Northern Wild Sheep and Goat Council

PROCEEDINGS OF THE 17TH BIENNIAL SYMPOSIUM

June 7 – 11, 2010
Hood River, Oregon

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

History of the Northern Wild Sheep and Goat Council Symposia, 1970 – 2010.

Date	Symposium	Location	Symposium Coordinator/Chair	Proceedings Editor(s)	NWSGC Executive Director
May 26-28, 1970	NWSC 1	Williams Lake, BC	Harold Mitchell		
April 14-15, 1971	NAWSC 1	Fort Collins, CO	Eugene Decker/Wayne Sandfort	Eugene Decker	
April 11-13, 1972	NWSC 2	Hinton, AB	E.G. Scheffler		
April 23-25, 1974	NWSC 3	Great Falls, MT	Kerry Constan/James Mitchell		
Feb. 10-12, 1976	NWSC 4	Jackson, WY	E. Tom Thorne		
April 2-4, 1978	NWSGC 1	Penticton, BC	Daryll Hebert/M. Nation	Daryll Hebert/M. Nation	
April 23-25, 1980	NWSGC 2	Salmon, ID	Bill Hickey		
March 17-19, 1982	NWSGC 3	Fort Collins, CO	Gene Schoonveld	James Bailey/Gene Schooneveld	
Apr. 30-May 3, 1984	NWSGC 4	Whitehorse, YK	Manfred Hoefs	Manfred Hoefs	Wayne Heimer
April 14-17, 1986	NWSGC 5	Missoula, MT	Jerry Brown	Gayle Joslin	Wayne Heimer
April 11-15, 1988	NWSGC 6	Banff, AB	Bill Wishart	Bill Samuel	Wayne Heimer
May 14-18, 1990	NWSGC 7	Clarkston, WA	Lloyd Oldenburg	James Bailey	Wayne Heimer
Apr. 27-May 1, 1992	NWSGC 8	Cody, WY	Kevin Hurley	John Emmerich/Bill Hepworth	Wayne Heimer
May 2-6, 1994	NWSGC 9	Cranbrook, BC	Anna Fontana	Margo Pybus/Bill Wishart	Kevin Hurley
Apr. 30-May 3, 1996	NWSGC 10	Silverthorne, CO	Dale Reed	Kevin Hurley/Dale Reed/Nancy Wild (compilers)	Kevin Hurley
April 16-20, 1998	NWSGC 11	Whitefish, MT	John McCarthy	John McCarthy/Richard Harris/Fay Moore (compilers)	Kevin Hurley
May 31-June 4, 2000	NWSGC 12	Whitehorse, YK	Jean Carey	Jean Carey	Kevin Hurley
April 23-27, 2002	NWSGC 13	Rapid City, SD	Ted Benzon	Gary Brundige	Kevin Hurley
May 15-22, 2004	NWSGC 14	Coastal Alaska	Wayne Heimer	Wayne Heimer/Dale Toweill/Kevin Hurley	Kevin Hurley
April 2-6, 2006	NWSGC 15	Kananaskis, AB	Jon Jorgenson	Margo Pybus/Bill Wishart	Kevin Hurley
April 27-May 1, 2008	NWSGC 16	Midway, UT	Anis Aoude	Tom Smith	Kevin Hurley
June 7 –11, 2010	NWSGC 17	Hood River, OR	Craig Foster	Vern Bleich, Don Whittaker	Kevin Hurley

GUIDELINES OF THE NORTHERN WILD SHEEP AND GOAT COUNCIL

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

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

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

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

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

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

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

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

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

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

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

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

FOREWORD

The papers/abstracts included in these proceedings were presented during the 17th Biennial Symposium of the Northern Wild Sheep and Goat Council, held June 7-11, 2010 at the Hood River Inn in Hood River, Oregon.

All manuscripts were peer edited by NWSGC members and Proceedings Editor Dr. Vern Bleich, prior to publication. Editorial comments were provided to each senior author. Formatted page proofs were forwarded to respective senior authors prior to incorporation into the final proceedings. Final content, particularly verification of literature citations, is the responsibility of the authors. Critical evaluation of information presented in these proceedings is the responsibility of the readers.

A heart-felt thanks is extended to the sponsors of, and participants in, the 17th Biennial NWSGC Symposium. In addition, Craig Foster (Symposium Chair) and Don Whittaker (Program Chair) were instrumental in leading the dedicated Oregon organizing committee and delivering a first-class symposium. Proceedings were edited by Dr. Vern Bleich, CADFG (ret.).

Kevin Hurley
NWSGC Executive Director
June 17, 2010

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Mountain Goats in North America: A Survey of Population Status and Management

NICK A. MYATT, Oregon Department of Fish and Wildlife, 2995 Hughes Lane, Baker City, OR 97814, USA
AUTUMN N. LARKINS, Oregon Department of Fish and Wildlife, 237 Highway 20 South, Hines, OR 97738, USA

Abstract: We surveyed the 13 state and provincial fish and wildlife agencies in North America to collect information on population status and management of mountain goats. Data were collected on funding, survey methodology, harvest management, and ongoing research. Range wide total estimated mountain goat populations in 2010 ranged from 80,278 to 116,278 individuals with population status being variable by area.

Key Words: *Oreamnos americanus*, mountain goat, population status, species management.

Biennial Symposium of the Northern Wild Sheep and Goat Council 17:1–7; 2010

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Mountain goats occur in 13 states and provinces in North America (Figure 1). Biologists from those areas typically present status reports for each state and province during the biennial Northern Wild Sheep and Goat Council Meeting. Instead of individual status reports, we surveyed all 13 states and provinces with mountain goats and summarized the data across mountain goat range in North America. We obtained range-wide information on funding for management and research, population status, surveys conducted, hunter and harvest management, current research being conducted, and concerns and issues affecting the species.

METHODS

Surveys were sent to representatives from each state and provincial fish and wildlife agency within the range of mountain goats. Surveys were completed using an online survey tool call Survey Monkey (www.surveymonkey.com). We surveyed for information on management funding, populations surveys, hunter and harvest information, population trends, and current research (Table 1). We summarized data by topic and location. Incomplete responses, insufficient detail and/or lack of data lead to incomplete summaries of some topics.

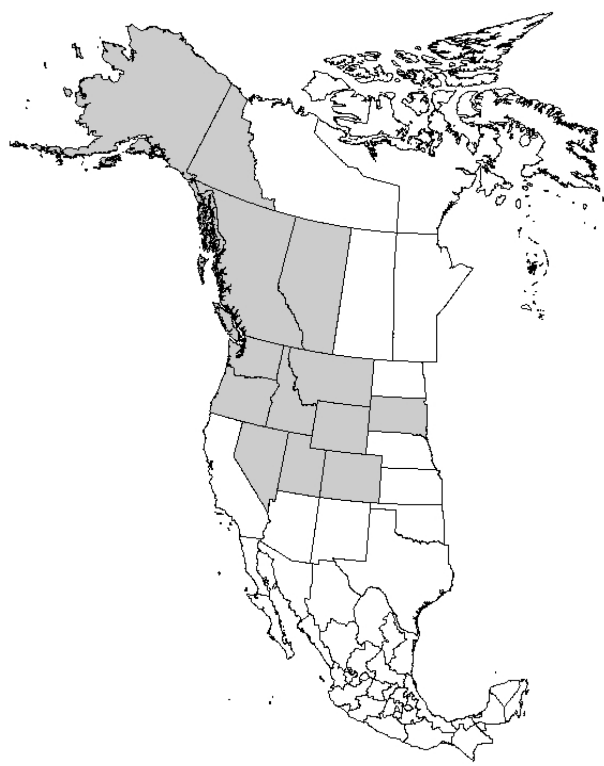

Figure 1. Alaska, Yukon, British Columbia, Alberta, Washington, Oregon, Idaho, Montana, Colorado, South Dakota, Wyoming, Utah and Nevada reported having mountain goat populations in 2010.

Table 1. Summary of survey questions sent to the state or provincial biologist responsible for mountain goat management.

Does your state/province have mountain goats?
What is the primary source of funding for this species?
What are your historic (1970-2000) and current population estimates?
Are populations stable, increasing, or decreasing?
What methods are used to collect population and ratio estimates?
Are these estimates statistically valid?
How frequently do you update your population estimates?
What are the 3 primary reasons for changes in population levels over the last 30 years?
Please provide a summary of recent transplants and/or reintroductions in the last 5 years.
Please provide information on historic (1970-2000) and current male and female harvest.
Please provide information on historic (1970-2000) and current hunter numbers and harvest success.
What type of hunts do you have?
What type of season restriction (i.e. bag limit) do you have?
Please identify any ongoing research your agency is conducting.

RESULTS

Funding

Fifteen percent of states/provinces reported receiving goat funding from the auction and/or raffle tags, 38% from hunting licenses and tags, 31% from general funds, 15% from federal funds, and 8% from other (Table 2).

Population Estimate and Status

Population estimates provided by participants ranged in detail and duration, so we can only provide a range-wide population estimate for 2010 of 80,278 to 116,278 goats. Between 78% and 85% of the estimated North American population occurs in Alaska and British Columbia (Table 3). Thirty eight percent of participants described their populations as stable, 31% as increasing, 8% as declining, 15% as stable to declining, and 8% as variable (Table 4).

Respondents reported a wide range of survey methodologies and timing. The majority (85%) reported using aerial methods for population estimation, while 46% and 38% reported ground and computer modeling, respectively (Table 5). Sixty-two percent of respondents reported using ground methods to estimate ratios, while 46% reported using aerial methods. Most of the survey effort was in the summer, with some in the fall and spring, and minimal effort in the winter. Most respondents reported that their methodologies were not statistically valid. Sixty nine percent of respondents updated their population estimates annually, 15% every 5 years, 7% said it varied by year and funding, and 7% reported their estimates were just crude figures (Table 6).

Respondents provided a wide variety of reasons why populations have changed in the last 30 years, but some reported that there were insufficient data to even detect a population change. The most common reasons were changes in harvest management, population introductions or augmentations, or expansion into unoccupied habitat. Reasons that were mentioned once or twice were conifer encroachment into alpine habitat, human disturbance, increased access to hunters, climate change, pneumonia, and predation. Fifty-four percent of respondents reported no change in goat distribution, while 38% and 7% reported expanding and reduced populations, respectively (Table 7). Forty-six percent of respondents reported moving goats as part of population reintroduction or augmentation efforts (Table 8).

Harvest

Respondents reported Harvest of mountain goats had increased since 1970, with a 2009 range-wide harvest estimate of 1,273 males and 467 females (Table 9). Mountain goat hunter numbers increased from 2,006 in 1980 to 3,709 in 2009 (Table 10). Hunter success averaged 72%, but ranged from 36% to 100% (Table 10). All respondents reported having limited entry hunts, 15% had general seasons, 15% had a quota system, and 30% had a special auction and/or raffle tag (Table 11). All respondents reported a bag limit of "one goat" (i.e. non-gender specific), while 15% had some "male only" hunts and 23% had some "female only" hunts (Table 12).

Research

Six of 13 states or provinces reported conducting mountain goat research. Table 13 lists the responses for those states/provinces that reported conducting research.

