female goats was 68.3 kg, with most females achieving this weight by age 3

(Figure 8). Mean weight of adult males was 107.7 kg, although mean weight of males aged ≥5 was 124.3 kg. The largest male captured (161.8 kg) was 8 years old (Figure 9).

Several lactating females caught in July 2019 were in poor condition (Harris *et al.* 2019). Consequently, we delayed the capture operation in 2020 to allow females to regain condition following pregnancy and lactation demands. This strategy appeared successful: 71% of females caught in 2020 were lactating but none was in poor condition (i.e., scored < 2). Mean weights of all sex and age cohorts caught between 27 July and 7 August 2020 were intermediate to weights observed in July and August 2019 (Table 5).

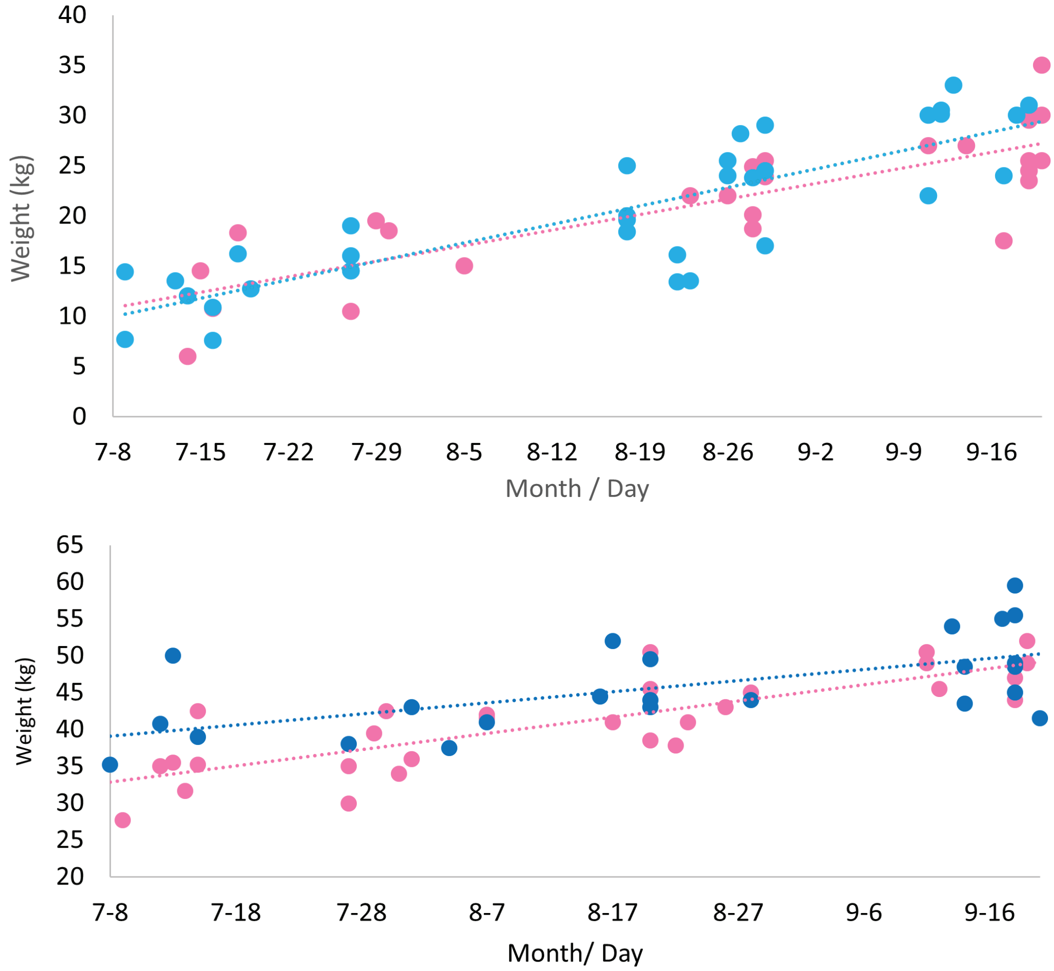

Figure 7. Weights of mountain goat kids (top panel) and yearlings (bottom panel) across all years, captured on Olympic Peninsula, Washington. Individual weights indicated by filled-in circles (females in pink, males in blue). Best fitting linear regression for each gender indicated by dotted lines. Capture dates for kids and yearlings ranged from 7/08 to 9/20.

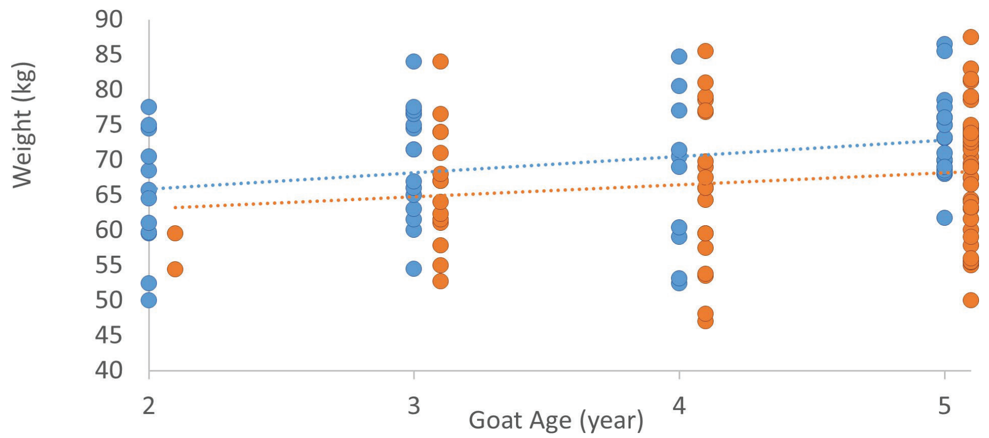

Figure 8. Weights of adult female goats captured on Olympic Peninsula, Washington, during 2018-2020, and whether lactating (orange) or non-lactating (blue). Age 5 includes goats aged 5 and older.

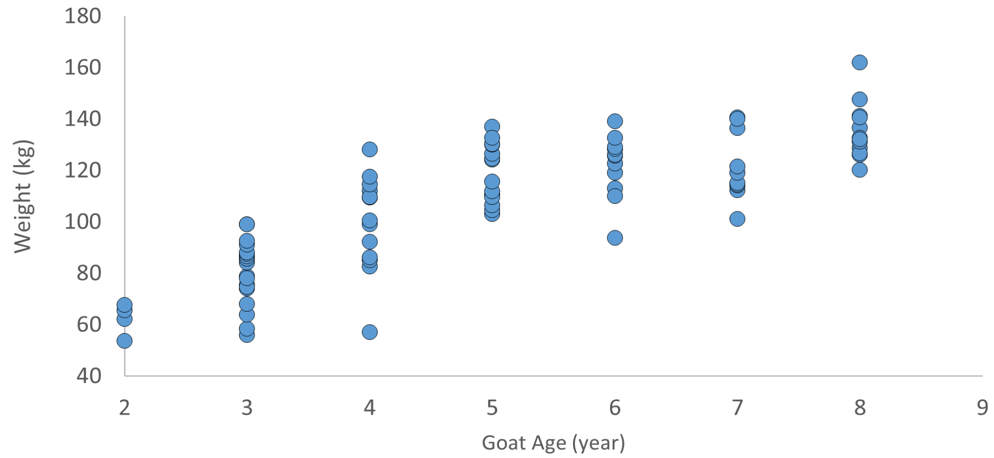

Figure 9. Weights of adult mountain goats captured on Olympic Peninsula, Washington during 2018-2020. Age 8 includes all goats aged 8 and older.

DISCUSSION

In designing the capture and processing protocols, we were very concerned about capture myopathy, and strove to design a program that kept overall capture mortality rates low while maximizing the number of goats translocated. The protocols appeared successful, as the only goats that potentially died due to capture myopathy were the two large males caught on the first day of capture.

We had to compromise between choosing capture periods when the weather was on average better and more consistently conducive to aviation, and when the goats were in better body condition. For the objective of mountain goat removal, the July and early August operational periods were optimal as that is when the weather is typically best in western Washington. However, goat condition and weights (and consequently survival upon translocation, see Harris *et al.* 2020) were better in September. Moreover, a future project constrained to this later period would risk capturing and translocating fewer goats due to the likelihood of encountering weather unsuitable for helicopter operations (needed for both capture and release). In hindsight, our choice of operating in early July (in 2018) was a poor one because so many of the adult females were in poor condition (Table 5). Considering all factors, mid to late August was the capture period when we were most successful overall.

Table 5. Weight (kg) and body condition score (1-5) of goats captured on Olympic Peninsula, Washington in 2019 and 2020. Data not recorded for all goats. (sample size).

Cohort		Mean Weight (kg)			Mean Condition Score (1-5)		
Sex	Age	July 8-19, 2019	August 16-29, 2019	July 27-Aug 7, 2020	July 8-19 2019	August 16-29, 2019	July 27-Aug 7, 2020
Female	Adult	60.4 (33)	68.3 (41)	63.4 (17)	2.3 (30)	2.7 (41)	3.1 (14)
	Yearling	34.6 (6)	42.8 (8)	37.6 (8)	1.9 (6)	2.6 (7)	2.7 (8)
	Kid	12.4 (4)	22.4 (7)	15.9 (4)	--	2.7 (6)	--
Male	Adult	101.3 (27)	111.1 (37)	105.3 (17)	3.2 (26)	3.8 (36)	3.9 (16)
	Yearling	41.3 (4)	47.6 (7)	39.9 (4)	2.1 (4)	2.4 (8)	2.4 (4)
	Kid	11.9 (8)	21.3 (14)	16 (4)	--	2.3 (12)	--

By the end of the operation, mountain goats became increasingly difficult to capture safely; during the last week of captures, we averaged only 3.75 releasable goats per day and capture mortalities rose to >11%. In areas where the terrain was more favorable for capture, we removed a large percentage of the estimated local population. However, in areas where the terrain was not conducive for capture, e.g., on the southern flanks of Mt Olympus or near Chimney Peak (Figure 6), a substantial number of goats remained. Plans call for removal of these goats through lethal means.

When we started planning this project, we faced skepticism from some members of the public that the operation could be completed safely and efficiently.

Much of the resistance was a consequence of memories of the 1980s, during which similar operations ceased due to concerns about safety. At the onset of activities in 2018, we estimated there were approximately 725 mountain goats in the Olympic range. We anticipated (National Park Service 2018) removing ~50% in the capture phase. By the end of the 4th capture session, we removed 53% of the estimated population, and either translocated or donated to zoos 341 goats. We met our objectives due to several factors. Firstly, the operation was founded on a thorough interagency Environmental Impact Statement (EIS) that had several iterations of public review, scrutiny, and consequent modification. The success of the implementation of the plan was in large part due to modern capture techniques, hard work of a highly skilled capture team, processing supervised by veterinarians and other experienced professionals, a strong inter-agency partnership, and hundreds of volunteers.

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An integrated population model for Rocky Mountain bighorn sheep in the Elk Valley

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ABSTRACT: The Elk Valley of southeast BC has a substantial population of Rocky Mountain bighorn sheep (*Ovis canadensis canadensis*) that are notable for their use of high-elevation winter ranges. The region is subject to extensive overlapping land uses. We integrated the results of on-going research and inventory efforts into a model that can be used to predict the effects on population trend of various stressors and mitigative management actions. The model is structured as a causal Bayesian Belief Network and includes 15 different factors and associated relationships. The structure and logic of the model was developed by a team of bighorn sheep experts and community members. Parameters were based on data, where available, and through expert elicitation. As currently structured and parameterized, the model is most sensitive to the abundance of suitable winter range, followed by annual range forage. The risk of pneumonia is considered low but of very high consequence if it occurs. Predation and winter severity are also significant drivers of population size. Causal Bayesian Belief Networks blend empirical evidence with expert and traditional knowledge and can be used to characterize cause-and-effect pathways in ecological systems to support management planning and decision-making.

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KEY WORDS Bighorn Sheep, *Ovis canadensis*, Bayesian Network modelling, population

INTRODUCTION

Bighorn sheep (*Ovis canadensis*) are a species of cultural and recreational interest in the Elk Valley of southeastern British Columbia (BC). The east side of the valley (known to contain the Elk Valley East Population Management Unit [PMU]) is home to a relatively large (>600 animals), stable subpopulation that is characterized by its use of high elevation winter range, in contrast with other subpopulations of the Kootenay region (Poole and Ayotte 2020). The Elk Valley is subject to a variety of overlapping land uses, including, but not limited to, mining, forestry, agriculture, human settlement, public recreation and hunting. Sustaining this subpopulation as land use evolves is a key conservation objective of the BC government, Indigenous communities, industry and public stakeholders. The objective of this project was to capture the knowledge generated by ongoing research and inventory, as well as expert and local knowledge, into a model that can be used to predict the population status of bighorn sheep, based on the current and future state of habitat and other biotic factors, and based on the various management actions that could be taken to mitigate stressors.

METHODS

The model is structured as a causal Bayesian Belief Network, illustrating the system as a directed acyclic graph (DAG; Elwert 2013) with relationships represented probabilistically (Marcot *et al.* 2006). We developed the model iteratively with experts and stakeholders through a series of workshops. The *nodes* of the model represent random variables and the directed *edges* represent the relationships among variables. The graph is "directed" because arrows indicate the hypothesized causal direction of relationships and is "acyclic" because feedbacks are not allowed. This is because a causal model implies a temporal ordering, such that an effect cannot influence the past by affecting its own cause.

Each node was assigned a number of discrete *states*, which represent the values that each node can assume. The relationships between nodes were then defined using probabilities, stored in tables associated with each node. Probability tables were populated using existing data, where available, as described in the following sections. Where data were not available, input was solicited from a small expert team through a workbook exercise, which presented questions about specific parameters and asked for probability assignments as well as confidence ratings. Responses from 10 separate workbooks were combined using prior linear pooling (Farr *et al.* 2018) and presented back to the experts for discussion and revision. Following this second round of elicitation, the model was populated with final parameters.

More general feedback was sought via polls conducted during a webinar with invited outdoor enthusiasts. Answers to 9 polling questions were received from up to 18 participants. Questions addressed many of the same nodes as the workbook questions completed by experts; specifically, nodes related to predation, health (including observations of contacts with domestics and observations of sick bighorn sheep), trends in winter severity and the relative role of different factors affecting over-winter survival.

The final model was analyzed to determine the sensitivity of the output to different input variables. This identified the most important factors hypothesized to be driving bighorn sheep population dynamics and therefore where interventions are likely to have the greatest impact. Model outputs were also graphed across the full range of various input values to characterize rates of response and to identify any non-linear relationships.

RESULTS

The model is composed of 15 inputs and associated relationships among nodes (Figure 1). There are five additional nodes that serve purely computational roles (beige nodes). Key bighorn sheep population variables are trend and their direct inputs (i.e., green nodes: *Annual adult female survival* and *Observed lamb:ewe ratios*), habitat abundance and condition (blue), predator-prey (green), weather (pink), human-cause mortality (yellow) and health and nutrition (red). The model predicted the probability of a positive population trend, given the conditions of the factors represented by the model nodes. The following sections describe each node and associated parameters.

Population Trend

Population trend is the output of the model and represents the probability of a positive or negative population response. The metric is lambda, based on the standard equation of Hatter and Bergerud (1991):

```
Population_trend
(Observed_lamb_ewe_ratios,
Annual_adult_female_survival) =
Annual_adult_female_survival/
(1-((Observed_lamb_ewe_ratios/5)/
(100+(Observed_lamb_ewe_ratios/5))))
```

Lamb:100 ewe ratios are adjusted to reflect estimated mortality between observation on surveys and time of recruitment.

Annual Adult Female Survival

Annual adult female survival (%) is estimated from all sources of mortality, based on the following equation:

```
Annual_adult_female_survival
(Human_related_mortality,
Predation_pressure,
Ewe_effect_condition,
Ewe_effect_pneumonia) = 1 -
Human_related_mortality -
Predation_pressure * (1 -
Ewe_effect_condition) -
Ewe_effect_pneumonia +
Ewe_effect_condition
```

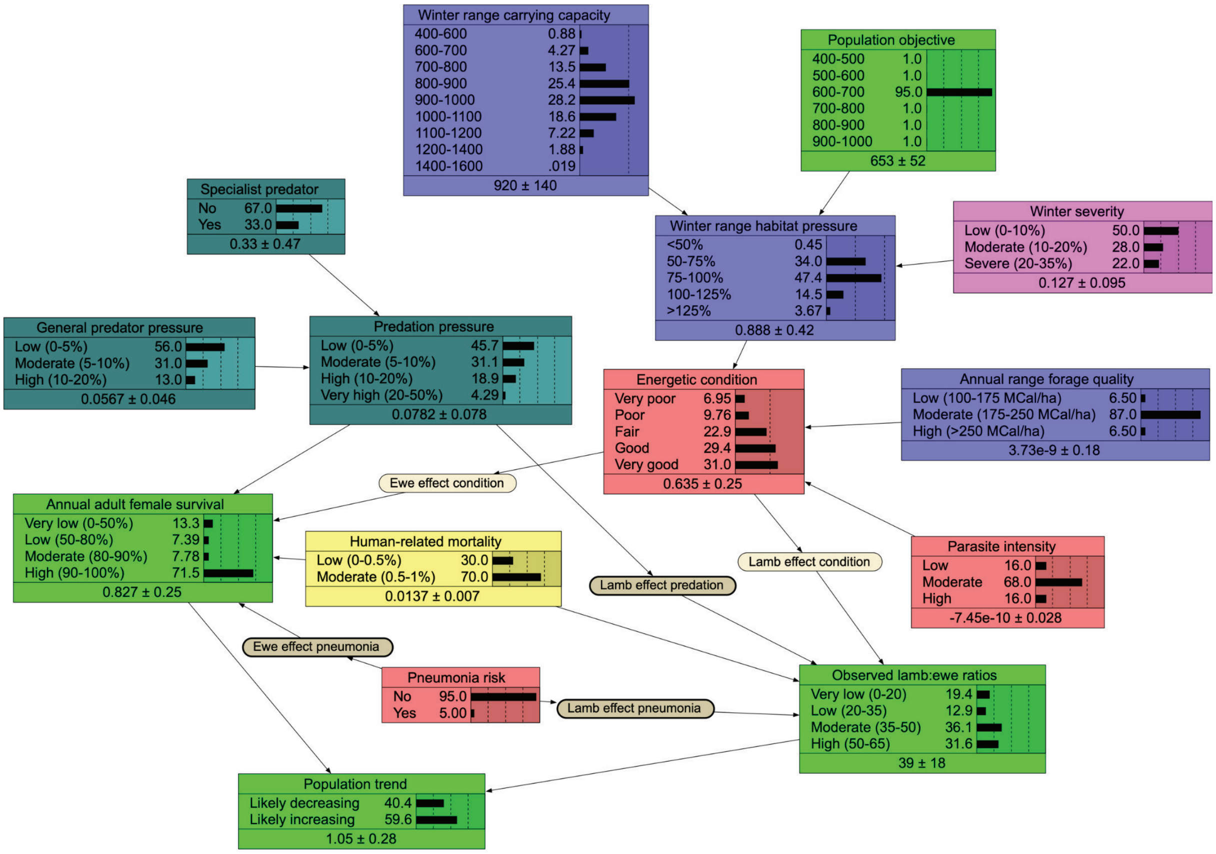

Figure 1. Structure of the bighorn sheep population model. Population variables are presented as light green nodes, habitat-related variables are blue, predator-prey are dark green, weather is pink, human-caused mortality is yellow and health and nutrition are red. Beige nodes are used for intermediate calculations. Each node is assigned discrete states and associated probabilities.

Observed Lamb-ewe Ratios

Observed lamb-ewe ratios is an estimate of the expected observed lamb:100 ewe ratios observed during mid-winter population surveys, using the equation:

```
Observed_lamb_ewe_ratios
(Human_related_mortality,
Lamb_effect_condition,
Lamb_effect_pneumonia,
Lamb_effect_predation) = 80 -
(Human_related_mortality * 0.75 +
Lamb_effect_predation * (1 -
Lamb_effect_condition) * 0.75 +
Lamb_effect_pneumonia + (0.3 - 0.3 *
Lamb_effect_condition)) * 100
```

Lamb survival rates to 10 months of age ranged between 0.41 and 0.54 in southwestern Alberta (Jokinen *et al.* 2008). The most recent Elk Valley survey recorded 48 lambs:100 ewes (Poole 2020). Note that there is some uncertainty in lamb:ewe ratios and their relationship with an increasing or decreasing population because of the difficulty of correctly classifying the sex of yearlings, and distinguishing 2-year-old ewes, which are less likely to give birth than older ewes (Festa-Bianchet 1988).

Population Objective

Population objective is the population size that represents the draft management objective. The February 2020 population estimate for the Elk Valley East PMU was 638 ± 85, based on an aerial total count survey and adjusted for a sightability of 0.77 (Poole 2020). The sheep population averaged about 400 individuals throughout the late 1980's and 1990's and then peaked in 2010 at approximately 800 (Poole and Ayotte 2020). It is not known whether the peak in 2010 indicated a population that was close to the carrying capacity of the habitat at that time. Poole and Ayotte (2020) proposed a target population of 640 ± 20%. The model assumes an objective of approximately 650 sheep, with the state 600-700 assigned with a 95% probability and all other states being assigned 1%.

Winter Range Carrying Capacity

Winter range carrying capacity estimates the number of sheep that can be sustained on winter ranges within the Elk Valley East PMU.

Winter is a critical season for bighorn sheep because forage is naturally restricted and energetic requirements are high due to low ambient temperatures and increased mobility costs in snow. Therefore, the abundance of suitable winter ranges available to bighorn sheep is assumed to be a major determinant of the carrying capacity of this PMU. To be used, winter ranges need to be close to suitable escape terrain (e.g., Hamel and Côté 2007, Golder 2019b) and must be accessible by ensuring adequate connectivity among seasonal ranges.

The number of sheep that winter ranges can support is a function of area- and selection-based estimates of forage production and quality in relation to the average energetic requirements of bighorn sheep, as well as a "safe use factor," which is intended to protect the sustainability of forage supply from over-grazing (Golder Associates 2019d). The total area of winter ranges currently identified in the Elk Valley East PMU is 11,021 ha (Golder Associates 2019b, 2019c).

Detailed methods and results for the winter range forage estimates are presented in Golder (2020). Estimates were developed using different nutritional performance classes and safe use factors. For this model, we used the estimate for a safe use factor of 0.5 and the nutritional performance class *good.* The standard deviation applied was intended to roughly capture the upper and lower limits of population estimates based on safe use factors of 0.75 and 0.25, respectively. The node is assigned a range of 400-1600 sheep, using a normal distribution with mean of 920 and a standard deviation of 135.

Bighorn sheep compete for available forage with other species that use their ranges. This can be a significant problem on low-elevation winter ranges that are used by elk (*Cervus canadensis*) and often by domestic stock as well (Poole and Ayotte 2020). Off-take by other species in the growing season can reduce the standing crop available to sheep on winter ranges. Conflicts on high elevation winter ranges in the Elk Valley are expected to be less severe than in low-elevation ranges because there is no domestic grazing and elk use low-elevation winter ranges (Szkorupa *et al.* 2013).

Annual Range Forage Quality

Annual range forage quality estimated the total forage available to bighorn sheep within their annual range (MCal/ha).

Conditions on seasonal ranges can positively influence energetic condition by ensuring that sheep enter the winter season in good condition and can recover quickly in the spring, in particular before lambing and lactation. While forage outside the winter season is rarely limiting, sheep are limited by their rates of intake, which are in turn influenced by forage quality.

Annual range forage quality was assessed using the same data, models and assumptions of Golder (2020). Estimates for the Elk Valley East PMU ranged between 162–261 MCa/ha, depending on subunit. *Low, moderate*, and *high* classes were defined to capture the empirical ranges and were assumed to correspond to *high*, *moderate*, and *low* forage requirements, as specified in the winter range carrying capacity model. *Low* was assigned a coefficient of -0.5, *Moderate* = 0 and *High* = 0.5 and these values were passed to the *Energetic condition* equation (below).

Winter Range Habitat Pressure

Winter range habitat pressure estimates the adequacy of winter ranges to support the current sheep population objective, given the likelihood of severe winters that could reduce access to ranges:

```
Winter_range_habitat_pressure
(Population,
Winter_range_carrying_capacity,
Winter_severity) = Population /
(Winter_range_carrying_capacity * (1 -
Winter_severity))
```

This assumes that the main effect of severe winter is to make some portion of the winter range unsuitable for bighorn sheep due to deep snow. No other effects of severe weather (e.g., icing events, droughts) were included in the model.

Winter Severity

Winter severity represents the probability of severe conditions associated with deep snow that are sufficient to reduce the ability of winter ranges to support bighorn sheep.

The marginal probability table for this node was based on snow pillow data from nearby Mount Morrissey (Figure 2). Maximum snow-water equivalents from 1984 to 2020 were stratified into classes (0–400, 400–500, 500+), roughly calibrated to the adult female survival rates observed during 2010–11 (i.e., 2010 representing a *low* snow year and 2011 representing a *high* year). Public feedback suggested changing winter conditions, including (in decreasing order of reporting) an increase in freeze/thaw events, more extreme weather events in general, less snow and milder temperatures. This negative trend is evident in Figure 2.

General Predator Pressure

General predator pressure estimates the effect of the current density of predators on adult bighorn sheep survival. Experts assigned the following probabilities: *Low (0-5%)*: 56.1%; *Moderate (5-15%)*: 30.7%; and, *High (15-25%)*: 13.1%.

Poole (2013) recorded 20 mortalities among 41 radio-collared bighorn sheep over 27 months (2009-2011). Two were confirmed predation events, one by a grizzly bear (*Ursus arctos horribilis*) and one by a wolf (*Canis lupus*). There were also 6 mortalities of unknown causes recorded on private land, and the fates of 7 other sheep were unknown because radio-collars were lost prematurely. Predation is likely higher on adults than reflected in the collaring data, and predation on lambs is likely higher than on adults.

More generally, cougars (*Puma concolor*) are considered to be the most significant predator of bighorn sheep in the Kootenay region (Poole and Ayotte 2020). The public agreed that cougars were the most significant predator in the Elk Valley and many thought that predator populations in general were increasing.

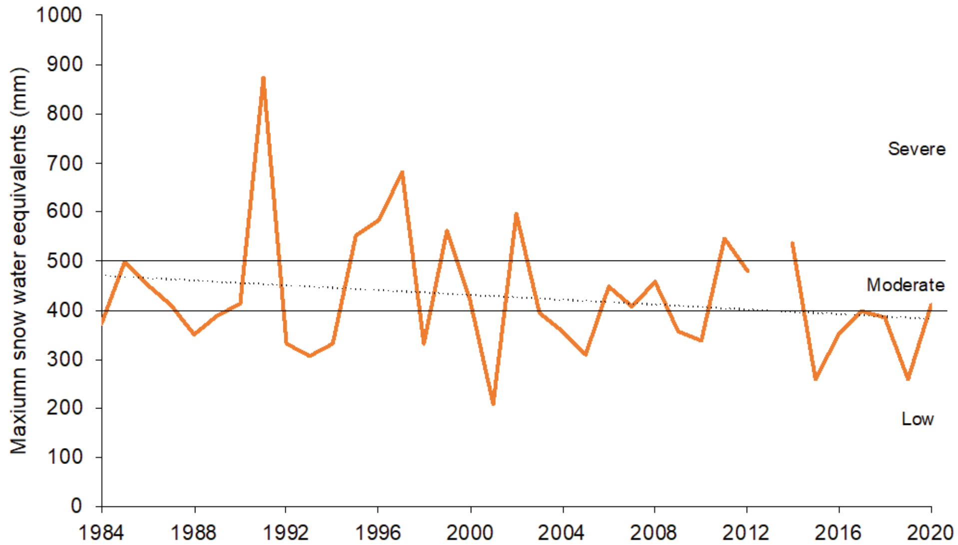

Figure 2. Mount Morrissey snow pillow data (1984-2020) used to calibrate the winter severity node (compiled by K. Poole). Class breaks were informed by survival rates observed among bighorn sheep in 2010-2011. The dotted line indicates the linear trend over time.

Specialist Predator

The specialist predator node estimates the probability that a cougar specializing on sheep could increase the overall predation rate on adult female sheep by 100%.

Experts assigned the probability of occurrence of a specialist predator to be 32.7%. There was feedback from the public indicating that some had seen evidence of cougars specializing on sheep.

Specialist predators can have substantial impacts on bighorn sheep populations (Festa-Bianchet *et al.* 2006, Bourbeau-Lemieux *et al.* 2011). Ross *et al.* (1997) concluded that a single, specialist cougar in southwestern Alberta killed 11 individuals, including 6 lambs, in a single winter. In the Kootenay region, cases of cougar specializing on sheep has been observed or suspected, but primarily in populations wintering at low elevations (K. Poole, *pers. comm.*). Because most bighorn sheep in the Elk Valley East PMU spend most of the year at moderate to high elevations, cougars are not considered as much a risk as they are elsewhere in the Kootenay region.