ACKNOWLEDGMENTS

We thank biologists from the 13 states and provinces that provided responses to our survey. We would also like to thank 2 anonymous peer editors for reviewing the document.

Table 2. Funding sources for the management of mountain goats.

Jurisdiction	Auction/ Raffle Tags	License Tag Fees	General Fund	Federal Fund	Other
Alaska				X	
Alberta			X		
British Columbia			X		X
Colorado		X			
Idaho			X		
Montana		X			
Nevada				X	
Oregon	X				
South Dakota		X			
Utah		X			
Washington	X				
Wyoming		X			
Yukon			X		

Table 3. Current (2009) mountain goat population estimates.

Jurisdiction	1970	1980	1990	2000	2010
Alaska				24,000-29,000	24,000-33,500
Alberta			1,560	1,650	1963
British Columbia					39,000 - 65,500
Colorado	475	0	1,090	1,620	1,600
Idaho	2,600	2,415	3,000	2,700	2,600
Montana					2,700
Nevada	30	80	170	280	340
Oregon	30	75	200	300	800
South Dakota	300	100	150	150	70
Utah	10	50	250	960	1,900
Washington					2,815
Wyoming	75 - 100	75 - 100	150 - 200	275	325
Yukon				1,700	1,700

Table 4. Status of mountain goat populations by jurisdiction.

Jurisdiction	Status
Alaska	Stable
Alberta	Increasing
British Columbia	Stable to declining
Colorado	Stable
Idaho	Stable to declining
Montana	Stable
Nevada	Declining
Oregon	Increasing
South Dakota	Stable
Utah	Increasing
Washington	Variable
Wyoming	Increasing
Yukon	Stable

Table 5. Methods of mountain goat population and ratio estimation by jurisdiction. Statistically valid methods are marked with an asterisk.

	Population Estimate			Ratio Estimate	
Jurisdiction	Ground	Aerial	Model	Ground	Aerial
Alaska	X	X	X	X	X
Alberta		X			
British Columbia	X*	X	X*	X	X
Colorado	X	X		X	X
Idaho		X		X	
Montana		X			
Nevada		X	X		
Oregon	X			X	
South Dakota	X	X	X*	X	X
Utah		X	X	X	
Washington		X*			
Wyoming	X	X		X	X
Yukon					X

Table 6. Frequency of population estimate updates by jurisdictions with mountain goats.

Jurisdiction	Update Frequency
Alaska	Variable
Alberta	Annually
British Columbia	5 years
Colorado	Annually
Idaho	5 years
Montana	Annually
Nevada	Annually
Oregon	Annually
South Dakota	Annually
Utah	Annually
Washington	Annually
Wyoming	Annually
Yukon	Estimates are crude figures

Table 7. Change in distribution of mountain goats by jurisdiction from 1980 to present.

Jurisdiction	Distribution Change
Alaska	No Change
Alberta	No Change
British Columbia	Reduced
Colorado	Expanding
Idaho	No Change
Montana	No Change
Nevada	Expanding
Oregon	Expanding
South Dakota	No Change
Utah	Expanding
Washington	No Change
Wyoming	Expanding
Yukon	No Change

Table 8.Jurisdictions that reported capturing and/or releasing mountain goats for population reintroduction or augmentation.

Jurisdiction	Total Moved	Capture Jurisdiction	Release Jurisdiction	Release Events
Colorado	18	CO	SD	2
Idaho	24	UT	ID	1
Montana	30	MT	MT	3
Oregon	77	OR	OR	5
South Dakota	18	CO	SD	1
Utah	44	UT	UT 20 ID 24	2

Table 9. State and provincial male and female mountain goat harvest from 1970 to 2009.

	Male Harvest					Female Harvest				
Jurisdiction	1970	1980	1990	2000	2009	1970	1980	1990	2000	2009
Alaska	0	189	300	309	362	0	139	136	155	160
British Columbia	0	499	747	545	527	0	267	365	171	126
Alberta	0	7	0	0	5	0	13	0	0	1
Colorado	0	33	59	114	101	0	21	43	73	55
Idaho	157	67	52	33	28			24	15	14
Montana	354	230	215	225	113	0	0	0	0	64
Nevada	0	0	4	16	18	0	0	0	0	9
Oregon	0	0	0	3	13	0	0	0	0	0
South Dakota	14	6	3	3	0	10	4	1	0	0
Utah	0	0	4	19	77	0	0	0	9	30
Washington			54	20	11			41	10	2
Wyoming	3	5	5	14	15	0	2	2	1	6
Yukon	0	13	10	3	3	0	0	0	0	0
Total	528	1,049	1,453	1,304	1,273	10	446	612	434	467

Table 10. State and provincial mountain goat hunter numbers and success rates from 1970 to 2009.

	Number of Hunters						% Hunter Success				
Jurisdiction	1970	1980	1990	2000	2010		1970	1980	1990	2000	2010
Alaska	0	767	1170	1267	1184			43	37	37	44
British Columbia	0	0	2178	1994	1819				52	36	36
Alberta	50	45	0	0	7		30	44			86
Colorado	0	77	110	210	201			70	93	91	78
Idaho	290	141	93	56	46		52	48	82	86	91
Montana	803	339	283	295	270		44	68	76	76	68
Nevada	0	0	4	18	28				100	89	96
Oregon	0	0	0	3	11					100	91
South Dakota	25	10	4	4	0		96	100	100	75	
Utah	0	0	6	29	107				67	97	100
Washington		619	189	35	15			43	49	86	79
Wyoming	4	8	8	15	21		75	88	88	100	100
Yukon											
Total	1,172	2,006	4,045	3,926	3,709	Average	59	63	74	79	79

Table 11. State and provincial mountain goat hunt types.

Jurisdiction	General Season	Limited Entry Draw	Harvest Quota	Auction / Raffle
Alaska		X		
Alberta		X		
British Columbia	X	X	X	
Colorado		X		X
Idaho		X		
Montana		X		
Nevada		X	X	
Oregon		X		X
South Dakota		X		
Utah		X		X
Washington		X		X
Wyoming		X		
Yukon	X	X		
Total	2	13	2	4

Table 12. State and provincial mountain goat harvest restrictions.

Jurisdiction	Male Only	Female Only	Non-Gender Specific
Alaska			X
Alberta			X
British Columbia			X
Colorado		X	X
Idaho			X
Montana			X
Nevada			X
Oregon			X
South Dakota			X
Utah	X	X	X
Washington			X
Wyoming			X
Yukon			X
Total	1	2	13

Table 13. Responses from states and provinces reporting ongoing mountain goat research.

Jurisdiction	Research Information
Alaska	Nepal, N. Mountain goat habitat modeling for the Kenai Peninsula. U.S. Forest Service and the Alaska Department of Fish & Game. Manuscript in prep.
Alaska	White, K., and N.L. Barten. Mountain goat assessment and monitoring along the Juneau access road corridor and near the Kensington Mine, Southeast Alaska. Alaska Department of Fish & Game. Project is ongoing and includes assessment of life history and climate effects on survival.
Alaska	Shafer, A.B.A., S.D. Cote, and D.W. Coltman. Temporal and geographic patterns of genetic differentiation in mountain goats. Collaboration with Alaska Department of Fish & Game. Project is ongoing.
Alberta	Caw Ridge Goat Research with Steve Cote, University of Laval
British Columbia	Meagher Mountain and Bell 2 - summaries are in new plan
Oregon	Evaluating effects of trapping and transplanting on kid survival.
Oregon	Opportunistically monitoring movements of dispersing animals when they can be captured.
Wyoming & Idaho	Comparative studies of sympatric bighorn sheep and mountain goats in the Greater Yellowstone Area. Dr. Bob Garrott/Montana State University - Principal Investigator (please see Garrott et al. abstract for 2010 NWSGC Symposium). Information online at <www.homepage.montana.edu/~rgarrott/html/sheep_goat.htm>

Wild Sheep Status and Management in Western North America: Summary of State, Province, and Territory Status Report Surveys

AUTUMN LARKINS, *Oregon Department of Fish and Wildlife, P.O. Box 8, 237 Highway 20 South, Hines, OR 97738, USA*

Abstract: I surveyed 21 western game and fish agencies in western North America to collect information wild sheep (*Ovis spp*.) population status and management. I utilized a new on-line data collection method called Survey Monkey. I received responses from 21 agencies (100% return rate). Information and data was interpreted as accurately as possible; and are summarized by state, province, or territory, wild sheep species or subspecies, and by issue. My objectives were to: 1) collect and synthesize long term demographic data for wild sheep in western North America; and 2) illustrate current issues affecting wild sheep management.

Key Words: California bighorn sheep, *Ovis canadensis californiana*, Dall's sheep, *Ovis dalli dalli*, Desert bighorn sheep, *Ovis canadensis nelsoni*, Rocky Mountain bighorn sheep, *Ovis canadensis canadensis*, Sierra Nevada bighorn sheep, *Ovis canadensis sierrae*, Stone sheep, *Ovis dalli stonei*.

Proceedings of the Northern Wild Sheep and Goat Council 17:8–28; 2010

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The Biennial Conference of the Northern Wild Sheep and Goat Council (NWSGC) is one forum wildlife biologists and mountain ungulate advocates can utilize to interact, and exchange data and ideas. The symposium typically includes a status report on wild sheep populations, and related management issues, provided by participating western game and fish agencies. My objectives with this report were to disseminate standardized, comprehensive information to participants on 1) wild sheep funding; 2) population status; 3) surveys conducted; 4) hunter numbers and harvest; 5) current research being conducted; 6) formats that allows possible determination of long term trends; and 7) explore current issues and concerns related to wild sheep management in western North America.

METHODS

Surveys were sent to 21 state, provincial and territorial game and fish agencies. Surveys were sent to lead biologists at each agency for each taxon of interest in that jurisdiction. Numerous attempts and liberal timelines were allowed to ensure as complete a summary as possible.

I utilized a new on-line data collection method called Survey Monkey. I purchased a professional account that allowed for an unlimited number of questions and unlimited responses. The Survey Monkey professional account provided the ability to download all data into spreadsheets and also utilize advanced reporting and charting tools. The design phase was enabled with skip logic to speed entry response time, and to modify settings and restrictions tailored to suit my specific survey needs. This electronic survey system theoretically saves data entry and analysis time for the compiler. The survey requested information on species-specific demographic information, funding, population status, survey and management techniques, introductions and augmentations, hunter numbers and harvest, current research projects and published papers, habitat issues, and disease incidence or concerns. Responses were summarized and reported by taxon, topic, and state, province or territory where possible. Due to incomplete responses and non-reporting, few statistical analyses were conducted. However, in many cases trends in various population and hunter parameters may be apparent in the tabularized information.