Predation Pressure

Predation pressure adjusts *general predator pressure* for probability of the occurrence of a *specialist predator*:

```
Predation_pressure
(General_predator_pressure,
Specialist_predator) =
General_predator_pressure +
Specialist_predator *
General_predator_pressure
```

Poole (2013) reported survival rates of 0.93 and 0.78 and attributed the lower survival in the second year to severe winter conditions. A survival rate of 0.93 is likely close to the theoretical maximum for a wild ungulate population (Loison *et al.* 1999), so it is unlikely that bighorn sheep during the study were suffering significant predation pressure. The study coincided with the highest recorded population size in the Elk Valley East PMU and likely reflected optimum conditions. Survival rates can vary with the age structure of populations because older ewes have higher mortality (Festa-Bianchet *et al.* 2003).

Experts estimated that predation on lambs is likely 2.6 times greater than that on adult females and this value was used in the *lamb effect predation* node to estimate the effect of predation on observed lamb:100 ewe ratios.

Parasite Intensity

Parasite intensity estimates the average, relative parasite load experienced by sheep in the population unit. The effect of parasite loading on fitness in livestock and related wild species is an area of active research (K. Ruckstuhl, *pers. comm.*). Recent work has clearly demonstrated that infections can negatively affect energetic condition and subsequent reproduction and survival (e.g., Roeber *et al.* 2013) and there is a link to range conditions if aggregations of sheep shed parasites that become sources of reinfection (K. Ruckstuhl, *pers. comm.*). No data were available to parameterize this node from the Elk Valley. Additional research and monitoring is required to characterize infection rates and impacts. Initial coefficients were –0.05 for *low*, 0 for *moderate* and 0.05 for *high*.

Energetic Condition

Energetic condition is an estimate of average, relative, overall energetic condition of sheep resulting from the interaction of range conditions and parasite intensity:

```
Energetic_condition
(Winter_range_habitat_pressure,
Annual_range_forage, Parasite_intensity)
= -Winter_range_habitat_pressure + 1.5 +
Annual_range_forage - Parasite_intensity
```

The subjective classes were mapped to a normalized range between 0 and 1 (e.g., *Very low* = 0 - 0.2, *Low* = 0.2 - 0.4, etc.). The equation generated weights among the inputs that approximates feedback provided by the technical team; specifically, experts assigned the following weightings: *Winter range habitat pressure*: 5.3; *Annual range forage condition*: 3.6; and, *Parasite* *intensity*: 1.1. Public feedback weighted annual range forage condition higher than winter range habitat pressure but weighted parasite intensity similarly.

Poor energetic condition can increase mortality directly through starvation but also indirectly through increasing susceptibility to predation and disease. There is weak evidence that indirect measures of energetic condition (e.g., chest girth and mass measured during capture) are correlated with survival for some bighorn sheep age-sex classes (Festa-Bianchet *et al.* 1997).

The relative effects of energetic condition on survival of lambs and ewes were estimated by experts and their parameters populated the *lamb effect condition* and *ewe effect condition* nodes, respectively. Specifically, the effect of being in *good* condition was estimated to improve survival by 36.9% for lambs and 25.3% for ewes, relative to *fair* condition, while being in *poor* condition was estimated to reduce survival by 64.7% for lambs and 44.1% for ewes, relative to *fair* condition.

Pneumonia Risk

Pneumonia risk is the probability in any given year that sheep in the Elk Valley East PMU are likely to come in contact with domestic sheep, leading to an all-age die off.

Experts assigned the probability of occurrence of a pneumonia outbreak in any given year to be 5%. Pneumonia is expected to affect lambs and ewes differently and experts estimated that annual mortality resulting from pneumonia would range between 53.0% and 94.3% for lambs and between 39.5% and 76.6% for ewes. These parameters were used in the *lamb effect pneumonia* and *ewe effect pneumonia* nodes.

Bighorn sheep wintering at low elevations in the East Kootenay have experienced pneumonia-related die-offs, but herds in the Elk Valley have not (Poole and Ayotte 2020). Of public respondents, 69% (n = 16) reported seeing evidence of risk of contact between bighorn sheep and domestics, as well as evidence of poor health. Four respondents reported observations of feral *Caprinae* within the past 4 years.

Human-related Mortality

Human-related mortality refers to the non-hunting mortality of sheep (only the female component of the population was modelled) recorded in the population unit. These were primarily road and rail mortalities.

The marginal probability table was derived from BHS Expert Team (2018) and Teck records, using the highest number of sheep recorded in either dataset for each year since 2010. The maximum number of mortalities recorded between 2000 and 2019 was 15 in 2014. Sex-age class was not reported for all mortalities, but assuming that mortality is independent of sex-age class and that approximately 70% of the total population is female (Poole 2020), then approximately 10 females were killed by these sources out of a total population of 600 animals or 420 females. This was used as the maximum rate of loss, which is approximately 2.5%.

Instantiation and Diagnostics

The model, when fully instantiated with available data and expert opinion, estimates the current condition of the Elk Valley East PMU in relation to the proposed draft population objective of approximately 650 bighorn sheep and predicts a 60% probability of a positive population trend (Figure 1).

A sensitivity analysis of the model indicated that the model output is most sensitive to the habitat input variables; specifically, winter range carrying capacity followed by annual range forage quality (Figure 3).

Increasing the winter range carrying capacity by 10% increases the probability of a positive population trend by about 6%. Holding the carrying capacity of winter range constant but increasing annual range forage quality by 16% could accommodate an increase in the population objective from 650 to 740 sheep, holding the probability of a positive population trend constant.

Pneumonia risk was the next most sensitive input. While the likelihood of an outbreak was estimated to be low (5% per annum), the consequence was considered to be very high and

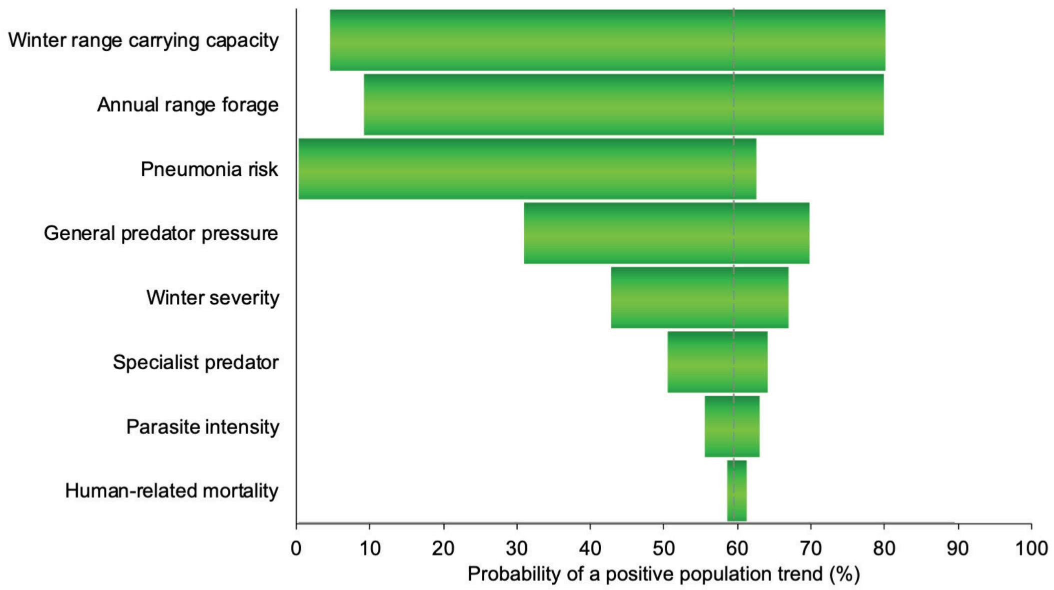

Figure 3. "Tornado" diagram of model sensitivity, with input variables ordered from the one that generates the largest variation in model output to the one that generates the smallest. The minimum and maximum of each bar indicates the effect on the probability of a positive population trend by changing the parameter to the lowest or highest values considered in the model.

could reduce the probability of a positive population trend to zero.

General predator pressure was estimated to have a greater effect than the risk of occurrence of a specialist predator causing an acute increase in adult female mortality. Reducing annual predation pressure to 0-5% of the adult female population is estimated to increase the likelihood of a positive population trend from about 60% to 72%.

The model predicts that a reduction in the frequency of severe winters will improve conditions for sheep by increasing, on average, the accessibility of winter ranges. For example, if the frequency of deep snow winters declines from approximately 1 year in 5 to 1 year in 20, the probability of a positive population trend increases by 3%, which is equal to increasing the carrying capacity of winter ranges by 50 sheep.

The instantiated model was relatively insensitive to changes in human-related mortality and parasite intensity because the range of parameters for both was relatively narrow.

Examining the shape of the response curves for each variable against a standardized axis (Figure 4), changes in the habitat variables are associated with a non-linear response in population trend under a fixed population objective of 650 sheep because additional habitat and forage provides diminishing returns to a fixed population size. All other inputs are stressors and are associated with negative and largely linear slopes, although this is partly due to the coarse precision of states and associated probabilities, particularly where parameters were estimated via expert opinion. Those inputs associated with steeper slopes cause relatively larger changes in the probability of positive population trends and the inputs ordered by slope in Figure 4 correspond to the order of bars from longest to shortest in Figure 3.

Focusing specifically on the expert input, the team was most certain about potential effects of pneumonia and least certain about condition-related mortality impacts and general predator pressure (Table 1).

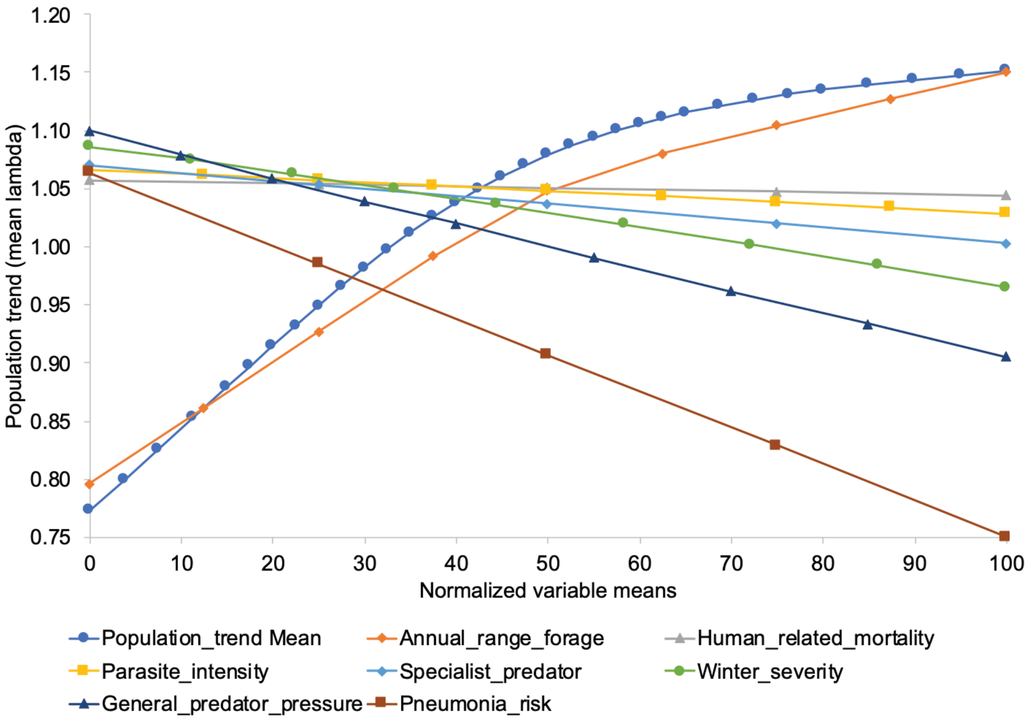

Figure 4. Response of population trend to changes in each input variable, measured against a standardized axis.

Table 1. Confidence (highest to lowest) and variability among experts (expressed as the coefficient of variation) in relation to the model parameters experts were asked to estimate.

Parameter	**Average confidence (1 = low, 5 = high)**	**Variability among experts (coefficient of variation)**
Pneumonia mortality lambs	3.5	0.16
Pneumonia risk	3.3	0.32
Pneumonia mortality ewes	3.2	0.21
Lamb predation	2.9	0.25
Energetic condition	2.9	0.30
Specialist predator	2.4	0.45
General predator pressure	2.2	0.56
Condition-related mortality	1.9	0.41

DISCUSSION

There are many interacting factors affecting the bighorn sheep population in the Elk Valley and the population model presented here represents the first attempt to characterize these factors in a causal framework and to estimate parameters. Like all models, it represents a simplification of the system and can address only circumstances that are reasonably foreseeable. Outputs are presented probabilistically, meaning that the most likely outcome is not necessarily the one that is always going to occur. In addition, there are many estimated parameters and relationships that could change substantially as knowledge of the system improves. As a result, model outputs should be considered adaptive management hypotheses based on best available information, rather than deterministic predictions about future system responses.

Development of the model identified a number of knowledge gaps that could be addressed through additional research. Perhaps most significantly, the interaction between energetic condition and winter and annual range condition is not well understood.

Although there is good evidence that improving annual range and sustaining winter range conditions can benefit bighorn sheep, it is unknown how changes in conditions affect subsequent survival and reproductive success. In the model these functions were estimated by experts but, ideally, they would be informed by data collected through future research. Detailed body condition data are difficult to collect but there might be opportunities to index the condition of sheep captured on cameras or by some other indirect means to provide information on energetic condition (e.g., Smiley *et al.* 2020). Indices could be correlated back to local and seasonal range conditions, although such indices might not be as reliable indicators of condition as reproductive performance.

In addition to snow depth, there are many other dimensions of weather that can affect sheep. These have been observed or hypothesized in other sheep populations and may be significant in the Elk Valley:

- Freeze-thaw and icing events that can restrict access to forage even when snow is shallow. If such events occur at critical times (e.g., during lambing) the effect on populations could be significant.
- Displacement of animals off of winter ranges by deep snow that might make them more susceptible to predation at lower elevations.
- Direct mortalities due to avalanches.
- Late or early snowfalls that affect sheep at times of greatest energy demand.
- Summer droughts that affect forage quality and hence weight gain by sheep.
- Spread of pathogens that may be facilitated by warmer weather.

Bighorn sheep are social animals and behaviours such as seasonal movements and range use can be habitual and persist for generations. As a result, sheep cannot necessarily be expected to respond immediately to management actions intended to improve conditions. For example, the model might predict a positive response to range improvements, but habitual behaviour might have to change significantly for any population response caused by the improvements to be realized. Investing in mitigation that is aligned with current behaviour might generate greater short-term benefits for the population.

Habitat improvements could include activities such as burning, seeding, weeding and/fertilizing and the most appropriate treatments are likely to vary with site characteristics (BHS Expert Team 2018). While there will always be unexpected events, knowledge will improve over time and the model can be refined to improve the reliability of predictions.

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Stone's sheep lambing habitat selection in the Cassiar Mountains, British Columbia

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ABSTRACT: Parturient wild sheep are known to use steep, rugged terrain at high elevations during parturition events to avoid predation on newborn lambs. Lambing habitat selection studies in North America have largely focused on *bighorn sheep* (*Ovis Canadensis*), and this is the first study of its kind on Stone's sheep (*Ovis dalli stonei*), a subspecies of thinhorn sheep residing predominately in British Columbia. Our study focuses on a Stone's sheep population in the Cassiar Mountains, a relatively remote area with varying levels of landscape disturbance. Recent increases in human activity, including mining, snowmobiling, ATV use and highway traffic could threaten recruitment, creating a need for identifying critical lambing habitat. We equipped ewes in 2018 (n = 8) and 2019 (n = 10) with GPS radio-collars collecting relocations every 2hrs (2018) and every 1hr (2019). Ewes confirmed pregnant (n = 17) were outfitted with a vaginal implant transmitter. We estimated parturition events using step lengths from GPS relocations and information obtained from the vaginal implant transmitters. We found that timing and synchronicity of parturition events varied annually. We used resource selection functions to identify significant variables influencing habitat selection during the periods of parturition and lactation. Understanding lambing habitat selection will help wildlife managers to identify and conserve critical habitats for Stone's sheep recruitment in the Cassiar Mountains.

Biennial Symposium of Northern Wild Sheep and Goat Council 22:105; 2020

KEY WORDS: British Columbia, Cassiar Mountains, habitat selection, lambing, *Ovis dalli stonei*, parturition, radio-collaring, resource selection function, Stone's sheep.

Limiting factors on a small herd of Rocky Mountain bighorn sheep residing in the Kicking Horse Canyon, near Golden, British Columbia

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ABSTRACT: This case study identified limiting factors on a herd of about 15 Rocky Mountain bighorn sheep (*Ovis canadensis canadensis*) residing in the Kicking Horse Canyon, near Golden, British Columbia, using noninvasive techniques. These included observations on recruitment and highway mortalities plus fecal analysis to test inbreeding, parasite loads, and cortisol levels. Herd health results showed heterozygosity at over 65% of the loci tested. Dorsal spine larvae and a range of gastro-intestinal parasites were present, and baseline cortisol levels were higher than those documented in other bighorn sheep studies. The widespread presence of a dorsal spine larvae, possibly *Muellerius sp*, could be of concern as stress potentially increases in this herd because of additional anthropogenic influences associated with upcoming highway widening. Recruitment varied between 0.17 and 0.33 juveniles per ewe between 2015 and 2020. The Trans-Canada Highway (HWY 1) occupies almost 20 % of the study area, and BC Ministry of Transportation and Infrastructure data indicates that highway mortality is not uncommon. The data from this case study suggests that low recruitment and highway-related mortality are the principal factors limiting this herd of bighorn sheep and that fencing placement and breaching of one-way "escape" gates and jump-outs may contribute to highway usage. Several conclusions are presented which could result in improved outcomes for this herd.

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KEY WORDS: British Columbia, cortisol, fecal analysis, highway mortality, inbreeding, limiting factors, noninvasive techniques, parasites, recruitment, fencing

INTRODUCTION

Identification of limiting factors can inform management decisions which may alleviate threats faced by free-ranging wildlife. Using non-invasive methods, this case study illuminates our understanding of the threats faced by a small group of sheep residing in a restricted canyon in southeastern British Columbia (BC), which is bisected by the Trans-Canada Highway (HWY 1) and a heavily-used Canadian Pacific Railway train line. Inbreeding (Coltman *et al.* 1999; Luikart *et al.* 2008), parasite loads (Flanagan 2009), stress hormones (Coburn *et al.* 2010; Miller *et al.* 1991; Millspaugh and Washburn 2004), recruitment (Enk *et al.* 2001), and highway mortality (Neumann *et al.* 2012) are all evaluated in this case study of the Golden Rocky Mountain bighorn sheep (*Ovis canadensis canadensis*) herd.

Inbreeding, defined by a reduction of alleles and an increase in homozygous loci, can be associated with inbreeding depression (Rioux-Paquette *et al.* 2011) and may significantly affect birth weight, survival, reproductive success, resistance to disease, predation, and environmental stress (Fitzsimmons *et al.*1995; Keller and Waller 2002; Luikart *et al.* 2008; Luikart and Allendorf 1996). Due to the physical isolation of the Golden sheep herd from other bighorn sheep herds, lower than average genetic diversity would be expected.

Parasite loads fluctuate seasonally (France 2015) and some level of intestinal parasites is not uncommon; bighorn sheep are known to remain in good health despite the presence of various parasites although the presence of *Mycoplasma ovipneumoniae* (M. ovi) has been linked to pneumonia outbreaks and related die-offs (Besser *et* *al.* 2013; Cassirer *et al.* 2018; Festa-Bianchet 1989).

High stress levels can also negatively impact 4,000) along HWY 1 to the Yoho Bridge (7 kms), south of the highway to the Kicking Horse River and north of the highway for approximately 300m (Figure 1).

Sixty freshly excreted bighorn sheep fecal samples were photographed, mapped and collected into plastic bags which were labelled and stored in a cooler in the field. Thirty samples were collected between February 24 and July 19, 2019; an additional thirty samples were collected in 2020, between February 7 and April 9. Samples were refrigerated or frozen depending on the testing to be done.

Extracted DNA from fecal samples was typed at 13 (U. of Alberta) to 28 (Wildlife Genetics International) microsatellite loci following procedures described in Deakin *et al.* (2020), Paetkau (2003) and Woods *et al.* (1999). All loci selected were believed to be neutral except for MMP9 (Luikart *et al.* 2008). Since marker loci used varied, a measure of individual heterozygosity was calculated (H_I = number of heterozygous loci/total number of loci typed for each individual animal). Observed heterozygosity (H_O) was calculated for each of the loci tested by dividing the number of heterozygous individuals by the total number of individuals sampled. Parasite loads were analyzed using the Baermann test and the fecal flotation test (Foreyt 2001) by the Washington Animal Disease Diagnostic Lab (WADDL) at Washington State University. Fecal cortisol was measured at the Toronto Zoo following the procedure described in Miller *et al.* (1991) and Dulude-de Broin *et al.* (2019).

Reproductive success was documented through observation from a vehicle. Between 2016 and 2018, the number of ewes and lambs was documented on 53 trips through the study area, between 14:00 and 17:00 between May and August each year. If animals were sighted, they were filmed if possible. In 2019 and 2020, bighorn sheep were observed and filmed daily during lambing season and throughout the year (79 trips in 2019 and 198 trips in 2020) to determine lambing areas, lambing dates, reproductive success, fall recruitment and to observe use of the highway corridor and escape structures.

Highway mortality was assessed based on known (observed or reported) losses and road-kill data collected by the Ministry of Transportation and Infrastructure (MOTI; WARS 2020).

RESULTS

Genetic analysis of the fecal samples identified nine individual members of the Golden bighorn sheep herd. The average proportion of the loci that were heterozygous (H_I) was 0.641 ± 0.102 and the average number of alleles per locus was 2.88 ± 1.05. The average observed heterozygosity at each locus (H_O) was 0.66 ± 0.25. Baermann tests found dorsal spine larvae (DSL) in 88.24% of 17 samples with a mean value for larvae per gram of 14.99 ± 25.90 and a range = 1-81. Two samples believed to be from lambs contained no parasites. Although the DSL were not able to be identified to species, the likelihood is high that they are *Muelleris capilaris* (Laura A. Williams, personal communication, June 4, 2020). Fecal flotation tests found gastrointestinal parasites of the genera *Strongyles, Eimeria, Nematodirus, Capillaria, Wyominia, Moniezia* and *Trichuris ovis,* in 65% of 17 samples, with a prevalence ranging from 5% - 35% depending on the genus. Although one individual had three different isolates, all other samples contained 2 or fewer. Stress hormone results showed a range of values from 15.23 ng/g to 245.79ng/g with standard deviation of 42.99 ng/g (n = 34). Between 2015 and 2020, recruitment ranged from 0.17 to 0.30 juveniles/adult female, based on 6 ewes able to give birth each year. Several adult females died on the highway which kept the adult ewe number constant during this period. Highway mortality data from MOTI (WARS, 2020) and citizen reporting (Mike Nickle, personal communication, June 15, 2019) documented 10 deaths between 2000 and 2020. Between 2015 and 2020, highway mortality was the only known cause of mortality for this herd; three lambs died between June and September, 2020 and at least 2 of these deaths were highway-caused (Helen Schwantje, personal communication, July

22, 2020). Bighorn sheep were observed accessing the Trans-Canada highway corridor by breaching one-way gates and jump-outs and going around fence end points to access winter and spring ranges (www.wildsight.ca/goldensheep).

DISCUSSION

The various non-invasive techniques employed in this case study addressed several of the potential limiting factors faced by the Golden herd. The individual heterozygosity (H_I) for the 9 unique individuals for which analysis was completed was similar to that documented in other studies (Hedrick and Wehausen 2014; Hogg *et al.* 2006; Wehausen and Ramey 2004), and the observed heterozygosity (H_O) for this herd is higher than expected and higher than that found in Alberta by Deakin *et al.* (2020) for the same loci. The analysis at the MMP9 locus showed especially high H_O which may indicate less susceptibility to lung infection than in animals with low heterozygosity at this locus (Luikart *et al.* 2008). In contrast, the fixed allele (all samples homozygous) at the MAF36 locus may warrant further study.

Seven or more types of gastrointestinal parasites infect the Golden bighorn sheep herd and may degrade body condition, change behavior, and lower immune response (Foreyt 2001; Miller *et al.* 2012), although levels of concern have not been established (Hoar *et al.* 1996; Jenkins and Schwantje 2004) and no individuals harbored more than 3 unique species of gastrointestinal parasites.

Stress, as indicated by cortisol level, may be relatively high (up to 250 ng/g) in this herd. Results from other studies show levels between 20-50 ng/g (France 2015; Goldstein *et al.* 2005) although different methods of extraction can affect these values and limit the value of comparison between studies. These animals may be under stress due to their interactions with HWY 1. Variability in hormone levels between studies makes this data primarily useful as a baseline for future comparison.

Low recruitment is of considerable concern for this herd. Ewes give birth and lambs survive for the initial months but are threatened once they leave the lambing area and enter the highway corridor. The proximity of the historic lambing area to HWY 1 makes highway mortality almost inevitable, unless changes are made to force sheep to go under the nearby Yoho bridge versus over the roadway.

Highway accidents appear to be a significant source of mortality for both the Golden herd and the Radium herd (Dibb 2010), located 100 kms south of Golden. While human activity may lead to reduced habitat quality and/or quantity, it may also cause sheep to abandon usage areas (Bunch *et al.* 1999; DeForge 1972; DeForge 1981; Hamilton *et al.* 1982). That has not yet been the case with the Golden herd, members of which spend a lot of their time near, or on, the highway likely seeking food, water, minerals, and easy passage. Grain spills from transport trucks seeking to reduce their weight occur 3-5 times per summer in the canyon and attract sheep which feed on these protein-rich grains. Planting of preferred plants like alfalfa, *Medicago sativa*, and wheatgrass, *Agropyron* spp., make roadside areas even more desirable than they already are due to their SW facing aspects. Patches of preferred shrubs like scrub birch, *Betula nana*, chokecherry, *Prunus virginiana*, and prickly rose, *Rosa acicularis*, close to the highway also attract sheep as do "road salts". Using HWY 1 to access different parts of their home range likely saves energy, despite the traffic, and fencing placement forces sheep to use the highway to reach desirable areas. These incentives make the highway corridor appealing. Bighorn sheep are currently able to gain access to fenced portions of HWY 1 by jumping up at jump-out structures and opening one-way gates from the back making highway mortality a serious concern.

Impacts of highway mortality are well-documented and have been found to be speed-related (Hardy *et al.* 2006; Neumann *et al.* 2012). Lower speeds have been shown to reduce highway mortality (Bond and Jones 2013) and various forms of signage, including signs associated with remote cameras have been effective in reducing speeds (Hardy *et al.* 2006). Fencing has effectively kept animals off of roadways (Huijser *et al.* 2008); Members of the Golden sheep herd have learned how to gain access to fenced portions of HWY 1 by breaching escape structures. These jump-outs and one-way gates should be modified to reduce the chance of breaching or removed from fenced sections of highway. Modifications could include creating a depression at the base of the jump-out, installing a bar at the top (Siemers *et al.* 2013) or fabricating gates using inflexible materials for the gate tines. Effective strategies to reduce collision rates on highways exist (Huijser *et al.* 2008), but they cost money and require planning and cooperation.

bighorn sheep, leading to lowered resistance to disease. Long-term or chronic exposure to stressful events is thought to cause an increase in cortisol and a lowering of immune functions (Miller *et al.* 1991) with reduced reproductive success (Coburn *et al.* 2010). Given the high level of anthropogenic influence and the frequency of interactions between bighorn sheep and vehicles, a high stress level would be predicted for the Golden herd.

The rate of recruitment required to sustain a population varies considerably. Relatively high survival rates have been documented in bighorn sheep adults (Overstreet *et al.* 2014), such that even minimal recruitment could increase herd size; estimates of 0.30 juveniles per adult ewe have been made for bighorn sheep (Buechner 1960; Jorgenson 1992). Based on reports and observations of the Golden herd, recruitment is likely to be low.

Finally, highway-mortality has the potential to significantly impact animal numbers and herd viability. Bighorn sheep near Radium, BC preferred winter ranges close to human habitation over steeper habitat, leading to a variety of management concerns (Dibb 2010). Demarchi (2004) noted that, "roads and railways occupy habitat, dissect migration routes, and result in direct mortality. Furthermore, salt used for road maintenance can attract and hold sheep in highway corridors. In some cases, significant numbers of adults have been lost in single seasons" to vehicle traffic. Various other studies (Huwer 2015; Keller and Bender 2007) have documented the impacts of highways on wildlife, which is expected to be high in this study. Urbanization and human developments impact habitat selection and have the potential to attract wildlife with high quality forage, water, and possible protection from predation, while also exposing them to disease transmission, stressful interactions, and highway mortality (France 2015; Rubin *et al.* 2002). Fencing with escape gates and jump-outs has been the principal method employed to keep sheep and other wildlife off of HWY 1 in this area.