RESULTS

I received responses from 21 of 21 surveys sent (100%). I did encounter some technical difficulties with the system: 19% of agencies surveyed had initial problems saving data, 14% were unable to complete the survey electronically and submitted hard copies, and 5% found the survey design to be incompatible with their specific data set. Sixty-two percent of the respondents had no issues with the system. Some additional issues that we experienced using Survey Monkey were 1) limited question design options; 2) difficulty in capturing detailed responses (no explanation option); 3) many questions had specific requirements (i.e., numerical answer only) which would "hook" the user and not allow the respondent to move forward to the next question. Some other comments that I received on the process were that participants would prefer to be able to review questions, gather information and enter data in stages, be allowed to go back and modify answers that had already been submitted, and users wanted the ability for multiple people to enter data for different sections of the survey. The numbers of state, provincial or territorial agencies reporting specific data varied considerably and was inconsistent throughout the survey. However, all complete and partial responses were included in this report. The potential shortcomings of the summary must be considered when reviewing the results as they were received from the responding agencies and interpreted by the compiler.

Funding

Every agency provided information on funding sources for each species of wild sheep that they manage (Figure 1). I combined results for all bighorn and thinhorn species for easier representation of the data. Out of the bighorn data, 50% indicated the use of auction and/or raffle money for funding, 27% utilized license and tag fees, 13% used general funds, 10% used federal funds, and 23% used other sources of funding. The thinhorn data indicated that 83% utilized general funds, and 17% used both federal funds and other sources of funding.

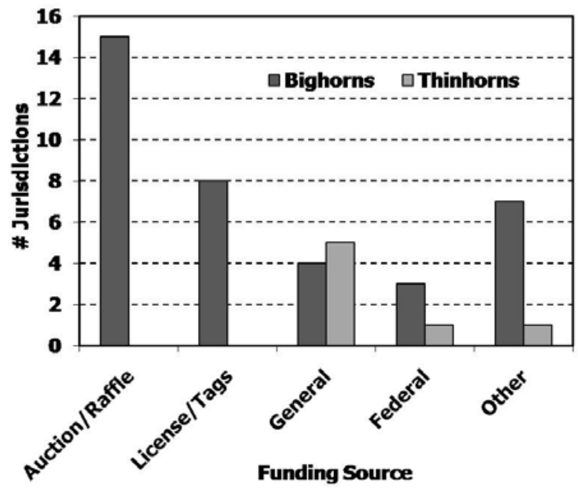

Figure 1. Funding sources reported by NWSGC agencies for bighorn and thinhorn sheep management.

Rocky Mountain Bighorn Sheep.—Fifteen out of 21 (71%) agencies reported on Rocky Mountain bighorn sheep (*Ovis canadensis canadensis*). Of those agencies providing data, only 60% provided data for 1970, 73% provided data for 1980, 86% provided data for 1990, and 100% provided data for years 2000 and 2010 (Table 1). These gaps in the data must be noted when looking at the overall population estimates. Two agencies (North Dakota and South

Table 1. Wild Sheep population estimates reported by western states, provinces, and territories in North America 1970 – 2010.

Species	Jurisdiction	1970	1980	1990	2000	2010
Rocky Mountain Bighorn Sheep	Alberta	6,500	6,500	6,900	6,300	6,400
	Arizona		50	200	700	1,000
	British Columbia				2,000	2,300
	Colorado	2,200		5,500	7,500	6,900
	Idaho	2,000	2,090	3,850	1,710	2,000
	Montana	1,500	4,600		5,820	6,370
	Nebraska			60	100	250
	Nevada		50	140	210	300
	New Mexico	275	740	595	650	840
	North Dakota	100	150	250	150	350
	Oregon			500	800	750
	South Dakota	200	200	300	425	500
	Utah	50	100	300	900	1,900
	Washington		70	300	210	229
	Wyoming	2,577	4,220	7,069	6,495	6,200
	Totals	15,402	18,770	25,964	33,970	36,289
California Bighorn Sheep	British Columbia				2,400	3,000
	Idaho	90	350	1,240	1,350	1,250
	Nevada	20	50	480	1,400	1,900
	Oregon			1,700	3,000	3,400
	Utah				100	425
	Washington	300	550	600	795	900
	Totals	410	950	4,020	9,045	10,875
Desert Bighorn Sheep	Arizona	4,000	4,500	5,000	5,000	4,500
	California	3,700		3,465	4,143	
	Colorado			275	460	480
	Mexico					3,800
	Nevada	2,500	2,900	3,800	4,900	7,400
	New Mexico	170	70	130	195	550
	Texas	70	100	150	450	1,500
	Utah	400	600	1,500	2,500	2,800
	Totals	10,840	8,170	14,320	17,648	21,030
Sierra Nevada Bighorn Sheep	California	250	300	200	120	400
Dall's Sheep	Alaska	35,000 – 50,000	73,650	73,250	50,000 – 64,000	
	British Columbia				400 – 600	400 – 600
	Northwest Territories				14,000 – 26,000	14,000 – 26,000
	Totals	35,000 – 50,000	73,650	73,250	64,400 – 90,600	14,400 – 26,600
Stone Sheep	British Columbia				8600-12500	9600-13400

Dakota) indicated increases in Rocky Mountain bighorn sheep populations in the last 40 years. Eight agencies (53%) reported stable populations, one agency (Nebraska) reported stable to slightly declining populations, two agencies (Idaho and Oregon) indicated declining populations, and one agency (New Mexico) reported variable population trends depending on herd.

California Bighorn Sheep.— Six out of 21 (29%) agencies reported on California bighorn sheep (*Ovis canadensis californiana*). Of those agencies providing data only 50% provided data for both 1970 and 1980, 67% provided data for 1990, and 100% provided data for years 2000 and 2010 (Table 1). Two agencies (Nevada and Washington) indicated increasing California bighorn sheep populations. Two agencies (British Columbia and Utah) reported stable to slightly increasing populations. Idaho reported a stable population. Oregon reported variable population trends depending on the herd.

Desert Bighorn Sheep.— Eight out of 21 (38%) agencies reported on desert bighorn sheep (*Ovis canadensis nelsoni*). Of those agencies providing data only 75% provided data for 1970, 63% provided data for 1980, and 88% provided data for the remaining three time periods 1990, 2000, 2010 (Table 1). Six agencies indicated increasing desert bighorn sheep populations. Arizona reported a stable to slightly increasing population, and Utah reported their population as stable.

Sierra Nevada Bighorn Sheep.— Only the state of California has this subspecies. They provided population estimates for all forty years and indicated that the population of Sierra Nevada bighorn sheep (*Ovis canadensis sierrae*) is increasing (Table 1).

Dall's Sheep.— Four agencies out of 21 (19%) reported on Dall's sheep (*Ovis dalli dalli*). Of those agencies providing data only 25% provided data for 1970, 1980, and 1990, 75% provided data for 2000, and 50% provided data for 2010 (Table 1). Unlike the bighorn sheep data, many of the thinhorn sheep agencies reported populations as a range with lower and upper bounds. Three out of the four agencies reported stable Dall's sheep populations, while Alaska reported a variable population trend.

Stone Sheep.— Two agencies out of 21 (9.5%) reported on Stone sheep (*Ovis dalli stonei*). Only British Columbia offered population estimates and only they provided the data for 2000 and 2010 (Table 1). Both British Columbia and Yukon declared that their Stone sheep populations are considered stable.

All twenty one agencies listed what they felt were the one to three main causes of population change by subspecies in their respective state, province or territory over the last forty years (Table 2). A wide variety of causes were given but several were repeated numerous times. Disease events were identified by 13 (62%) agencies as a negative effect, and translocations were listed by 13 (62%) agencies as a positive effect on sheep populations. Predation, primarily by mountain lions, was reported by 10 (47.6%) agencies as the third largest detriment to wild sheep populations. Proactive herd management and habitat improvements were listed by 9 (43%) agencies. Climate change ranked as the next highest cause of change in 8 (38%) agency reports. Vegetative succession, noxious weeds, cattle grazing, and overall habitat fragmentation were each listed by 7 (33%) agencies. Land use (increased access and/or abuse) was identified by 6 (29%) agencies.

Some reasons for population change specific to each subspecies were also identified. Changes to winter feeding programs in Washington and increased road

Table 2. Main causes of wild sheep population changes reported by western states, provinces, or territories over the last forty years.

Species/Subspecies	Jurisdiction	Causes of Population Change
Rocky Mountain Bighorn Sheep	Alberta	1) Vegetative successon affecting wintering habitat.
		2) ATV/OHV abuses in habitat.
		3) Predation (mountain lions).
	Arizona	1) First immigrated from population in New Mexico.
		2) Focused on managing populations.
		3) Increased translocation and enhancement activities.
	British Columbia	1) Pressure from access, land use, development.
		2) Die-off in 1980s in East Kootenay.
		3) Subsequent habitat management and proactive herd management.
	Colorado	1) Multiple transplants to reestablish new populations.
		2) Stabilization during last 10 years a result of decreased transplant activity coupled with disease outbreaks causing poor lamb recruitment in several herds and all age die-offs in a few herds.
	Idaho	1) Disease: periodic all-age die-offs believed due to contact with domestic sheep, and long-term chronic effects on subsequent lamb recruitment.
		2) Habitat change: noxious weed and tree encroachment on critical habitat.
		3) Transplants within the Hells Canyon National Recreation Area and the Lost River Range.
	Montana	1) Populations have been increased and expanded through transplant efforts.
		2) Since 1984, Montana has had 18 dieoffs of varying magnitudes, some due to documented contact with domestic sheep.
		3) Roadkill has been significant in several populations.
	Nebraska	1) Reintroductions to increase.
		2) Private Land Acceptance to increase.
		3) Disease outbreaks (Pasteurella pneumonia).
	Nevada	1) Introductions.
		2) Disease events.
		3) Mountain lion predation.
	New Mexico	1) Establishing new populations via translocation--from 4 herds to 9 herds.
		2) Declines induced by pnuemonia dieoffs resulting from domestic sheep contact (n=4).
		3) Recent declines in alpine herds due to unknown causes, probably linked to winter severity.
	North Dakota	1) All-age-class die-off occured in the southern metapopulation.
		2) Introductions.
		3) Reintroduced O. c. canadensis from MT's Breaks in 2006 and 2007.
	Oregon	1) Disease events.
		2) Mountain lion predation.
	South Dakota	1) Introductions and supplemental transplants.
		2) Habitat improvements (controlled burning or wildfires).
	Utah	1) Transplants.
		2) Disease issues.

Table 2. Continued.