METHODS

Rocky Mountain bighorn sheep are a blue-listed (vulnerable) species in BC whose numbers have been in steady decline. Several small

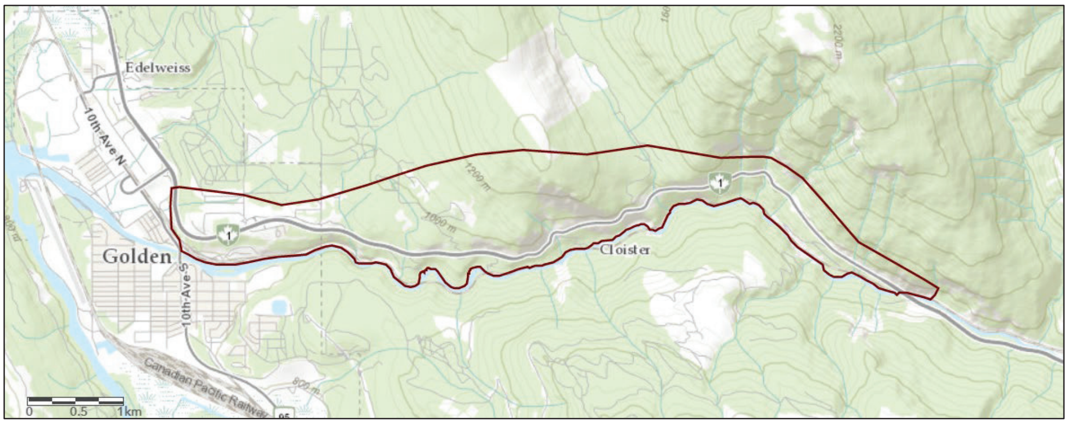

Figure 1. Study area (620 ha), located in and to the east of Golden, BC, Canada. The maple leaf with the number one represents the Trans-Canada highway (HWY 1). The red line is the border of the study area.

populations exist in eastern British Columbia (Poole 2019; Teske 2015), including the Golden herd, numbering approximately 14 individuals and residing in the Kicking Horse Canyon. The 620-hectare study area encompasses the annual range of the nursery group and is located on the western extreme of the Rocky Mountains in southeastern BC (51°N, 117°W; 800 - 1300 m elevation). It extends east from the town of Golden (population

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PERSONAL COMMUNICATIONS

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Behavioural states as a proxy for habitat hotspots by mountain goats (*Oreamnos americanus)* using hidden Markov models

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ABSTRACT: Understanding where, why, and how individual animals move is a fundamental biological question, but, directly observing animal behaviour and the habitat they utilize is logistically challenging. Mountain goats (*Oreamnos americanus*) are elusive high alpine ungulates that live in steep and mountainous environments where it is difficult to directly observe and record behaviour. Hidden Markov models (HMM) are emerging as a useful method for predicting the behaviour of animals over space and time. We used HMM to identify hidden behavioural states and predict habitat hotspots of mountain goats. We evaluated how these inferred states can serve as a proxy for identifying habitat hotspots. We explored associated environmental covariates, time of day, and distance from escape terrain, to explain these behaviours, and visited field sites selected by mapping fast and slow movements of mountain goats to look for physical evidence of several behaviours, including foraging, travelling and bedding. We found mountain goats are most likely to forage during daylight hours away from escape terrain, travel within and away from escape terrain during the crepuscular periods and bed nearest to escape terrain in the night-time and afternoon. The inferred behavioural states were validated against the field observations. Our results illustrate that HMMs have the power to predict habitat hotspots of mountain goat and this approach may assist wildlife managers in assessing locations where mountain goats spend most of their time and the movement corridors that connect them.

Biennial Symposium of Northern Wild Sheep and Goat Council 22:113; 2020

KEY WORDS: Mountain goat (*Oreamnos americanus*), Hidden Markov Models (HMM), movement ecology, animal behavior, Rocky Mountains

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Colonization of a reclaimed landscape by bighorn sheep *(Ovis canadensis)*

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ABSTRACT: Bighorn sheep (*Ovis canadensis*) have high fidelity to seasonal ranges and as such are thought to be poor colonizers. Under certain conditions bighorn sheep are quite capable of occupying new habitat. We documented a colonization event of newly available habitat on the Gregg River Mine (GRM) in west-central Alberta by bighorn sheep from adjacent alpine habitat with little to no spatial separation from the mine development. Wishart *et al.* (1998) described the rapid population increase of the nursery herd during this event. This paper is a companion article that documents and maps the pattern of mine reclamation and spatial occupation of bighorn sheep by sex/age class throughout the life of the mine. Initial colonization was accomplished by ram groups moving into recently reclaimed areas which provided basic habitat requirements for bighorn sheep (quality forage adjacent to pit walls retained as escape terrain). Colonization by nursery groups lagged by several years, occurring after larger areas of reclamation became available; once established however, nursery groups rapidly expanded into new habitat. Bighorn sheep did not abandon previously occupied habitat in favour of new habitat during the colonization event. Progressive reclamation as practiced by GRM provided the opportunity for bighorn sheep to discover and voluntarily colonize new habitat made available during the active phase of mining. Rewilding of the mine disturbance is an example of deliberate ecosystem rehabilitation in order to produce productive wildlife habitat. The reclamation of the Gregg River Mine demonstrates that given appropriate planning and design, reclaimed landscapes can provide habitat that fulfill the life requirements of bighorn sheep and other sympatric species.

Biennial Symposium of Northern Wild Sheep and Goat Council 22:114-130; 2020

KEY WORDS: bighorn sheep, colonization, ecosystem function, Gregg River Mine, *Ovis canadensis*, reclamation, restoration ecology, rewilding

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INTRODUCTION

The distribution of bighorn sheep in North America was historically much larger than current day. Decimation of bighorn sheep populations occurred during settlement of the American west due to unregulated killing, diseases introduced by domestic livestock, competition with domestic, feral, or exotic hoofstock, and human encroachment (Brewer *et al.* 2014). This resulted in small and isolated populations that occupy a fraction of their historical range. Various wildlife agencies supported by public groups and organizations have developed management plans to actively restore lost or diminished populations, often by reintroduction of bighorn sheep to areas previously occupied. Understanding colonization of unoccupied habitat is necessary to manage fragmented populations. As habitat diminishes on the continent, creating new bighorn sheep habitat through restoration of disturbed landscapes may be a key factor in conservation of the species.

Bighorn sheep habitat is specialized; it is composed of grasslands adjacent to escape terrain; is generally associated with alpine environments; and is fragmented by mountainous terrain. During the course of one year, bighorn sheep may move between six seasonal ranges that may or may not be spatially connected (Geist 1971). Travel between seasonal ranges is a learned behaviour and site fidelity is strong. Bighorn sheep are thought to be poor colonizers of habitat that is unknown to them (Geist 1971). Under certain conditions bighorn sheep are known to colonize new habitat made available by natural means (e.g., fire, avalanches) or through the use of management tools like prescribed burning, logging, and mechanical treatments (Arnett *et al.* 1990, Smith *et al.* 1999, Dibb and Quinn 2006).

Geist (1971:127,128) in his benchmark book *Mountain Sheep: A Study in Behaviour and Evolution* provided the theoretical conditions required for bighorn sheep to colonize new habitats: decreasing distance of unoccupied range to occupied range; large concentration of rams in spring; segregation of rams into age classes; younger rams roaming in groups, leading to the discovery of unoccupied range; and the discovery of new range by young two-year-old ewes, following rams on their spring excursions.

Jesmer *et al.* (2018) found that when reintroduced to previously occupied areas, bighorn sheep did not migrate as historical herds had; rather, new migratory patterns were formed over many generations, as culturally transmitted information was accumulated by individual experiences. Singer *et al.* (2000) indicated that high dispersal rates and rapid reoccupation of large areas could occur if bighorn sheep were placed in large patches of habitats with few barriers to movement to other patches. MacCallum and Geist (1992) documented colonization of the partially reclaimed Luscar Mine in Alberta by bighorn sheep from nearby occupied alpine range. A later study indicated there was no evidence of range abandonment of existing habitat in favour of newly created habitat (MacCallum 2008). Likewise, Smith *et al.* (1999) used radio collars and an experimental design to document bighorn sheep using nearby logged and burned areas while maintaining fidelity to original areas of occupation, indicating range expansion rather than abandonment.

The GRM is situated in west-central Alberta adjacent to the older Luscar Mine. It was predicted that bighorn sheep would colonize the GRM as they had the Luscar Mine, therefore reclamation was intentionally designed to provide habitat for bighorn sheep and other wildlife. Open pit mining creates benched highwalls and steep footwalls which provide escape terrain for bighorn sheep. Reclamation of GRM included not only replacing topsoil and establishing a vegetation cover but also the retention of walls in strategic areas to provide escape terrain, lambing sites, loafing sites, and secure travel for bighorn sheep. Mining and reclamation began on the east side of the GRM where the mine was closest to the alpine environment and progressed in an orderly fashion to the west. Since non-authorized human use is not permitted on mineral surface leases, the boundary creates a temporary refuge for wildlife where human activity is predictable. Bighorn sheep quickly learn that mining activity does not cause the energy expenditure required to respond to random human activity (i.e., hiking, photography, skiing, off-highway vehicle use, and other recreational activities). Hunting is not allowed on the GRM mineral surface lease.

Wishart *et al.* (1998) described the rapid population increase of the nursery herd during colonization of the newly available habitat on the GRM. This paper is a companion article that documents and maps the pattern of reclamation and spatial occupation by bighorn sheep through time by sex/age class since the beginning of the life of the mine. The purpose of this paper is to use spatial analyses to measure expansion of home range. The east-to-west progression of reclamation over 30 years provides a unique opportunity to document bighorn sheep response to the annual westward expansion of habitat.

STUDY AREA

The GRM is an open pit metallurgical coal mine that began construction in 1981 with coal production following in 1983 and ending in 2000. Mining occurred in subalpine habitat immediately adjacent to alpine habitat occupied by bighorn sheep. The primary end land use for the mine was identified as wildlife habitat and watershed protection as there was no potential for commercial timber prior to mining.

GRM is located on the east side of the Canadian Rocky Mountains about 40 km southwest of Hinton, Alberta in an area known as the Coal Branch (Alberta Forestry, Lands and Wildlife 1990). The mine occurs at the eastern limit of the subalpine ecoregion, elevations range from 1400 m to near tree line at 2000 m (4620 - 6600 feet) and is characterized by a Cordilleran Climatic Regime and Rocky Mountain vegetation. Lodgepole pine (*Pinus contorta*), Engelmann spruce (*Picea engelmanni*), and subalpine fir (*Abies lasiocarpa*) forests are dominant. Primary succession shrub communities of willow (*Salix* spp.) and dwarf birch (*Betula glandulosa*), and scattered grasslands also occur (Strong 1992). Soils are generally thin and rocky. Summers are cool (July daily mean temperature <13° C) and showery, with a short 165 to 170 day growing season (Chetner *et al.* 2003). The frost-free period is 85 to 95 consecutive days. Most precipitation falls in summer (>325 mm between May 1 to August 31). Winters are snowy (250 to 275 mm precipitation between September 1 and April 30), cold (January daily mean temperature -12 to -10°C) and characterized by frequent chinooks: warm dry winds that descend on the eastern side of the Rocky Mountains, periodically reducing snow cover.

METHODS

Mining and Reclamation

Mining at GRM progressed in two phases beginning in 1981 with the area referred to as the 15-Year Area and then proceeded northwest in 1998 to the Sphinx West area (Figure 1). Prior to mining, tree cover was logged and salvaged where possible. In anticipation of reclamation, all topsoil from disturbed areas was salvaged and stockpiled in accordance with legislation. Open pit mining was conducted using a truck and shovel method. As mining progressed the waste rock was used to backfill pits where mining had been completed, unless pit walls had been designated as escape terrain habitat for bighorn sheep. The slope angle on backfilled pits was reduced to less than 27 degrees using primarily D10N Caterpillars and backhoes. Sloping was done to create a smooth interface between the undisturbed and reclaimed landscapes, and to reduce erosion potential. Lines of sight were broken up to provide a diverse landscape designed to resemble natural landforms (Brand 2010). Following sloping, if the waste rock fell outside the specified regolith criteria, subsoil materials were added to re-establish overburden. Stockpiled topsoil was then placed on the recontoured slope. The final step in the process was revegetation, i.e., seeding and tree and shrub planting. The seed mix consisted of 14 species of native (25%), and agronomic (75%) grasses and legumes (Luscar 2003). Overall seeding application rates were reduced in later years to accommodate tree and shrub growth. In order to minimize erosion of precious topsoil, seeding occurred the same year of soil placement, or the following year if placement occurred in the fall. Seed mixes were designed to rapidly establish vegetation, accomplished largely through an initial fertilizer application and the inclusion of nitrogen fixing legumes. Tree and shrub planting was done the year after seeding when possible. As per regulation (Alberta Government 2016), native conifer seeds were collected on the GRM prior to disturbance, germinated in a greenhouse and planted in two-year-old stock containers. Similarly, native shrub seeds or cuttings were collected locally (i.e., green alder (*Alnus crispa*), dwarf birch, shrubby cinquefoil (*Potentilla fruiticosa*), and willow) and planted with tree stock. Areas designated for bighorn sheep were not planted with trees and shrubs to maintain field of view and quality forage.

In addition to providing forage for grazing ungulates, the rapid establishment of vegetation had the benefit of initiating soil development. Minerals accrue to the soil through rainfall, dust, microorganisms that fix materials from the atmosphere, and decomposition of plant material. Grazing ungulates present during vegetation establishment significantly affect mineral cycles in plant communities by returning 80-90% of ingested nutrients to the soil by excreta (Heady 1975:76). This pathway for nutrient cycling in soil occurs at an accelerated rate compared to cycling of detritus directly from plant material (Vanderwaal *et al.* 2011).

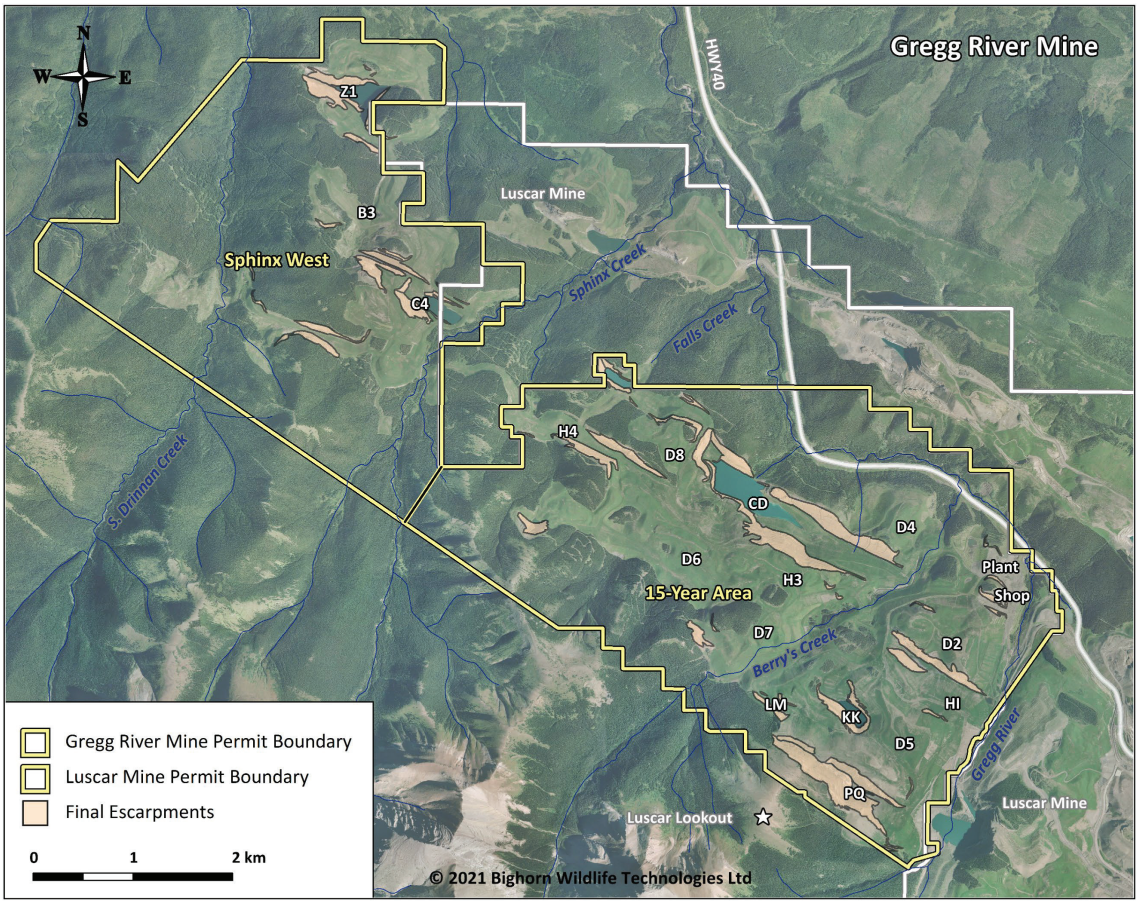

Figure 1. Gregg River Mine place names (Imagery 2011).

Coal seams at GRM were folded during mountain forming processes allowing for discontinuous pit development. This along with the intent of minimizing disturbance led to the preservation of areas of undisturbed vegetation cover within the disturbance boundary. Thirty tree islands were interspersed throughout the reclaimed landscape, averaging 3.3 hectares (range: 0.05-23.2 ha) and amounting to ~100 ha. The patches of undisturbed forest, meadow, and riparian vegetation were a vital feature in restoring a diversity of habitats during reclamation. The final reclaimed landscaped included patches of coniferous forest, grassland, escarpments, planted forest, riparian habitat, and end pit lakes (Figure 1).

Umbrella Species

The umbrella species concept provides a clear conceptual framework for reclamation planning for wildlife habitat. An umbrella species (or population) can be broadly defined as one whose conservation confers protection to a large number of naturally sympatric species (Branton and Richardson 2010). By creating habitat for umbrella species, other components of the wildlife community will benefit even though reclamation will not be aimed specifically at them (Green and Yonge 1985). Ungulates are suitable for use as umbrella species for reclamation to wildlife habitat because they have large home ranges, require a variety of landform features and vegetation types to fulfill their annual life requirements, and are important prey for carnivores. Bighorn sheep, mule deer (*Odocoileus hemionus*), and elk (*Cervus elaphus*) are representative of the wildlife in the GRM area. These ungulates were chosen as the umbrella species for pre-planning of reclamation activities and for monitoring wildlife response to reclamation. Design criteria for the 15-Year Area was informed primarily by habitat requirements by bighorn sheep, with reclaimed grassland placed adjacent to pit walls that serve as escape terrain. The Sphinx West area was designed primarily as mule deer and elk habitat and included grassland, open and closed forest, escarpments, end pit lakes and riparian areas (GRM 1998); bighorn sheep habitat was a secondary goal. While the umbrella species provided the framework for landscape design, smaller scale habitat features were incorporated based on the needs of species with specialized habitat requirements. Selective placement of brush and rock piles provided perching sites for raptors and various mammal uses (MacCallum 2003). Talus features created for travel and bedding of bighorn sheep using unsloped waste rock in turn provided habitat for small alpine mammals (i.e., hoary marmot (*Marmota caligata*), golden-mantled ground squirrel (*Callospermophilus lateralis*), and American pika (*Ochotona princeps*). Mineral licks were identified and preserved. Water features provided a source of insects for aerial insectivores, and habitat for shorebirds, waterfowl, and fish; water is not limiting to bighorn sheep in this area.

Wildlife Surveys

A population-based approach to monitoring the response of wildlife to reclamation on the GRM was initiated in 1989 (MacCallum and Kielpinski 1991) a few years after bighorn sheep began to use GRM systematically. The primary intent was to monitor the response of the umbrella species to the habitats designed for them; additionally, all wildlife species observed during monitoring were reported. From these surveys, bighorn sheep population characteristics, seasonal core use areas, annual home range, connectivity, movement, and lambing and rut areas were generated.

Ground-based wildlife surveys on GRM were conducted multiple times per year by driving, or walking, or observing from viewpoints from a fixed survey route as per Irby *et al.* (1988). Fixed surveys were designed to cover 100% of the mine lease; the length of the survey increased over time with expansion of mining. MacCallum (1991) used shifts in movement and behaviour to identify six biologically meaningful seasons for bighorn sheep on the Luscar Mine. These were combined into three generalized seasons for reporting: winter/early spring (mid-November to end of April), lambing/summer (May to mid-August) and pre-rut/rut (mid-August to mid-November). A minimum of one survey was conducted per season with the exception of the pre-rut/rut surveys when a minimum of 3 surveys were conducted. Mortality records (species, location, date, cause of death) were documented during surveys, and by the mine personnel and conservation officers throughout the year. Fall surveys were corrected with known mortality and the maximum count was used to generate demographic information.

Spotting scopes and binoculars were used to locate individuals or groups of large terrestrial mammals (bighorn sheep, elk, mule deer, white-tailed deer, carnivores), small and medium-sized mammals, and resident and migrating birds. The centroid of each group was recorded on 1:5,000 large scale maps. The age class and sex of each animal was recorded. For bighorn sheep, sex/age are identified using the classification by Geist (1971). Sign of carnivore activity was also recorded (e.g., bear digs, wolf tracks in fresh snow).

Reclamation mapping for bighorn sheep

Distribution of bighorn sheep was mapped every five years spanning the entire colonization event using scheduled survey observations for the calendar years: 1990, 1995, 2000, 2005, 2010 and 2015. Epanechnikov kernel home range and 65% core areas were generated using the *kernelUD* function in the *adehabitatHR* R package (Calenge 2006, R Core Team 2019). Harmonic mean centres were generated using the *Location Analysis* function in Range 9 v.14 (Kenward *et al.* 2014). Cumulative changes in the amount of revegetation, pit walls retained as escape terrain, and disturbance limits were included on maps to demonstrate quantity and distribution of newly available habitat over time. Distance to escape terrain was calculated for each survey observation using the 'distance calculator' tool using MapInfo V.19.

In order to generate reclamation mapping, a combination of GIS methods was employed. Hardcopy maps from 1981 to 1998 GRM Annual Reports were borrowed from David Brand and scanned. These hand drawn maps showed the amount and location of seeding, reseeding, planting (tree and shrub), replanting, and proposed seeding and planting for each year; these were geo-registered (MapInfo V.8), digitized in GRM mine grid and reprojected to UTM Zone 11 (NAD83). AutoCAD mapping was available for 1997 to 2006 and was more comprehensive, including layers for seeding, planting, soil placement, waterbodies, escarpments, roads, ponds and other mine features. Both the digitized maps and the AutoCad layers were opened over orthorectified air photos from 2000 (1 m resolution), 2004 (1 m resolution) and 2011 (30 cm resolution). Any errors resulting from conversion from mine grid to UTM were corrected. Most reclamation was completed by 2006, with the exception of the former plant, shop, and silo areas near Hwy 40 which was completed in 2011.

Areas of revegetation were subject to different treatment in different years, including topsoil placement, seeding, reseeding, and planting. For the purposes of this study, an area was considered to be revegetated once the initial seeding was complete. A cumulative reclamation map was created for each year that included revegetated areas and retained pit walls. During the course of this study the reclaimed areas remained (and still remain) primarily open landscapes. Trees were planted in selected areas protected from the desiccating effect of chinook winds. Trees grow slowly in these alpine and subalpine environments, and during this study planted trees had not reached a height that would reduce the field of view or access to forage; tree growth did not influence the home range expansion of the bighorn sheep.

There may be discrepancies between areas generated from these GIS methods and those submitted in GRM annual reports. The areas generated for this study are intended to quantitatively track the spatial and temporal response of bighorn sheep to reclamation over time and may not be suitable for other purposes.

RESULTS

1981 to 1990

Mining and reclamation at GRM began on the eastern corner of the mine lease boundary near the Hwy 40 access (Figure 1). Small amounts of seeding (<50 ha) occurred in these areas from 1981 to 1984. By 1987 development had proceeded to the D6 area. Within the first ten years of development (1981 to 1990) ~132 hectares of the disturbed area had been seeded, mostly in the D4 area (near the Gregg River and shop/plant area) and the D5 area.

The progression of clearing, mining, and reclamation at the GRM was followed directly by colonizing bighorn sheep. It is suspected that bighorn sheep initially gained access to the mine in the southwest corner where the multi-benched PQ wall adjoins an alpine meadow below the former Luscar Lookout site (Figure 1). The PQ wall created new escape terrain adjacent to native grasslands. Winter aerial surveys (Stelfox 1964, Bibaud and Dielman 1980, Cook 1982) and results of a telemetry study (Lynch and Smith 1974) confirm that bighorn sheep used these alpine meadows prior to mining. By 1987, mine personnel consistently reported eight rams using the GRM (pers. comm. R. Zroback, March 27, 1987).

By 1990, patches of reclamation loosely connected the area between the PQ wall and D4 reclaimed area. These areas were within the annual 95% ram home range boundary (Figure 2a). Use by bighorn rams was concentrated on the D4 and D5 where a significant amount of reclamation had been completed. A small disjunct area on the west side of the ram home range in 1990 (Figure 2a) indicates a westward expansion of range. On 4 September 1989, seven young rams (six Class I and one Class II) were observed grazing in the Berry 's Creek undisturbed valley bottom. By the following spring three young rams (two Class I and one Class II) were observed west of Berry's Creek along the access road to the D6 area (22 April 1990). This westward expansion was enabled by the wide clearing adjacent to the D6 access road where

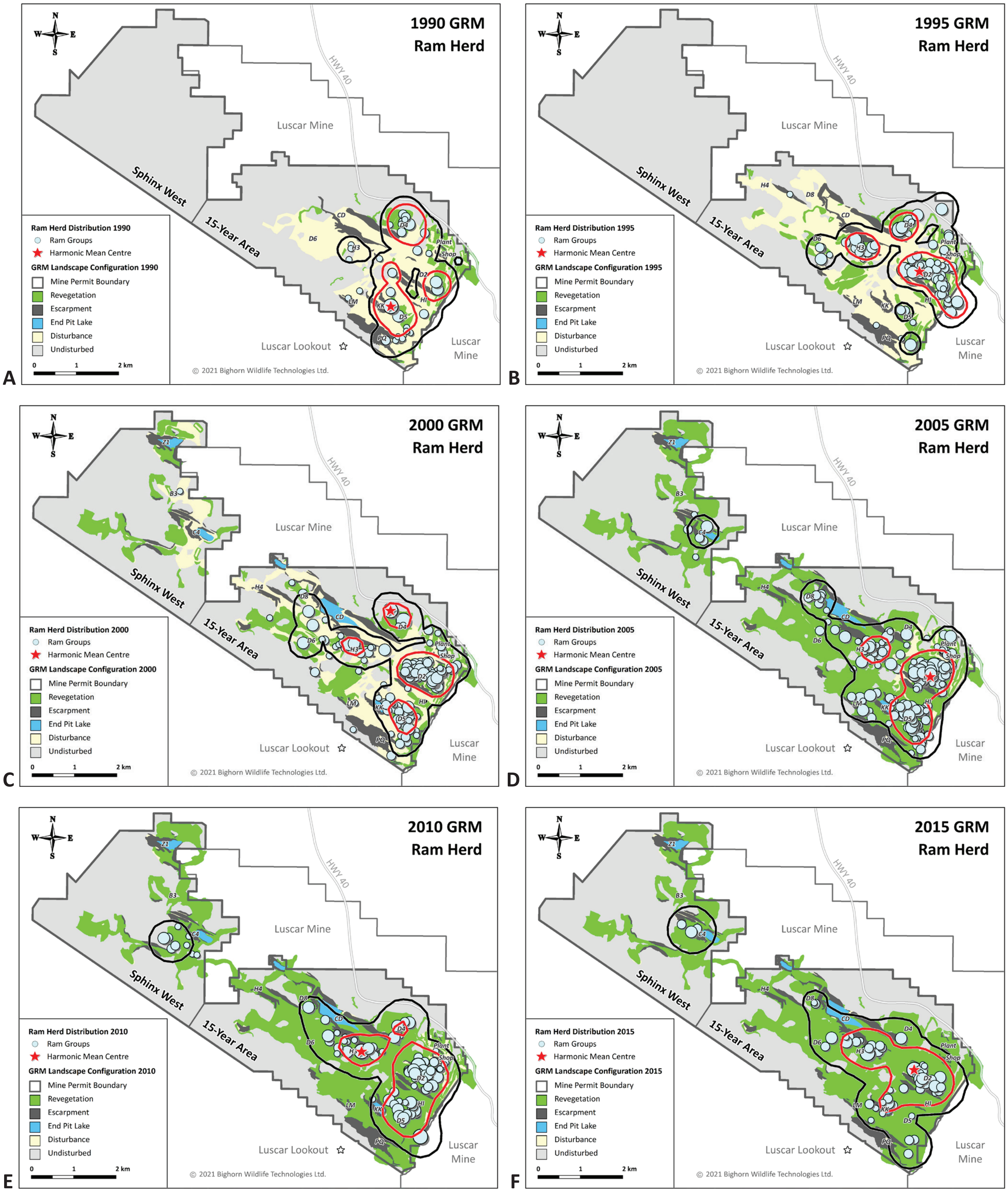

Figure 2. Annual ram herd distribution and reclamation progression on the GRM mapped at five year intervals during the 1989-2015 colonization period. Blue points are wildlife survey ram observations for the given year, scaled by group size; red isopleths are 65% core areas and black isopleths are 95% home range areas (Epanechnikov kernel use distribution).