Species/Subspecies	Species/Subspecies	Species/Subspecies
Rocky Mountain Bighorn Sheep	Washington	1) Disease events.
		2) Stopped winter feeding.
	Wyoming	1) Disease events.
		2) Shut down in-state BHS transplant actions from 1995-2009.
		3) Chronic drought during 2000-2008 impacted herbaceous forage production on many winter ranges.
California Bighorn Sheep	British Columbia	1) Land use, access, development, recovery efforts for Okanagan sheep after die-off in 1999/2000.
		2) Herd specific health issues associated with winter range conditions (overgrazing by cattle, forest encroachment, predation).
	Idaho	1) Reintroductions in historic unoccupied habitat.
		2) Natural range expansion.
		3) Law enforcement.
	Nevada	1) Introductions.
		2) Vast areas of moderate to good forage conditions that have allowed for expansion and population increases.
		3) Periodic disease event/dieoffs.
	Oregon	1) Drought and associated habitat issues.
		2) Predation.
		3) Possibly some latent respiratory disease issues in some herds.
	Utah	1) Transplants.
		2) Our nursery herd for CA sheep on Antelope Island State Park has recently dropped in population and may have some disease issues.
	Washington	1) Declines due to disease outbreaks (pneumonia).
		2) Increases due to transplants to suitable vacant habitat.
Desert Bighorn Sheep	Arizona	1) Drought.
		2) Increased mountain lion predation.
		3) Habitat fragmentation, primarily roads.
	California	1) Reduced connectivity from habitat fragmentation.
		2) Disease risk posed by domestic livestock.
		3) Habitat loss through climate change.
	Colorado	1) Reintroduction of the subspecies to Colorado beginning in 1979.
		2) Mountain lion predation.
		3) Disease events.
	Mexico	1) Populations are increasing due to the economic value.
		2) This has led to active management programs and aggressive transplants.
		3) This has also led to greater protection of both the animals themselves and their habitats as their value has been increasingly appreciated by landowners.
	Nevada	1) Reintroductions and augmentations.
		2) Water developments.
		3) Precipitation patterns.
	New Mexico	1) Predator control (mountain lion) since 2001.
		2) Translocations primarily from a captive breeding facility since 1979.

Table 2. Continued.

Species/Subspecies	Species/Subspecies	Species/Subspecies
	Texas	1) Aggressive restoration efforts (transplants).
		2) Management (habitat management, protection, prevention of domestic sheep within bighorn habitat, management of exotic species and predator control).
		3) Improved cooperation between landowners, conservation organizations and TPWD.
	Utah	1) Growth due to transplants.
		2) Low reproduction.
		3) Potential disease/predation on some units.
Sierra Nevada Bighorn Sheep	California	1) Disease from domestic sheep
		2) Predation by mountain lions is directly responsible for the greatest share of mortality and had spiked during the last 2 years. This predation is not compensatory but rather is additive and has limited population growth in some herds.
		3) Demographic, genetic, and environmental stochasticity continue to pose a threat while the population is small.
Dall Sheep	Alaska	1) Extensive statewide predator control in the 1940s and 1950s likely contributed the growth of sheep populations throughout the 1960s.
		2) Severe winters played a large role in population declines in some areas in the late 1960s and early 1970s, as well as the 1990s. Partly in response to the Mt. Pinatubo eruption (1991) and subsequent cool, short summer in 1992.
	British Columbia	1) None - very remote area, little issues - rock and ice!
	NW Territories	1) Not applicable.
	Yukon	1) Large-scale climatic fluctuations (Pacific Decadal Oscillation).
		2) Harvest.
Stone Sheep	British Columbia	1) Predation and alternative prey issues.
		2) Fire - range improvements.
		3) Increased access with technological advances - jetboats! industrial exploration - seismic activity etc.
	Yukon	1) Large-scale climatic fluctuations (Pacific Decadal Oscillation).
		2) Harvest.

kills in Montana have affected Rocky Mountain bighorn sheep populations. Increased law enforcement in Idaho and natural range expansion in Idaho and Nevada has affected California bighorn sheep populations. Demographic, genetic, and environmental stochasticity continued to pose a threat to the Sierra Nevada bighorn sheep subspecies. Extensive predator control in Alaska has likely contributed to the growth of Dall's thin horn sheep populations.

Distributional changes

Rocky Mountain Bighorn Sheep.— Eight of 15 (53%) agencies have relocated animals and expanded the distribution or have established new populations in previously unoccupied habitat (Table 3). Two agencies (Arizona and Wyoming) have experienced increased distribution through natural immigration. North Dakota reported having a major paradigm shift in 2000 when NDGF, working with federal agencies, began managing fewer bighorns in more areas rather than more bighorns in fewer areas (i.e., increase distribution but with lower population densities).

California Bighorn Sheep.— Four of 6 (67%) agencies responded to the distribution change question for California bighorns. Of those, Utah and Washington reported that introductions and transplants were major causes of increases in distribution. Idaho populations experienced some natural range expansions. British Colombia reported little to no change in distribution.

Desert Bighorn Sheep.— Eight of 8 (100%) agencies responded to the distribution change question for desert bighorns. Colorado and Utah have both experienced increased distribution due to transplants and reintroductions. Arizona and California reported increases as well, but still have fewer occupied ranges than historically documented. Nevada's distribution has increased due to reintroduction and an aggressive water development program, although some available habitat is limited due to domestic sheep grazing and trailing Texas bighorns currently exceed population levels and distribution ranges of the 1800s and continue to expand, whereas New Mexico has remained essentially unchanged since the mid 1980s.

Sierra Nevada Bighorn Sheep.— In the 1970s, distribution of Sierra Nevada bighorn sheep had declined to only 2 known herds in California. Following a series of successful translocations, the number of occupied herd units increased to 7 by the 1990s. Currently, there are 8 herd units with self-sustaining female populations and small numbers of females (<4) have been documented in an additional 3 herd units during the past year. The federal recovery plan for this endangered subspecies requires that 12 of 16 recognized herd units be occupied for recovery.

Table 3. Reported causes of wild sheep distribution changes in the last forty years.

Species/ Subspecies	State/ Province	Little/No Change	Intro. & Trans.	Other
Rocky Mtn Bighorn Sheep	AB	X		
	AZ		X	
	BC	X		
	CO		X	
	ID		X	
	MT	X		
	NE		X	
	NV	X		
	NM			X
	ND			X
	OR	X		
	SD		X	
	WA		X	
	WY		X	
California Bighorn Sheep	BC	X		
	ID			X
	UT		X	
	WA		X	
Sierra Nevada Bighorn Sheep	CA		X	
Desert Bighorn Sheep	AZ		X	
	CA		X	
	CO		X	
	MX		X	
	NV		X	
	NM	X		
	TX		X	
	UT		X	
Dall Sheep	AK	X		
	BC	X		
	NWT	X		
	YK	X		
Stone Sheep	BC	X		
	YK	X		

Dall's Sheep & Stone Sheep.— The distribution of Dall's and Stone sheep for all reporting agencies (6) has for the most part not changed in the past forty years.

In summary it appears that bighorn sheep distribution generally is expanding in most western states and provinces, whereas thinhorn distribution has remained relatively stable over time (Table 3).

Introductions and Augmentations

Rocky Mountain Bighorn Sheep.— Ten of 15 (67%) agencies reported relocating or augmenting Rocky Mountain bighorn sheep within the last 5 years. Alberta, Idaho, Oregon, South Dakota, and Washington have not performed any translocations since 2005. Due to the variety of reporting styles (i.e. some agencies gave specific numbers and locations, but some did not) the tabular representation of the data has been generalized (Table 4). In central Arizona the

Table 4. Introductions and augmentations of wild sheep over the last 5 years (2005-2010).

	Rocky Mountain Bighorn			California Bighorn			Sierra Nevada Bighorn			Desert Bighorn			Dall Sheep			Stone Sheep		
Jurisdiction	None	Internal	Internal & External	None	Internal	Internal & External	None	Internal	Internal & External	None	Internal	Internal & External	None	Internal	Internal & External	None	Internal	Internal & External
Alaska													X					
Alberta	X																	
Arizona			X								X							
British Columbia		X			X								X			X		
California								X			X							
Colorado			X							X								
Idaho	X			X														
Montana			X															
Mexico											X							
Nebraska			X															
Nevada		X			X							X						
New Mexico			X								X							
North Dakota			X															
NW Territories													X					
Oregon	X					X												
South Dakota	X																	
Texas										X								
Utah		X			X							X						
Washington	X					X												
Wyoming			X															
Yukon													X			X		

primary translocation efforts have been from the main herd near Clifton-Morenci into the West Clear Creek drainage near Camp Verde. British Columbia relocations occurred in the East Kootenay from the Golden herd to south and from the Radium herd to south. During the last 5 years Colorado has conducted 8 translocations, and moved a total of 112 bighorn. Three involved small numbers of animals (<10) for supplemental or experimental purposes; two were reintroductions to historic habitat; one was a range extension into an area recently burned by wildfire; one was for a research project; and one was an out-of-state translocation. Montana reported moving 497 Rocky Mountain bighorn sheep since 2006, 187 within Montana and 310 to various other states. Nebraska received 2 translocations from Montana to western Nebraska in the last 5 years. Nevada moved 30 ewes and lambs to augment a herd and mix sheep from Alberta with sheep from the Wind River Range, Wyoming. New Mexico relocated 29 sheep to Arizona in 2005. During 2006-2007 two new herds were established in the Rio Grande Gorge, the first with translocations of 23 and 25 individuals, the other in 2007-2008 with translocations of 34 and 27 individuals. New Mexico's augmentations include 5 sheep moved to Turkey Creek in 2005 and an additional 25 sheep to the same location in 2006. North Dakota translocated 20 bighorns from Montana in 2006 and 2007. North Dakota has also conducted four in-state translocations that were all augmentations (n = 28). Utah translocated 249 sheep during eight separate efforts over the last 5 years, 2 of which failed due to disease outbreaks. Wyoming received 62 sheep from Montana during2006 and 2007, and performed an in-state relocation (12 sheep) in 2010.

California Bighorn Sheep.— Five of 6 (83%) agencies reported relocating or augmenting California bighorn sheep within the last 5 years; only Idaho has not performed any since 2005. British Columbia has translocated sheep from the Kamloops area herds to Fraser River herds and West and East Okanagan valley herds, and from Keremeos to the East Okanagan valley herd. Nevada performed augmentations occurring in 2006, 2007, and 2010 involving 3 release sites and 58 California bighorn sheep, primarily ewes and lambs. Oregon has conducted from 1- 4 transplants annually for the last five years. Most in-state transplants have been to augment existing populations, but several new herds have been started as well. Oregon has also provided wild sheep to several other states recently, including Wyoming in 2009. Utah's recent translocations have involved taking sheep from Antelope Island State Park and starting new populations on the Newfoundland and the Stansbury mountains. Within the last 5-years Washington started a new California bighorn sheep population near Chelan, which occurred over two years with sheep from Nevada and Oregon.

Desert Bighorn Sheep.— Six of 8 (75%) agencies reported relocating or augmenting desert bighorn sheep within the last 5 years; only Colorado and Texas have not done so since 2005. Arizona established a new population in the Mineral Mountains near Superior, and near Hell's Half Acre near Wikieup. Arizona also supplemented populations in the Harcuvar Mountains. During 2006, 13 adult females were translocated from the Old Dad Mountains to augment the Eagle Crags on the China Lake Naval Weapons Center in California. Nevada has transplanted 384 desert bighorn sheep into 10 different mountain ranges and has given the state of Utah 40 desert bighorn sheep. New Mexico has transplanted 122 sheep to the following locations: Little Hatchets (28), San Andres (30) in 2005, Big Hatchets (36) in 2006, and 18 to the Caballomountains; 5 to the Ladrones, and 5 to the Peloncillos in 2009. Utah's recent translocations have focused on moving sheep to empty canyons within the Kaiparowits Plateau and the San Juan Dirty Devil area.

Sierra Nevada Bighorn Sheep.— During 2005, 5 adult females were translocated from the Wheeler Ridge herd to augment the Mt. Baxter herd unit. Within 2 years, only 1 of those females remained in that herd. During 2009, 6 females were translocated to augment the Mt. Warren herd unit; 3 were removed from Wheeler Ridge and 3 from Mt. Langley. All 6 females were pregnant when moved and successfully gave birth in their new range. By the end of summer 2009, at least 5 of the lambs born to the translocated females survived.

Dall's Sheep & Stone Sheep.— No translocations or augmentations of Dall's or

Stone sheep have been conducted in the last 5 years by any of the reporting agencies.

Survey Techniques

I asked biologists to describe the field methods that they are using to collect survey data (population estimates and sex and age ratios) for each species. Additionally I asked them to indicate seasonal timing of surveys, frequency of surveys, and whether or not they considered the estimates to be statistically valid. Agencies reported using a variety of methods to survey sheep populations (Figures 2 and 3). Survey data are usually used in models to estimate sheep populations. I did not ask specifically what types of population models agencies used.

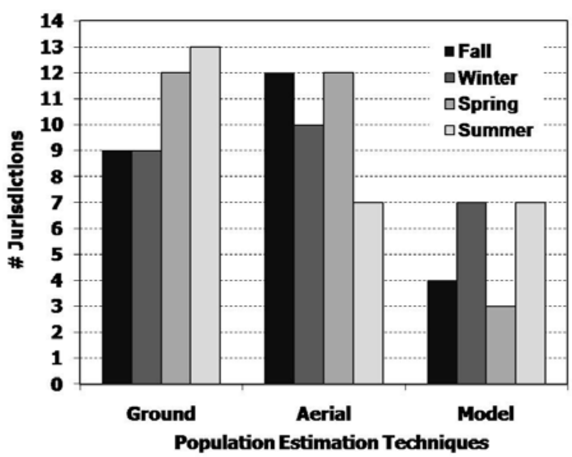

Figure 2. Bighorn and thinhorn sheep population estimation survey methods categorized temporally.

Of those agencies providing data for the fall survey time period, 43% used ground surveys, but only one agency reported these results as statistically valid. Twenty-nine percent calculated ratios from ground-based surveys, but none were being considered statistically valid. Fifty-seven percent of the agencies performed aerial population estimates during the fall, with 25% of those categorized as statistically valid. Forty-three percent obtained sex and age ratio estimates from the air in the fall, with 22% statistically valid. Only 19% agencies utilized population models from their fall surveys.

Of those agencies providing data for winter, 43% performed population estimates and 22% of those were considered statistically valid. Nineteen percent surveyed for ratio estimates on the ground, but none were considered statistically valid. Forty-eight percent of the agencies performed aerial population estimates during the fall, and only 30% of those were categorized as statistically valid. Thirty-three percent obtained sex and age ratio estimates from the air in the fall, and 57% were statistically valid. Thirty-three percent of the agencies utilized population models from their winter surveys.

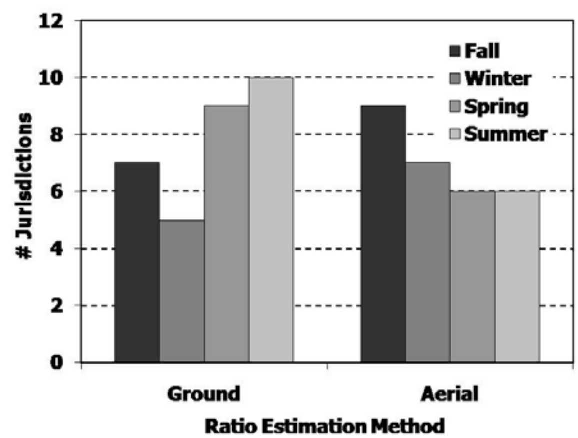

Figure 3. Bighorn and thinhorn sheep sex and age ratio estimation survey methods categorized temporally.

Of those agencies providing data for spring surveys, 52% surveyed for population estimates on the ground and 36% of those were considered statistically valid. Forty-three percent surveyed for ratio estimates on the ground, and 33% were considered statistically valid. Fifty-seven percent of the agencies performed aerial population estimates during the spring, and 50% of those were categorized as statistically valid. Twenty-nine percent obtained sex and age ratios from the air in the spring, but none were considered to be statistically valid.

Only 14% of the agencies utilized population models from their spring surveys.

Of those agencies providing data for the summer survey time period, 67% surveyed for population estimates on the ground and 21% of those were considered to be statistically valid. Forty-eight percent surveyed for ratio estimates on the ground, and 20% were considered to be statistically valid. Thirty-three percent of the agencies performed aerial population estimates during the spring, and 14% of those were categorized as statistically valid. Twenty-nine percent obtained sex and age ratios from the air in the spring, but none were considered to be statistically valid. Twenty-nine percent of the reporting agencies utilized population models from their summer surveys.

Almost all agencies conduct their surveys annually, but a few are performed every 2-5 years depending on herd ranges; several other agencies vary survey frequency depending on funding.

Harvest

The next series of questions in the survey asked agencies to report on their historic and current harvest trends for both males (Table 5) and females (Table 6), number of hunters and hunter success rates (Table 7), as well as type of hunts, weapon restrictions and season restrictions for each specific subspecies of sheep (Table 8).

Rocky Mountain Bighorn Sheep.— Fourteen out of 15 (93%) agencies reported their hunter numbers and harvest success rates; only Utah did not report. There were 16,754 hunters reported over the last 39 years for both sexes, and 3,477 males harvested, with Wyoming and Alberta reporting the highest numbers. There were 725 females harvested since 1970, with Montana reporting the most.

California Bighorn Sheep.— Six out of 6 (100%) agencies reported their hunter numbers and harvest success rates. There were 515 hunters reported for both sexes of California bighorns since 1970. The agencies reported 599 harvested males and 19 harvested females, with British Columbia harvesting the highest numbers overall.

Desert Bighorn Sheep.— Six out of 7 (86%) agencies reported their hunter numbers and harvest success rates. There were 1096 hunters reported since 1970. The agencies that provided data reported 923 males harvested, with Nevada reporting the highest numbers. There are no seasons for female desert bighorn sheep.

Sierra Nevada Bighorn Sheep.— There is no harvest for this taxon.

Dall's Sheep.— Three out of 4 (75%) agencies reported hunter numbers and harvest success rates. There were 11,633 hunters reported since 1970 excluding Yukon. The total harvest was 5097 males and 137 females over the last 39 years, with Alaska reporting the highest harvest rates for both sexes, but British Columbia and Yukon did not provide data on female harvest.

Stone Sheep.— Very little data were provided for Stone sheep. British Columbia reported 830 males harvested since 1980. There is no season for female Stone sheep. Hunter numbers and harvest rates were not provided by the agencies that manage for Stone sheep.

Hunt Type and Weapon Restrictions

Agencies were asked what type of hunts and weapon restrictions they allow for each species, with the option to choose all that apply (Table 8). The hunt type options provided were general season, limited entry/draw, harvest quota, and auction/raffle. The weapon choices were rifle, handgun, muzzleloader, archery and other. Lastly, the season restrictions that were available to select were male harvest only, female harvest only, non gender specific harvest, minimum age requirement, or minimum horn curl or length requirement (Figure 4). The data represented in this

Table 5. Reported ram harvest in North America, 1970-2009. States or provinces not reporting information for a species are not included.

Species/ Subspecies	Jurisdiction	1970	1980	1990	2000	2009
Rocky Mtn. Bighorn Sheep	Alberta	111	228	233	185	157
	Arizona			6	10	11
	British Columbia			60	22	51
	Colorado	15	76	115	137	125
	Idaho	63	28	73	28	34
	Montana	72	111	79	118	152
	Nebraska			3	10	2
	Nevada			2	4	11
	New Mexico	10	7	11	12	19
	North Dakota			7	4	5
	Oregon		5	6	9	11
	South Dakota	6	5	2	6	5
	Utah				9	
	Washington			3		3
	Wyoming	96	182	241	184	196
	Totals	373	642	841	738	782
California Bighorn Sheep	British Columbia			92	34	45
	Idaho	1	4	19	24	21
	Nevada			3	39	47
	Oregon	7	14	46	47	78
	Utah					4
	Washington	10	10	12	16	26
	Totals	18	28	172	160	221
Desert Bighorn Sheep	Arizona	39	39	60	89	75
	California			6	10	
	Colorado			4	7	6
	Nevada	18	66	91	113	172
	New Mexico	5			2	2
	Texas			1	6	16
	Utah	4	10	12	33	37
	Totals	66	115	174	260	308
Dall's Sheep	Alaska		684	1,366	726	788
	British Columbia			11		7
	Northwest Territories				200	200
	Yukon		255	368	243	249
	Totals		939	1,745	1,169	1,244
Stone Sheep	British Columbia			245	278	307

Table 6. Reported ewe harvest in North America, 1970-2009. States or provinces not reporting information for a species are not included.

Species/Subspecies	Jurisdiction	1970	1980	1990	2000	2009
Rocky Mtn. Bighorn Sheep	Alberta	29	44	31	35	45
	British Columbia			44	1	
	Colorado		3	18	56	25
	Montana	19	68	117	32	158
	Totals	48	115	210	124	228
California Bighorn	British Columbia			9	1	1
Dall Sheep	Alaska		11	40	63	3
	NW Territories				10	10
	Totals	0	11	40	73	13

Table 7. Reported number of hunters and (harvest success rates) for wild sheep in North America, 1970-2009. States or provinces not reporting information for a species are not included.

		# Hunters					Success Rate (%)				
Species/ SubSpecies	Jurisdiction	1970	1980	1990	2000	2009	1970	1980	1990	2000	2009
Rcky. Mtn. Bighorn Sheep	Alberta	1,202	2,561	2,402	2,123	2,377	9	9	9	9	7
	Arizona			6	10	11			100	100	100
	Colorado	98	305	340	332	255	15	26	39	58	57
	Idaho		102	181	62	64		28	40	45	53
	Montana	506	648	624	321	375	14	17	29	38	41
	Nebraska			3	10	2			100	100	100
	Nevada			2	4	11			100	100	100
	New Mexico	18	10	12	12	19	56	70	90	100	100
	North Dakota			8	4	5			88	100	100
	Oregon		5	6	9	11		100	100	100	100
	South Dakota	6	5	2	6	5	100	100	100	100	100
	Utah				9	24				100	100
	Washington			3		3			NA		100
	Wyoming	408	347	374	255	251	24	52	64	72	78
California Bighorn Sheep	Idaho	5	10	22	43	22	20	40	86	56	95
	Nevada			3	43	48			100	91	98
	Oregon	7	14	46	47	86	100	100	100	100	82
	Utah					4					100
	Washington	22	28	10	16	39	45	29	70	100	100
Desert Bighorn Sheep	Arizona	79	50	70	94	77	49	78	86	95	97
	California			6	10				100	100	
	Colorado			4	7	6			100	100	100
	Nevada		86	134	132	193		77	68	86	89
	New Mexico	5			2	2	100			100	100
	Texas			1	5	15			100	100	100
	Utah	10	19	15	33	41	40	53	80	100	90
Dall Sheep	Alaska		1,898	3,448	3,010	2,455		36	40	26	32
	British Columbia			39	35	36			26	0	19
	NW Territories			220	231	261			77	82	74

Table 8. Wild sheep hunt types and weapon restrictions reported by western states, provinces, and territories in North America, 1970-2009. States or provinces not reporting information for a species are not included.