Figure 3. Young rams grazing on a recently logged area, Gregg River Mine, 27 May 1990.

ground cover remained intact allowing for grazing and movement (Figure 3). Bighorn sheep use of areas recently cleared of trees was observed throughout the mine wherever these patches existed. Nine rams were observed on 31 May 1990 on the east side of the mine in the HI area which had been cleared of trees, but native ground cover and soil remained intact.

The first observation of members of the nursery herd on GRM occurred on 31 May 1990 when two ewes were sighted near new seeding close to PQ area in the southeastern part of the mine (Figure 4a). The two ewes spent a few days grazing then were seen in the alpine adjacent the top of the PQ multi-benched pit wall on 10 June 1990. They may have been seeking lambing sites or simply travelling to summer range in the alpine.

1991 to 1995

By 1995, a total of ~256 hectares of reclamation had been completed not only in the D4 and D5 areas but also in the H3, D6, D7, and D2 areas.

Between 1991 and 1995 rams continued to occupy newly reclaimed areas west of Berry's Creek. During these years more rams began to concentrate on D4, D2 and D5 areas causing the home range isopleths to tighten up when compared to the few, scattered bighorn sheep in the area in 1989-1990 (Figure 2b).

Ewes were not observed on the GRM in 1991. On 6 March 1992, five ewes, two lambs and one female yearling were observed at the base of the PQ multi-benched pit wall. Small numbers of ewes, lambs and yearlings continued to be observed during systematic surveys throughout 1992. Numbers and type of use by the nursery herd on the GRM began to increase after this initial occupation.

The nursery herd (six ewes, two lambs, two female yearlings, one male yearling) remained on GRM in the D5 area in fall of 1992, marking the first documented rut season on the reclaimed

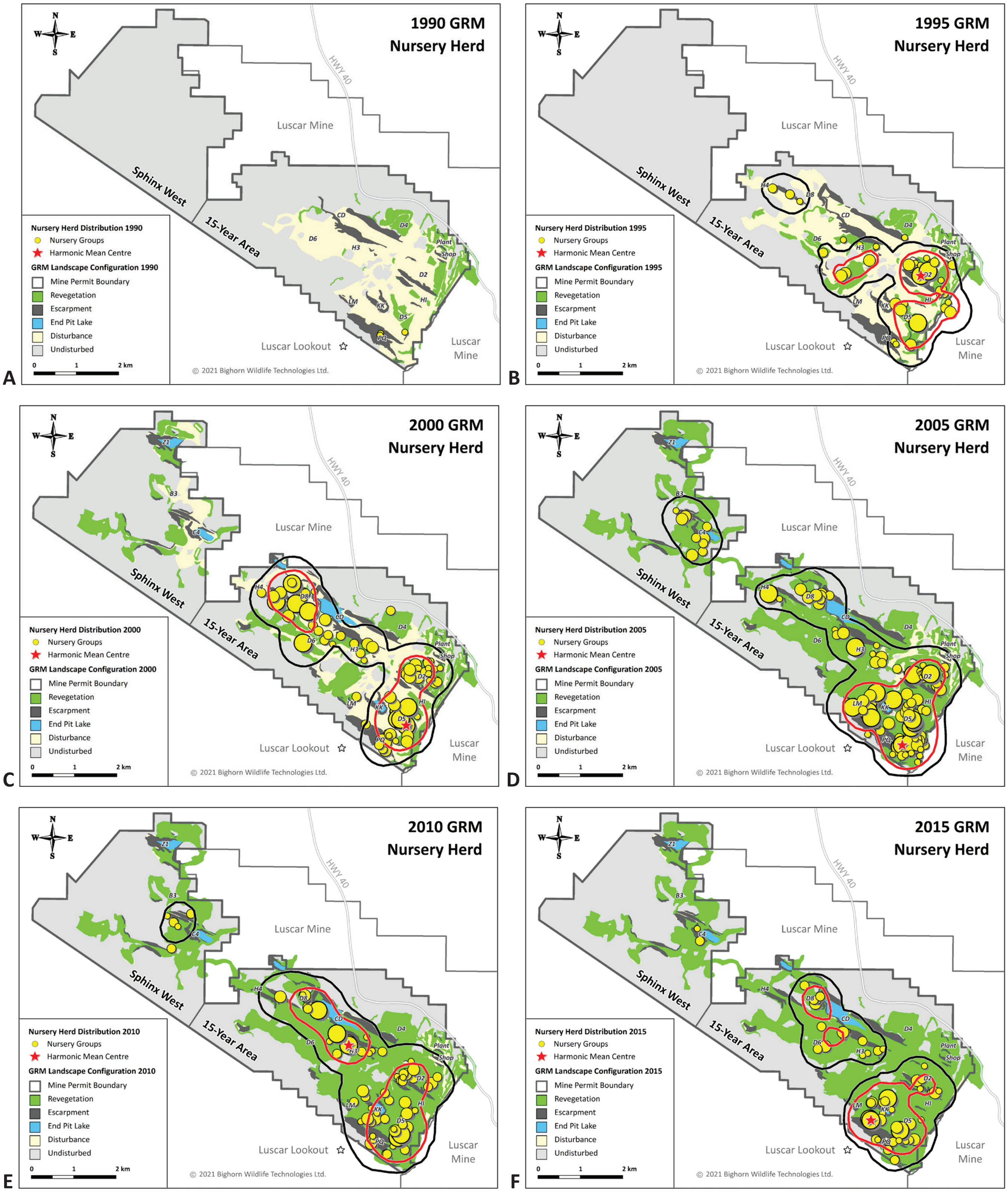

Figure 4. Annual nursery herd distribution and reclamation progression on the GRM mapped at five year intervals during the 1989-2015 colonization period. Yellow points are wildlife survey nursery observations for the given year, scaled by group size; red isopleths are 65% core areas and black isopleths are 95% home range areas (Epanechnikov kernel use distribution).

landscape. Rut behaviour continued in 1993 and 1994 and the D5 was established as a rut range. During the winter of 1993, members of the nursery herd were observed in small groups (2 to 5) on the eastern part of the mine. In 1994, the nursery herd made consistent use of the D5 area throughout the winter. The first record of lambing at GRM occurred on 10 May 1994 when one ewe with new lamb was observed on the LM highwall. By 1995 the nursery herd annual home range had extended west through the central part of the 15-Year Area and included a disjunct area known as the H4 pit (Figure 4b); annual (95%) home range more than doubled in size between 1992 and 1995.

1996 to 2000

Development in the Sphinx West area began in 1997. By 2000, cumulative reclamation on the GRM amounted to ~519 hectares and included seeding in both the 15-Year Area and in areas west of Sphinx Creek (Figure 2c).

The first records of bighorn sheep in the Sphinx West reclamation area were made 30 January 2000 when tracks of two young sheep were detected in fresh snow in the B3 area; later in the spring two Class I rams were observed in the B3 area 05 April 2000 (Figure 2c). The Sphinx West area is comprised of a series of rugged ridges and steep slopes. Bighorn sheep generally do not like to enter timber, but many records exist of bighorns making long, regular movements across forested valleys or through timbered areas (Geist 1971:119). Prior to mining development, the Sphinx West area was known as a traditional travel route for bighorn sheep linking Sphinx Mountain to the west with the reclaimed Luscar Mine to the east. Anecdotal records were confirmed in the fall of 1992 [16 November] when the tracks of two rams were followed through heavy timber from the western end of the Luscar Mine to the northern flank of Sphinx Mountain. Bighorn sheep will travel long distances in short periods during their seasonal migrations (Geist 1971:62).

By the year 2000, both the ram and nursery 95% home range extended throughout the 15-Year Area and were poised to follow the westward development into Sphinx West (Figure 2c and 4c).

2001 to 2005

Most of the revegetation of the 15-Year and Sphinx West areas was completed by 2005 amounting to ~1125 hectares (Figure 2d).

Bighorn ram groups began to use the Sphinx West area consistently beginning in 2002 when 2 male yearling, 4 Class I and 1 Class II were observed during the 3 November 2002 survey. Consistent use of this area by rams continued annually through to 2005 (Figure 2d). The ram 95% annual home range in 2005 was 1.4 times the size in 1990.

The first members of the nursery herd observed in Sphinx West occurred on 26 June 2003 when eight ewes, nine lambs, two female yearling, one male yearling, two Class I, and one Class II bighorn sheep were detected in the C4 area. By 2005, the nursery herd 95% annual home range encompassed most of the 15-Year Area as well as a disjunct area in Sphinx West (Figure 4d) and was four times the size in 1992.

2006 to 2010

Most of the disturbed area of the GRM was reclaimed by 2006 with only a few areas of roads and infrastructure remaining. The revegetated area in 2006 covered ~1182 ha.

From 2006 through to 2010 the ram and nursery 95% home range included all areas of suitable habitat previously occupied, stretching from the eastern side of the 15-Year Area to the west side, and also included a disjunct area in Sphinx West (Figure 2f and 4f).

The GRM population peaked in 2009 with 653 bighorn sheep recorded during the pre-rut (Figure 5a). During the 1989 to 2009 population expansion event, the GRM pre-rut surveys yielded a linear increase in both the ram herd (9.2 ± 0.86 SE sheep per year, $P < 0.001$, *CI:* 7.438 to 11.022) and the nursery herd (12.1 ± 1.9 SE sheep per year, $P < 0.001$, *CI:* 8.219 to 15.903).

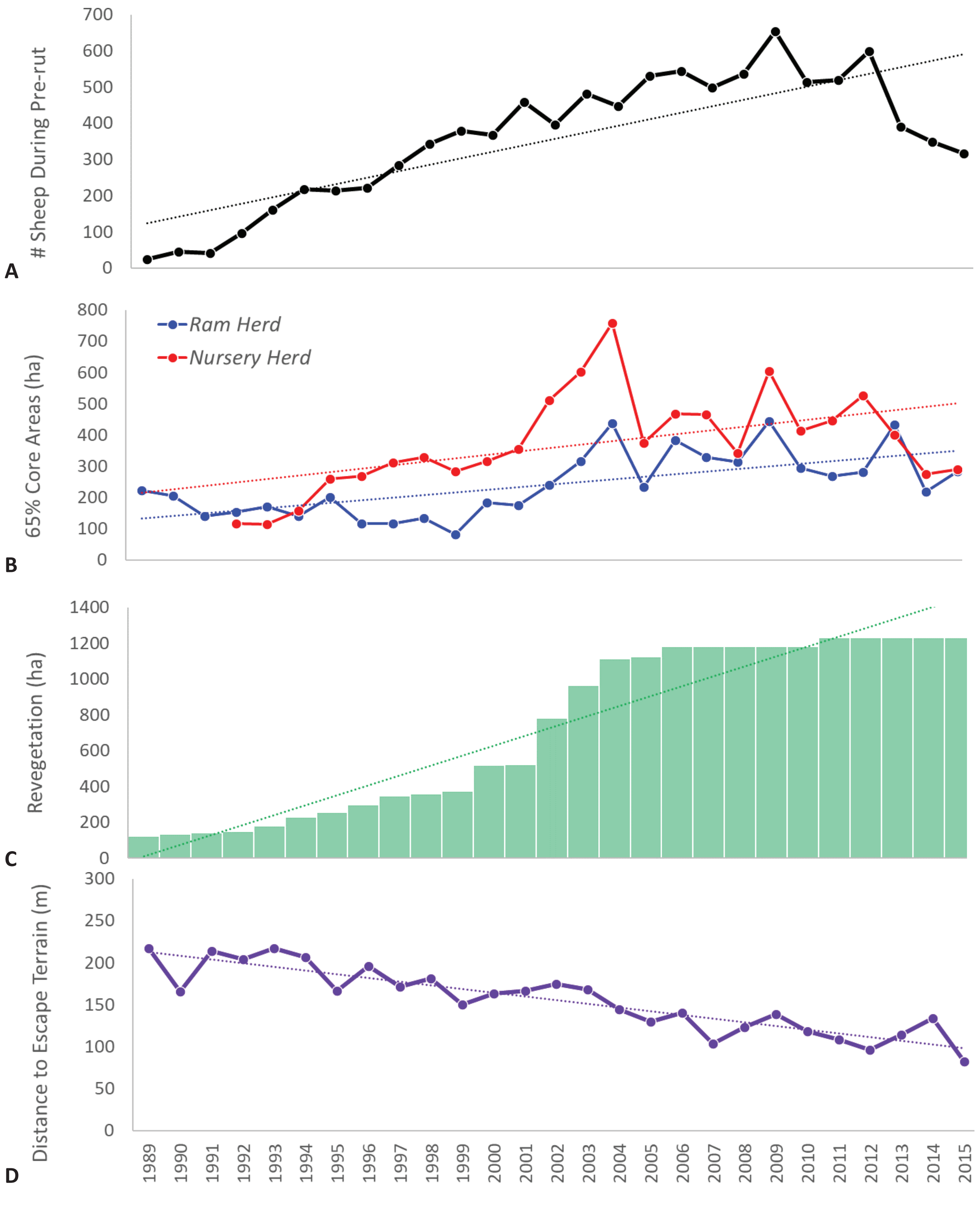

Figure 5. Gregg River Mine bighorn sheep colonization period 1989-2015. A) Maximum annual count from pre-rut ground surveys (mid-August to mid-November), adjusted for known mortality. B) 65% core areas for ram and nursery herd from Epanechnikov kernel use distribution analysis. C) Cumulative revegetation on the GRM lease. D) Average distance from observation location to nearest escape terrain feature.

During the design phase of the mine, it was predicted that the nursery herd would colonize once large areas of reclamation became available near the larger walls. The initial average annual group size of the nursery herd was relatively small in the early years (1.8 in 1990, 4.4 in 1992). By 1995, additional reclamation had become available and average group size was 9.8 and by 2009 the average group size was 14.3.

2011 to 2015

Reclamation was completed in 2011 with the removal of the shop, office and plant structures and seeding of those areas. While areas summarized in this section reflect revegetation (seeding and planting) the final composition of the reclaimed landscape included escarpments, end pit lakes, and tree islands which can be seen on the 2011 orthophoto in Figure 1. The total revegetated area in 2015 was ~1232 ha.