Species	Weapon	General Season	Limited Entry	Harvest Quota	Auction/Raffle
Rcky. Mtn. Bighorn	Rifle	Alberta Arizona British Columbia Montana North Dakota	Alberta British Columbia Colorado Idaho Montana Nebraska Nevada New Mexico North Dakota Oregon South Dakota Utah Wyoming	British Columbia Montana New Mexico	Alberta British Columbia Colorado Idaho Montana Nebraska New Mexico North Dakota Oregon Utah Wyoming
	Handgun	Arizona North Dakota	Colorado Idaho Nevada New Mexico North Dakota Oregon Wyoming	Nevada	Colorado New Mexico North Dakota Oregon Wyoming
	Muzzleloader	Arizona North Dakota	Colorado Idaho Nebraska Nevada New Mexico North Dakota Oregon Wyoming	Nevada	Colorado Nebraska New Mexico North Dakota Oregon Wyoming
	Archery	Arizona British Columbia North Dakota	Alberta British Columbia Colorado Idaho Montana Nebraska Nevada New Mexico North Dakota Oregon Wyoming	British Columbia Nevada	Colorado Nebraska New Mexico North Dakota Oregon Wyoming
	Other		Arizona Washington		Arizona Washington

Table 8. Continued.

Species	Weapon	General Season	Limited Entry	Harvest Quota	Auction/Raffle
California Bighorn	Rifle	British Columbia	British Columbia	British Columbia	British Columbia
			Idaho	Nevada	Idaho
			Nevada		Nevada
			Oregon		Oregon
			Utah		Utah
			Washington		
	Handgun		Nevada	Nevada	Oregon
			Oregon		
	Muzzleloader		Nevada	Nevada	Oregon
			Oregon		
	Archery	British Columbia	British Columbia	British Columbia	Oregon
			Nevada	Nevada	
			Oregon		
	Other		Washington		Washington
Desert Bighorn	Rifle		California	Nevada	California
			Colorado		Mexico
			Nevada		Nevada
			New Mexico		New Mexico
			Texas		Texas
			Utah		Utah
	Handgun		Colorado	Nevada	New Mexico
			Nevada		Texas
			New Mexico		
			Texas		
	Muzzleloader		Colorado	Nevada	Mexico
			Nevada		New Mexico
			New Mexico		Texas
			Texas		
	Archery		Colorado	Nevada	Mexico
			Nevada		New Mexico
			New Mexico		Texas
			Texas		
	Other	Arizona	Arizona		Arizona
			New Mexico		New Mexico
Dall Sheep	Rifle	NW Territories	British Columbia	British Columbia	Yukon
		Yukon	Yukon	Yukon	
	Archery	NW Territories	British Columbia	British Columbia	
			Yukon		
	Other	Alaska	Alaska		
Stone Sheep	Rifle	British Columbia	British Columbia	British Columbia	
		Yukon	Yukon	Yukon	
	Archery	British Columbia	British Columbia	British Columbia	

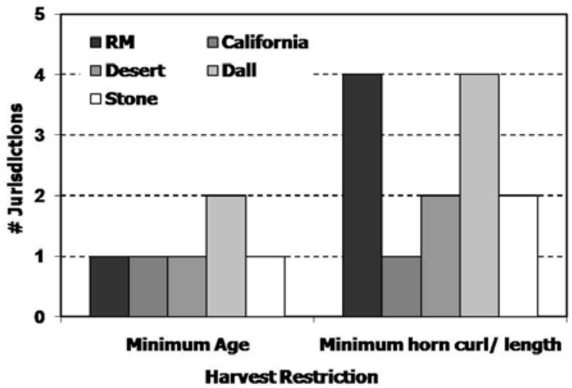

Figure 4. Harvest restrictions for bighorn and thinhorn sheep.

document both in text and in the tables is based on the details provided by each agency, and there may be some discrepancies as a result of vague responses.

Rocky Mountain Bighorn Sheep.— There was 100% compliance for these series of questions. Hunt types varied by weapon restrictions. Some agencies did not specify weapon restrictions among hunt types, but simply stated any legal weapon was allowed, and the use of a lesser weapon was allowed. In New Mexico crossbows were allowed for disabled hunters. Within the general season category 27% of agencies allowed rifles, 13% allowed handguns and muzzleloaders, and 20% allowed archery as the type of weapon. Within the limited entry hunt category, 87% of agencies allowed rifles, 47% allowed handguns, 53% allowed muzzleloaders, 73% allowed archery, and 13% indicated any weapon. Within the harvest quota category 20% allowed rifles, only Nevada allowed handguns and muzzleloaders, and 13% allowed archery as weapon type. For auction hunts 73% allowed rifles, 33% allowed handguns, 40% allowed muzzleloaders and archery, and 13% indicated any weapon of choice.

Season restrictions for Rocky Mountain bighorns resulted in 87% male only harvest, 33% female only harvest, 20% non gender-specific harvest; 7% (only British Columbia) required a minimum age requirement, and 27% had a minimum horn curl/length requirement.

California Bighorn Sheep.— All agencies managing for California bighorns responded to these questions. Only British Columbia holds a general season, and the weapon restrictions allow for rifle or archery only. Within the limited entry category, 83% of agencies allowed rifles, 33% allowed handguns and muzzleloaders, 50% allowed archery, and 33% indicated any weapon choice. For the harvest quota category 33% allowed rifles, only Nevada allowed handguns and muzzleloaders, and 33% allowed archery. For auction hunt types 83% allowed rifles, but only Oregon allowed handguns, muzzleloaders, or archery. Washington indicated that any type of weapon could be used.

Season restrictions for California bighorns resulted in 100% male only harvest and for 33% female only harvest. Only British Columbia required minimum age or minimum horn size restrictions.

Desert Bighorn Sheep.— The responses indicate that only Arizona has a general season for desert sheep and they allowed for any weapon type. Within the limited entry category, 63% of agencies allowed rifles and handguns, 50% allowed muzzleloaders and archery, and 25% indicated any weapon (including crossbows for disabled hunters in New Mexico). Only Nevada had a harvest quota hunt type, and they allowed for any legal weapon.. For the auction category, 63% allowed rifles, 38% allowed handguns, muzzleloaders, and archery, and 25% allowed any weapon type.

Season restrictions for desert bighorn sheep were fairly straight forward since there is no harvest of females. Only California and Colorado have minimum horn size restrictions.

Dall's Sheep.— Within the general season category 50% of the agencies allowed rifles, and 25% allowed archery. Alaska has no weapon restrictions aside from a few small-scale archery hunts. Within the limited entry category, 50% allowed rifles and archery. For harvest quota hunt types, 50% allowed rifles but only British Columbia allowed archery. Only Yukon reported an auction hunt type. There were no data reported specifically for handguns or muzzleloader weapon restrictions by any of the agencies managing Dall's sheep.

Season restrictions for Dall's sheep resulted in male-only harvests. Alaska also has a female harvest only, and non gender-specific hunts. Only Alaska requires a minimum age, but all four agencies (100%) have a minimum horn size requirement

Stone Sheep.— Both agencies, British Columbia and Yukon, allowed rifles for general season, limited entry, and harvest quota hunt types. Only British Columbia allowed archery for these same hunt types. There was no auction hunt type for Stone sheep. There was no information given specifically for handgun or muzzleloader weapon restrictions by either of the agencies managing Stone sheep.

Season restrictions for both agencies involved male harvest only, and both have minimum horn size requirements. Only British Columbia has a minimum age requirement. There is no harvest on female Stone sheep.

Current Research Projects

NWSGC agencies reported involvement in 40 sheep studies (Table 9). Seventeen of the 40 involve Rocky Mountain bighorns; only Nevada and New Mexico do not have any formal research for Rocky Mountain bighorn sheep. There are 3 studies currently being conducted on California bighorn sheep. Idaho, Nevada and Utah currently have no projects. California has eight research studies ongoing for Sierra Nevada bighorns. There are seven Desert bighorn sheep studies being conducted from just 3 agencies. California, Colorado, New Mexico, Texas, and Utah did not report any current projects. Only Alaska is performing research studies on Dall's sheep at this time. They currently have four ongoing projects. British Columbia reported the lone research project for Stone sheep. The project descriptions varied considerably and included vehicle collisions, movement studies, genetics, disease and parasites, habitat use, home range, mortality, predator-prey selection, landscape restoration, population viability, resource selection functions, and survey techniques.

DISCUSSION

I attempted to summarize sheep status reports received from 21 western states, provinces and territories in preparation for the 2010 Northern Wild Sheep and Goat Council Conference. I summarized data on funding, population status, distribution changes, introductions and augmentations, survey techniques, harvest and hunter numbers, hunt types, weapon and season restrictions, and current research projects. Rigorous statistical analysis was not possible due to deficient data sets and variability in responses. In spite of these deficiencies, I believe this information in this format will be useful to wild sheep managers.

As a result of my efforts to compile and summarize these data I offer a few observations. First, while the new on-line data collection survey method utilized this year did save some analysis time for the compiler, it did not allow for specific answers to some questions. Users complained that not every question can fall into a black vs. white category. Hopefully with increased options within the design phase of this software, Survey Monkey or other programs like it, will become more user friendly. Secondly, there is far too much variability of issues between the subspecies of wild sheep to be lumped together. After summarizing these data, I believe that the survey might benefit from taxon-specific surveys. This approach will minimize non-applicable questions and ensure all facets affecting each species are fully captured. Finally, it is extremely important to emphasize that this paper discusses the results "as reported" by the agencies. Due to the obvious restrictions of the survey technique and lack of full detail, the results represented here were completely open to my interpretation. Every attempt was made to clarify and fact check details that were unclear, but these results undoubtedly contain inaccuracies. I urge the reader to contact the individual agencies to clarify or confirm any questions brought forth by this summary.

Table 9. Current sheep research projects reported by western states, provinces, and territories in North America.

Species	Jurisdiction	Project Description
Rocky Mountain Bighorn Sheep	Alberta	Ram Mountain with Marco Festa-Bianchet, University of Sherbrooke Sheep River with Katreen Ruckhstal, University of Calgary
	Arizona	Primarily looking at roads and movements. Wakeling, B. F., Najar, H. S., and O'Dell, J. C. Mortality of bighorn sheep along U.S. Highway 191 in Arizona. Arizona Game and Fish Department, Game Branch 5000 West Carefree Highway, Phoenix, AZ 85086, USA. Arizona Game and Fish Department, Region I 2878 East White Mountain Boulevard, Pinetop, AZ 85935, USA.
	British Columbia	Elk Valley study - underway, genetics with various labs.
	Colorado	George, J. L., D. J. Martin, P. M. Lukacs, and M. W. Miller. 2008. Epidemic Pasteurellosis in a bighorn sheep population coinciding with the appearance of a domestic sheep. Journal of Wildlife Diseases. Vol 44, No. 2. Pages 388-403. Wolfe, L. L., B. Diamond, T. R. Spraker, M. A. Sirochman, D. P. Walsh, C. M. Machin, D. J. Bade, and M. W. Miller. 2010. A bighorn sheep die-off in southern Colorado involving a Pasteurellaceae strain that may have originated from sympatric cattle. Journal of Wildlife Diseases (revised draft in review, April 2010).
	Idaho	The Department is continuing long-term research on bighorn sheep distribution, movements, and effects of disease as part of the tri-state (Idaho, Oregon, Washington) Hells Canyon Bighorn Sheep Restoration Project, begun in 1997. Many publications. The Department is also working with the Nez Perce Tribe and other groups on the multi-year Salmon River Bighorn Sheep Restoration project, begun in 2007.
	Montana	Not a research project but Montana has just completed the "Montana Bighorn Sheep Conservation Strategy", primary author/editor/compiler: Tom Carlsen. It was posted on our website 4/23/10.
	Nebraska	Evaluation of the Use of the Escape Terrain and Buffer Model to Depict Northwestern Nebraska's Bighorn Sheep Habitat. Rana A. Tucker, Department of Applied Sciences, Chadron State College, 1000 Main Street, Chadron, NE 69337 U.S.A. Teresa J. Zimmerman, Department of Applied Sciences, Chadron State College, 1000 Main Street, Chadron, NE 69337 U.S.A.

Table 9. Continued.

Species	Jurisdiction	Project Description
	North Dakota	Wiedmann is currently writing a comprehensive management plan. Data will include historic population levels, population goals on a herd-by-herd basis, identification of suitable habitat for further introductions, and GIS home range and mortality analysis. Will be published by NDGF.
	Oregon	All Rocky Mountain bighorn research conducted through the Hells Canyon Initiative since 1998.
	South Dakota	Currently a research project looking at mountain lion prey selection within bighorn sheep habitat and cause specific mortality for bighorn ewes and lambs was started in 2009.
	Utah	Placed 12 GPS collars on ewes and rams in the Hoop Lake and Flaming Gorge areas to look at sheep movements, and in particular sheep movements into the high country of the Uinta Mountains and potential overlap with active domestic sheep allotments (in conjunction with Uintah-Wasatch-Cache National Forest).
	Washington	Hells Canyon Initiative; Frances Cassier; Idaho Fish and Game; published.
		Role and ecology of Mycoplasma ovipneumoniae in respiratory disease in bighorn sheep; Tom Besser; Washington State University; Dissertation and 3 peer-reviewed publications expected in 2012.
	Wyoming	Devil's Canyon BHS Supplemental Transplant and Resource Selection Analysis, 2004-2008 (July 2009)
		Tom Easterly, WGFD and Dr. Matt Kaufmann & Aly Courtemanch, WY COOP Unit Distribution and Habitat Selection Patterns of Mountain Sheep in the Laramie Range (June 2009)
		Hall Sawyer & Ryan Neilson, WEST, Inc., and Martin Hicks, WGFD Clarks Fork BHS Study Final Report (June 2009)
		Doug McWhirter, WGFD Resource selection, movement, recruitment and impact of backcountry recreation on BHS in the Teton Range, NW Wyoming (in progress)
		Dr. Matt Kaufmann & Aly Courtemanch, WY COOP Unit Non-invasive evaluation of the genetic status and parasite loads of Teton Range BHS, NW Wyoming (in progress) Sarah Dewey, Grand Teton Nat'l Park, and Dr. Gordon Luikart & Marty Kardos, Univ. of MT
California Bighorn Sheep	British Columbia	Thompson River University student looking at range use and stats of Kamloops herd Recovery of Okanagan herds and reintroductions in those genetics and horn stats with Marco and Dave Coltman
	Oregon	Recently completed research evaluating genetic implication of Oregon's bighorn reintroduction programs using a Ph.D. student (Olson et al. in this proceedings) through Purdue University.
	Washington	Landscape restoration and spatial response of bighorn sheep in the Sinlahekin Wildlife Management Area; Dr. Mark E. Swanson and Dr. Lisa A. Shipley; Washington State University; Thesis and publication expected 2011.
Sierra Nevada Bighorn sheep	California	Current research is focused upon evaluating population viability, disease risk, and effects of natural and prescribed fire. Projects are in collaboration with graduate students at the University of Montana and Yale University. Eight abstracts will be submitted separately.

Table 9. Continued.

Species	Species	Species
Desert Bighorn Sheep	Arizona	Primarily effects of roads, although we are investigating many aspects of the Kofa desert bighorn sheep population and may initiate increased genetic studies. Some ongoing studies on disease and water use.
	Mexico	Mexico's biologists are doing a better job of documenting the work being done in their country. As the number of projects and programs increase, the reports and publications of the results increase as well. Many of these reports are being published in the Desert Bighorn Council Transactions.
	Nevada	Collaborating with USGS and Dr. Kathy Longshore on monitoring population isolation and any remnant movement and movement corridors of desert bighorn sheep impacted by Las Vegas and surrounding infrastructure. She is also looking at strengthening inference and accuracy of the River Mountain (unhunted herd between Las Vegas and Lake Mead) population estimate through intensive marking.
		A new study is beginning on the Desert National Wildlife Refuge and Nevada Test Site to look at population dynamics of desert bighorn sheep and mountain lions. This is also being directed by Dr. Longhsore with several secondary contributors. Unknown plans for publications, though I am sure the Desert Bighorn Council will likely be the primary outlet of information.
		Also a small project is underway led by Dr. David Thain, DVM with University of Nevada, Reno, Cooperative Extension on forage quality and desert bighorn sheep health and body condition. Only limited knowledge of that study.
Dall Sheep	Alaska	Arthur, S., and T. Craig. Demographics and spatial ecology of Dall's sheep in the central Brooks Range. ADF&G collaboration with BLM.
		Schmidt, J., and K. Rattenbury. Using distance sampling to estimate Dall's sheep abundance in Gates of the Arctic National Park and Preserve. NPS.
		Lohuis, T. Dall sheep population dynamics in the Chugach Mountains. Alaska Department of Fish & Game. Project is ongoing.
		Lohuis, T. Dall's sheep population dynamics in the Kenai Mountains. Alaska Department of Fish & Game. Project is ongoing.
		Roffler, G.H., S.L. Talbot, G.K. Sage, K. Pilgrim, L.G. Adams, M.K. Schwartz, R. Schwanke, and G. Luikart. Evaluating the genetic structure of Dall's sheep populations in Wrangell St. Elias National Park and Preserve. Collaboration with Alaska Department of Fish & Game. Project is ongoing.
Stone Sheep	British Columbia	Genetics with Dave Coltman, horn stuff with Marco, Sulpur 8 Mile with Pam Hengeveld etc.

Situational Agency Response to Four Bighorn Sheep Die-offs in Western Montana

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Abstract: All-age die-offs occurred in 4 bighorn sheep (*Ovis canadensis*) populations in western Montana during the winter of 2009-2010. Montana Fish, Wildlife and Parks (MFWP) personnel became aware of the first die-off in the East Fork of the Bitterroot (East Fork) population in late November 2009. Subsequent die-offs in the Bonner, Lower Rock Creek and Upper Rock Creek populations became apparent in January 2010. MFWP personnel attempted to actively manage outbreaks by lethally removing (culling) 80 symptomatic bighorns in the East Fork and 99 in Bonner to prevent the spread of the disease to healthy herd segments and neighboring populations. We documented 5 additional bighorn carcasses in Bonner and 6 from the East Fork as potential pneumonia mortalities. MFWP personnel allowed the disease to run its course in Lower and Upper Rock Creek, but removed 48 symptomatic sheep from these populations for diagnostic purposes. All animals collected were necropsied and biological samples were obtained to test for pathogens. Comingling of wild bighorns with domestic sheep or goats was reported post hoc in the East Fork and Bonner, and the East Fork domestics were tested for pathogens. *Mycoplasma ovipneumonia*e was commonly detected utilizing Polymerase Chain Reaction techniques on lung tissue from all bighorn populations, and *Pasteurella multocida* was commonly isolated from the East Fork, Lower Rock Creek, and Upper Rock Creek samples, but not from Bonner in 2009-10. Based upon recent tests using cELISA on banked serum collected in 2007, these bacteria were not detected in the Lower Rock Creek and Bonner populations, but *M. ovipneumoniae* was detected in the East Fork samples. Baseline data were not available for the Upper Rock Creek population. In 2009-10, *M. ovipneumonia*e was detected in pharyngeal swabs from 4 of 7 domestic sheep tested in the East Fork. Prescriptively culled bighorn populations declined by 53-68%, while those populations where bighorn removal occurred only for diagnostic testing declined by 43-60% by March-April 2010. Culling was most successful in the East Fork, as indicated by stable bighorn numbers, no further evidence of pneumonia, and sustained ratios of 32 lambs:100 ewes surviving into August 2010. In contrast, in Upper Rock Creek where limited culling only occurred for diagnostic sampling, adults continued dying in spring and summer and no surviving lambs were documented into August. Although each

affected population was separated from the others by unsuitable habitat or a gap in bighorn occupancy, the die-off across populations highlighted their seasonal or occasional connectivity, and demonstrated the disadvantage of a connected metapopulation of bighorns should a highly contagious pathogen be introduced.

KEY WORDS: bighorn sheep, culling, die-off, disease, epizootic, Montana, *Ovis canadensis*, pneumonia, populations, response.

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During the winter of 2009-2010, 5 western states experienced 9 pneumonia epizootics among bighorn sheep (*Ovis canadensis*). Four occurred in western Montana within administrative Region 2 of Montana Fish, Wildlife and Parks (MFWP). Affected Montana populations were from the East Fork of the Bitterroot (East Fork), Bonner, Upper Rock Creek (URC) and Lower Rock Creek (LRC, Figure 1). The last die-off of comparable scale in Montana occurred along the Rocky Mountain Front in 1983 and 1984, though 16 other die-offs have occurred in isolated populations since then (MFWP 2010).

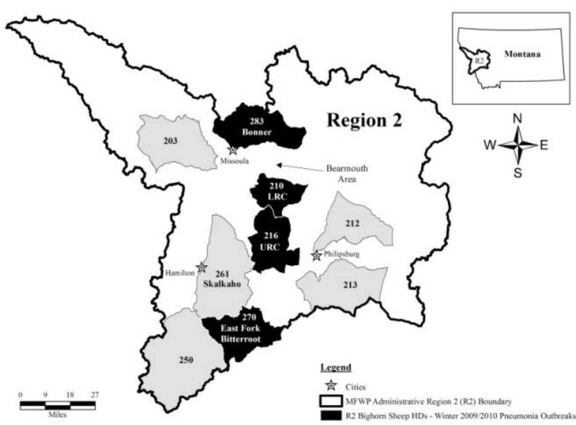

Figure 1. Map of bighorn sheep hunting districts and populations with pneumonia outbreaks during winter 2009-2010 in Montana Fish, Wildlife and Parks, Administrative Region 2, western Montana.