At this point in time, a combination of fixed habitat and pressure from poor winters, removals for translocation, predation, and increasing elk use brought bighorn sheep numbers down from their peak of 653 in 2009 to 317 in 2015. While the overall population came down from its peak in 2009, the spatial distribution in the 15-Year and Sphinx West areas remained constant; year-round occupation of the GRM reclaimed landscape by bighorn sheep was firmly established.

Overall

During the study period from 1989 to 2015 the ram 95% annual home range increased 36.5 ± 6.1 SE hectares per year ($P < 0.001$, *CI:* 23.979 to 49.011) while the 65% core area increased 8.3 ± 2.4 SE hectares per year ($P < 0.001$, *CI:* 4.186 to 12.359) (Figure 2 and 5b). From 1992, when the nursery herd first began to systematically use the reclamation, to 2015, the 95% annual home range increased 45.2 ± 12.6 SE hectares per year ($P = 0.0016$, *CI:* 19.194 to 71.267) while the 65% core area increased 16.0 ± 3.5 SE hectares per year ($P < 0.001$, *CI:* 8.672 to 23.269) (Figure 4 and 5b). The average distance to escape terrain (all seasons, all classes of bighorn sheep) decreased by 3.6 ± 0.5 SE m per year from 1989 to 2015 ($P < 0.001$, *CI:* -4.705 to -2.585) (Figure 5d). Since the early 1990s through to 2015, both the ram and nursery groups made consistent use of the GRM throughout all seasons (winter/spring, lambing/summer, and pre-rut/rut).

DISCUSSION

Geist (1971:127) described mountain sheep as a species that *"appear to be incapable of dispersal"* however, he discusses two possible mechanisms that allow bighorn sheep to perform range extensions. The first involves the presence of open terrain between occupied habitat and unoccupied habitat. Such a configuration would present no barrier to bighorn movement. The presence of occupied bighorn sheep habitat on the former Luscar Lookout site adjoining the reclaimed and unoccupied habitat on GRM fulfils this criterion. The second mechanism involves spring exploration movements by young rams in small groups. In the 15-Year Area, this type of movement was documented with the movement of young rams into the newly logged area on 27 May 1990 (Figure 3). In the Sphinx West area, the first observation of bighorn sheep was of two Class I rams 5 April 2000.

In the early years of colonization, rams were repeatedly observed using patches of vegetation which had been cleared of trees, but where the ground cover and soil remained undisturbed. These responses by bighorn sheep to newly cleared areas confirm the importance of a clear field of view. Opening habitat to provide an increased line of sight is a powerful tool for enhancing bighorn sheep habitat that has been encroached upon by shrub and tree cover. Indeed, bighorn sheep use of recently logged or mechanically cleared areas at timberline has been documented in south-central Wyoming (Arnett *et al.* 1990), Utah (Smith *et al.* 1999), and southeastern British Columbia (Dibb and Quinn 2006).

The nursery herd lagged behind the rams during initial colonization of the 15-Year Area in 1987 by six years. Once established the nursery herd home range expanded quickly, becoming established in Sphinx West one year after ram colonization.

In general, the shape of home range polygons for both the bighorn rams and the nursery herd started out as a north/south occupation of the eastern edge of the mine, stretching progressively westwards as mining and reclamation proceeded to the northwest. Maximum expansion of home range was achieved by 2005. Throughout the entire period to 2015, the harmonic mean centres for the ram and nursery herds remained in the 15-Year Area which was designed as primary bighorn sheep habitat. While expansion into Sphinx West did occur, this area was designed primarily for mule deer and elk; bighorn sheep concentrations remained highest in the 15-Year Area. The Sphinx West area was historically important for connectivity but once reclamation was mostly completed in 2005, the area became part of the 95% home range for both the ram and nursery herds.

Once established, the bighorn sheep population responded directly to the increasing amount of reclamation. This study shows that bighorn sheep can be quick and effective colonizers under the right conditions. The home range expansion can be seen spatially for rams in Figure 2 and for the nursery herd in Figure 4. During the initial colonization event between 1989 and 2009, total numbers of bighorn sheep surveyed during the pre-rut increased with expanding area of available habitat. A linear population response of bighorn sheep to newly available habitat was predicted and verified as forage adjacent to escape terrain became increasingly available throughout development (Figure 5a and 5c). At the end of the life of the mine, new habitat stopped increasing and as expected the bighorn sheep population also stopped increasing. At this point, factors other than new habitat availability began to affect the population growth rate. Stabilization of habitat, colonization by cow elk beginning in 2003, presence of large predators (grizzly bear, gray wolf, cougar), poor winters, and removal of bighorn sheep (to enhance lost or diminished populations in the US and Alberta) all contributed to the population dynamics at the GRM.

The grizzly bear population in Bear Management Unit 3, which includes the GRM, grew at 7% per year between 2004 and 2014 (Stenhouse *et al.* 2015). This is higher than commonly seen in most grizzly bear populations in North America (Mace *et al.* 2011, Garshelis *et al.* 2004). Wolves were present in the early years of reclamation on GRM, but more consistent use by packs was recorded during wildlife surveys after 2000. Use of the reclaimed areas for denning and rendezvous sites between 2011 and 2018 (and possibly earlier) denoted a year-round presence of these predators.

In 2011, spring greenup was delayed three weeks by unusually deep and persistent snow on the GRM and Luscar mines and resulted in higher than usual ungulate mortality (MacCallum 2012). Records of known mortalities (27) between 01 January and 30 April of 2011 indicated cougars were responsible for 44% of all bighorn sheep mortalities, followed by natural causes (22%), unknown (15%), and wolves (11%).

Various authors have suggested that if harassment is great or predation high, bighorn sheep will select larger or steeper cliffs (Van Dyke *et al.* 1983, Stemp 1983). A review by Sawyer and Lindzey (2002) indicated that virtually all predators sympatric with bighorn sheep have been documented to prey upon bighorn sheep. They noted that in some cases, predation may have population-level impacts. Shroeder *et al.* (2010) noted that female bighorn sheep used more rugged terrain than males; they hypothesized that females used more rugged terrain to reduce the risk of predation and for protection of their vulnerable offspring, An indirect effect of predation is the restriction of range utilized by bighorn sheep to areas adjacent to escape terrain, changing how bighorn sheep are distributed over the area. MacCallum (1991) predicted that over time the presence of predators could potentially cause the bighorn sheep using the reclaimed mines to adjust their pattern of use by using areas closest to the highest and steepest pit walls. In accordance with this prediction the average distance to escape terrain at GRM decreased over the course of colonization (Figure 5d). The decrease in size of ram and nursery herd 65% core areas between 2010 and 2015 (Figure 5b) may in part be the result of predation pressure. This emphasizes the importance of providing a large area of secure and open habitat for bighorn sheep. On GRM, the configuration of a series of large rock walls in parallel (PQ, KK, HI, D4, CD, H4, C4) provides secure habitat even during a period of high predation mortality. Conversely the decrease in distance from escape terrain may simply be a response to progressive reclamation of disturbed areas. Over time as sloping and revegetation were completed, more grasslands became established immediately adjacent the pit walls providing more opportunity for sheep to graze closer to escape terrain.

During the colonization of GRM, bighorn sheep did not abandon previously colonized habitat in favour of newly available habitat but maintained use of initially occupied areas while, at the same time, expanding to the northwest (Figure 2 and 4). Festa-Bianchet (1991) remarked that seasonal dispersion in the Sheep River Sanctuary may often be related to the gregarious nature of sheep: "*in certain seasons their movement within their ranges may be a function of the need to stay within a group and to follow the dominant animals"*. This plasticity of movement by bighorn sheep within their established range was described by Riggs and Peek (1980) who hypothesized that the "*lack of extreme rigidity in seasonal dispersion would be advantageous when new habitat is created through several changes following wildfires*".

A radio-collaring study of 19 bighorn sheep indicated that the bighorn sheep using the reclaimed GRM are part of a larger metapopulation that includes the adjacent partially reclaimed Luscar Mine, alpine ranges bordering the mines to the southwest and northwest, Whitehorse Wildland Provincial Park, and Jasper National Park (MacCallum 2008). There are no barriers preventing travel between these areas. Bighorn sheep that occupied adjacent historical alpine ranges initially shifted use patterns to include the reclaimed mines in their seasonal movements. With an increasing amount of available habitat, coupled with increasing numbers, bighorn sheep expanded into the newly available habitat, establishing new seasonal home ranges and traditions.

GRM is located within Wildlife Management Unit (WMU) 438. Bighorn sheep winter air surveys have been conducted by the Government of Alberta in the alpine ranges of WMU 438 adjacent the reclaimed mines beginning in 1963 (Alberta Wildlife Management 2015, Stelfox 1965). The surveys first recorded bighorn sheep on the mines in 1982; it is known anecdotally that bighorn sheep were present in small numbers in earlier years but were not detected by the surveys. Due to low survey frequency, these air survey counts should be used with caution when considering population demographics but are suitable for overall trend analysis (when incomplete surveys in 1999, 2012, and 2014 are excluded). In the undisturbed alpine portions of WMU 438 there was no evidence of a change in bighorn sheep between 1963 and 2015 ($P = 0.523$, *CI:* -1298 to 2.439, $n = 16$). In the whole of WMU 438 including the mines the overall trend showed evidence of increasing bighorn sheep numbers over the same period ($P < 0.0001$, $CI =$ 13.932 to 23.264, $n = 16$). This increase can be attributed to the bighorn sheep response to newly available habitat.

In *101 Things To Do With a Hole in the Ground*, Pearman (2009) stresses that an enlightened approach to landscape regeneration can lead to better solutions to the problems of mining legacy and closure. The GRM's use of progressive reclamation throughout the life of the mine provides an example of working towards end land use goals in anticipation of closure, with the intent of leaving something of value into the future. In this case the goal was primarily wildlife habitat with a specific emphasis on bighorn sheep. Actively salvaging soil, storing soil, banking native seeds, and sloping are part of the reclamation cycle that precedes revegetation. Operators on the GRM had completed 41% of revegetation by the end of active mining in 2000. An additional 49% was quickly revegetated between 2001 and 2005, with the remaining 9% completed by 2011 (Figure 5c). Their expedience ensured that ecosystem function was restored as quickly as possible to these disturbed lands.

Revegetation in combination with retaining specific pit walls to provide escape terrain promoted early occupation by bighorn sheep of this reclaimed habitat, thus adding to the regional bighorn sheep population and range. Given the decline of bighorn sheep in North America in the last century, the colonization of the GRM is a significant achievement. While bighorn populations elsewhere on the continent have declined due in large part to exposure to domestic diseases, the mine's remoteness has meant the GRM has never been exposed to domestic animals and diseases (MacCallum 2006); the reclaimed lands have thus contributed to the conservation of the species. Designing for and developing habitat on an on-going basis provides the opportunity for endemic wildlife populations to discover and voluntarily colonize newly available habitat during the active mining phase. On-going use of revegetated areas by grazing ungulates during the life of a mine promotes soil development and maintains grassland health. Rewilding, in this case deliberate rehabilitation of a highly disturbed area to produce a productive wildlife habitat, is part of David Attenborough's vision to restore biodiversity to mitigate the impacts of climate change (Attenborough and Hughes 2020). The reclamation of the GRM demonstrates that given appropriate planning and design, reclaimed landscapes can provide habitat that fulfill the life requirements of bighorn sheep and sympatric species. With appropriate management, these reclaimed lands can remain a valuable wildland into the future.

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Mountain Goat Response to Human Activity in Jasper National Park

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ABSTRACT: Mountain goats (*Oreamnos americanus*) typically exhibit low tolerance for human activity, and the degree to which they can adjust their behavior to accommodate human activity is poorly understood. The Glacier Skywalk, an interpretive glass-bottomed viewing platform and tourist attraction, was constructed in Jasper National Park in 2012 and 2013. Mountain goats extensively used the cliffs and other habitats below and adjacent to the Glacier Skywalk, and potential impact to mountain goats was a primary concern associated with the project. We used remote cameras to document seasonal, diel, and demographic use by mountain goats at the Glacier Skywalk over a 9-year period (2011-2019) and conducted focal animal sampling to measure responses to construction in 2013. Unlike most other places where they have been studied, goats at the Glacier Skywalk exhibited high tolerance for human activity. Seasonal and diurnal use by goats in 2012 and 2013 as the Skywalk was being built was like that observed prior to construction in 2011, and the amount of use increased in some years during operations (2014-2017). Behavioral observations indicate that goats access the site primarily to obtain minerals. Goats did not abandon the site during construction activities, were observed on the cliff the same day as blasting and were also present during periods of high human visitation during operations. Effects to mountain goats were lower than predicted in an environmental assessment for the Glacier Skywalk, and our results indicate that some mountain goat populations can accommodate high levels of human activity, particularly around mineral licks.

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KEY WORDS: mountain goat, camera trap, Glacier Skywalk, behavioural plasticity, tolerance

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Mountain goats and people: Cultural resurgence as Indigenous methodology

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ABSTRACT: *Mati* – Mountain goats in Gitxaała's indigenous language – are iconic beings that play an important role in Indigenous histories and culture. This is an Indigenous led project involving social and ecological components of Mati/Gitxaała relations. It has been generations since we have hunted *Mati* in the old way by hand in intimate contact with *Mati.* Oral histories recount the close relations between our ancestors and *Mati.* Engaging in cultural resurgence acts of walking with *Mati* through our shared *laxyuup* (territory) in *K'tai* (a space within Pitt Island) builds our understanding of what it was like and how it can become. This paper describes the methods and results that have come from walking along side of, and learning from, *Mati* as a proxy for humans in the context of cultural resurgence – relearning and re-establishing our relations with *Mati* within our shared *laxyuup*.

Note: Menzies is a member of Gitxaała Nation. This research project is funded by SSHRCC Insight Grant.

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From pellets to genomes: New tools provide novel insights into mountain goat ecology and evolution

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ABSTRACT: Advancements in DNA sequencing technology combined with increased use of non-invasive sampling provide a unique lens to understand demographic and behavioural patterns in natural populations. We have several ongoing projects using these novel tools to inform mountain goat management and conservation planning. Of note, we recently characterized the fecal microbiome of mountain goats and showed how it changes within a population over time and how it could be used to distinguish populations. We have extended the microbiome assay to show how it varies with movement and space-use patterns. We have also assembled the first mountain goat genome that will be used as a backbone for understanding population and adaptive processes in this species. Our genome-wide demographic analysis has shown a dramatic reduction in effective population size during the last ice age, with no evidence of a range-wide recovery. Spatial genetic patterns assessed in 265 individuals from across the range appear to be driven almost exclusively by distance, with genetic variation strongly correlated to latitude ($r^2 = 0.83$). These new tools and analyses should be of interest to the wild sheep and goat research and management community.

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