Pneumonia is a significant mortality factor in bighorn populations throughout the western states. Large-scale die-offs can reduce populations to just a few individuals, and poor lamb survival and low lamb recruitment may follow the pneumonia event (Onderka and Wishart 1984, Coggins and Mathews 1992, Ryder et al. 1994, Semmens 1996, Aune et al. 1998). *Mannheimia haemolytica* (formerly *Pasteurella haemolytica*), *Bibersteinia trehalosi*, *Pasteurella multocida*, and *Mycoplasma ovipneumoniae* frequently are isolated from lung tissue of affected bighorn sheep. However, the roles of these bacteria and other factors, such as respiratory viruses, parasites, and stressors such as malnutrition and competition are not clear. Contact with domestic sheep or goats have preceded some bighorn pneumonia outbreaks and, in other cases, contact could not be demonstrated.

Few wildlife management agencies have tested culling techniques to increase survival rates of bighorns during die-off events. Schwantje and Garde (Ministry of Water, Land, and Air Protection, unpublished data) reported that wildlife managers dispatched severely symptomatic sheep during a pneumonia outbreak in the South Okanagan metapopulation of California bighorns (*O. californiana*) in British Columbia. Six of the 8 treated subpopulations appeared to recover quickly, though it was not evident whether the recovery was due to culling or coincidence. During the 2009-10 die-offs, Montana, Washington and Utah implemented culling strategies. This paper describes methods and outcomes in Montana.

MFWP personnel implemented 3 response strategies to the die-offs as they unfolded in western Montana in 2009-10, including: selective culling, a combination of selective culling and containment zone culling, and limited culling with removal of only sick animals for diagnostic sampling. The strategy selected depended on the specific circumstances for each population and expression of disease in each locale. As described in the Montana Bighorn Sheep Conservation Strategy (MFWP 2010), every die-off is a unique event, with multiple and dynamic variables for wildlife managers to evaluate when determining a response strategy. These factors include the scope (extent and number of animals affected) of the die-off, stages of the die-off at the time of diagnosis, connectivity of infected bighorns with adjacent herd segments or populations, access to the area where the die-off is occurring, visibility of symptomatic bighorns to the public, time-of-year when the outbreak occurred, and seasonal distribution of the sheep. The protocol outlined in the Strategy allowed flexibility in determining the Agency's course of action, but it also included a recommendation to remove symptomatic animals during early stages of an outbreak in an attempt to reduce the extent of the die-off (MFWP 2010).

In the East Fork and Bonner populations, MFWP personnel culled bighorns to minimize the potential for contact and possible disease transmission between infected and healthy animals. MFWP personnel did not prescriptively cull in the LRC population due to hazardous, snow-covered terrain, or in URC due to the advanced scope of the infection in that population. However, we dispatched limited numbers of bighorns in LRC and URC for diagnostic evaluation of the pneumonia event.

The 4 case histories provide opportunities to examine 3 working hypotheses: 1) culling infected or exposed bighorns decreases the spread of pneumonia to healthy animals; 2) two or more pneumonia outbreaks were related; and 3) lamb recruitment in subsequent years can be improved by removing symptomatic animals during a pneumonia outbreak.

STUDY AREAS

East Fork

The East Fork population was located 5 miles southeast of Darby, Montana, in Hunting District (HD) 270 (Figure 1). More detailed descriptions of the 4 study areas are found in MFWP (2010). In 1972 MFWP reintroduced 19 bighorns to historic bighorn habitat in the Tolan Creek area and 35 into Bunch Gulch, all from the Sun River, Montana. The population responded quickly and MFWP allowed hunting in 1976. In recent years, license numbers ranged from 6 to 8 for either-sex and 10 to 20 for adult ewes.

During spring trend surveys in March 2006 and April 2009, MFWP personnel obtained a record-high count of 246 bighorns and a count of only 187, respectively. Population density prior to the die-off was indexed at ~1.54 bighorns per mi^2 across ~121 mi^2 of occupied habitat. Population objectives were to manage for 200 sheep +/- 20%. Lamb recruitment ranged from 35 to 40 lambs:100 ewes in good years and 18 to 25 lambs:100 ewes in poorer years, with a ratio of 39:100 recorded in 2009.

In 2002, 23 bighorns were translocated to Utah and 14 were moved to the Highland Mountains in Montana. One ewe tested positive for *Brucella ovis* in 2002; however, it was later determined to be a false positive. In 2004, 15 sheep were sent to Colorado for a challenge study. During the 2002 and 2004 capture operations, contagious ecthyma, or sore mouth, was detected in the East Fork herd by MFWP lab personnel who observed scabs on 1 adult ewe in each of those years.

The latest translocations from the East Fork population occurred in 2007 when 25 bighorns were moved to Utah. All 25 sheep tested negative on serology for *B. ovis*, *Brucella abortus*, Bluetongue, Anaplasmosis, Infectious Bovine Rhinotracheitis, and Bovine Viral Diarrhea Type I and Type II. Seven sheep (28%) had low titers ranging from 1:8-1:16 for Bovine Respiratory Syncytial Virus (BRSV), and 24 (96%) had low titers (1:8-1:32) for Para-Influenza 3 (PI3). *B. trehalosi* was isolated from 18 (72%) of the pharyngeal swabs, and beta-hemolytic *Streptococcus* spp. from 20 (80%) of the swabs. *M. haemolytica* was isolated from 3 (12%) of the swabs. Other organisms that were isolated included *Bacillus* spp., *Enterococcus* spp., *Actinobacillus* spp., *Arcanobacterium pyogenes*, and *Staphylococcus* spp. *M. ovipneumoniae* was not detected from any of the pharyngeal swabs from the East Fork of the Bitterroot in 2007, but Polymerase Chain Reaction (PCR) techniques were not available at that time to detect the presence of *M. ovipneumoniae*. Recent tests using cELISA on banked serum indicated that 19 out of 25 samples (1 result undetermined) were considered seropositive for exposure to *M. ovipneumoniae*. Eight sheep (32%) had low levels of *Nematodirus* spp. Most sheep had coccidia (*Eimeria* spp.), and of those 5 (20%) had high loads. Lungworm larvae (*Protostrongylus* spp.) were found in 75% of sheep, but all had low burdens.

Two large domestic sheep operations were located about 15 miles north of bighorn range. Additionally, there were numerous hobby producers of domestic sheep and goats in the Bitterroot Valley, including one within bighorn range in Whiskey Gulch. Comingling of wild sheep with those domestics was reported on 3 separate occasions by the public in August and September 2009. MFWP personnel responded to 1 of the reports but were unable to find the bighorns, and the 2 other reports did not reach MFWP personnel before the bighorn die-off began.

Bonner

The Bonner population was located northeast of Missoula, Montana, in HD 283 (Figure 1). In 1987, MFWP reintroduced 14 wild sheep to historic bighorn habitat on Woody Mountain from URC, and in 1990 added 30 bighorns from the Sun River in Montana. Bighorns soon became well established in all suitable habitats near the community of Bonner. A subpopulation inhabited portions of the Rattlesnake Wilderness and National Recreation Area, and another occupied the area south of the Blackfoot River between Bonner and LaFrey Creek. In 1996, MFWP implemented its first limited-license hunting season. From 1996 to 2009, license levels varied from 2 to 10 for adult ewes, and 1 to 3 for either-sex.

The population objective was 100 bighorns (+/-10 %) as reflected by a spring survey target of 90-110. Survey results ranged from 35 sheep in 1991 to 128 in 2007, and MFWP counted 94 bighorns in May 2009. Population density prior to the die-off was indexed at ~3.76 bighorns per mi^2 across ~25 mi^2 of occupied habitat. During good years, recruitment ranged from 45 to 55 lambs:100 ewes, but lamb:ewe ratios often fell below 35:100. Low ratios in 2008 (28:100) and 2009 (25:100) may not reflect lamb recruitment across the population. In 2008, a large band of ewes, lambs, and young rams was unclassified, and in 2009 MFWP personnel conducted the survey when ewes were lambing and therefore, less observable than usual.

Ground classifications of yearlings during the summer were in the mid-thirties for both years.

In December 2009, MFWP personnel estimated the population at 160-180 bighorns and had considered translocating sheep from this population before the die-off occurred. Human-bighorn conflicts were especially prevalent in the West Riverside community where $\geq$ 98 bighorns grazed on residential lots. Numerous domestic sheep and goats were present for many years as hobby flocks and commercial operations, but there had been no previously known incidence of pneumonia in the Bonner population. After the die-off was detected in January 2010, the public reported a case of bighorns and domestics comingling in the fall of 2009.

Four translocations of bighorns from Bonner occurred over a 10-year period, including 27 to Utah in 2007. All 27 sheep from the translocation tested negative on serology for *B. ovis*, *B. abortus*, Bluetongue, Infectious Bovine Rhinotracheitis, and Bovine Viral Diarrhea Type I and Type II. Six sheep (22%) had a titer for Anaplasmosis, and 8 (30%) had a titer for BRSV. Most BRSV titers were 1:8, but 1 sheep had a 1:32 titer. All sheep had a titer for PI3, ranging from 1:8 to 1:64 for most sheep, but 2 sheep had titers of 1:128. *B. trehalosi* was isolated from 25 (93%) pharyngeal swabs. *Streptococcus* spp. was isolated from 21 (78%) pharyngeal swabs, and *M. haemolytica* was isolated from 7 (26%) swabs. *Staphylococcus* spp. and *Bacillus* spp. were occasionally isolated. *M. ovipneumoniae* was not detected among the pharyngeal swabs from Bonner in 2007, but PCR techniques were not available to evaluate the samples. However, exposure to *M. ovipneumoniae* was not detected in banked serum tested in 2009 utilizing cELISA. Fourteen of the Bonner sheep (52%) had coccidia (*Eimeria* spp.); most had low burdens, but 3 had burdens that were considered moderately high. Twelve (44%) of the bighorns had low levels of lungworm (*Protostrongylus* spp.), and 11 (41%) had a low burden of *Nematodirus* spp.

Lower Rock Creek (LRC)

The LRC population was located about 20 miles southeast of Missoula, in HD 210 (Figure 1). MFWP introduced 25 sheep to historic bighorn habitat in LRC from Wild Horse Island in 1979 and added 28 sheep from Lost Creek (near Anaconda, Montana) in 1987. Either-sex license numbers have ranged from 1 to 10 since 1986, and ewe licenses have ranged from 0 to 30 annually.

The population objective was 200 bighorns (+/- 20%). The population grew to 44 by 1983 and peaked at 268 bighorns observed in 1996. In 2008, MFWP personnel observed 201 bighorns during the annual aerial survey of winter range, which we consider to be the baseline number going into the 2010 die-off. (A low count in 2009, was thought to be an anomaly due to a late survey.) Population density prior to the die-off was indexed at ~2.87 bighorns per mi^2 across ~70 mi^2 of occupied habitat. Lamb recruitment from 1983 to 2008 averaged 36 lambs:100 ewes and ranged from 19:100 to 65:100. On 4 April 2008 (the best aerial survey flight prior to the die-off), 44 lambs:100 ewes were observed.

LRC bighorns congregated in numbers occasionally exceeding 100 in small pastures and residential lawns in summer and fall. Domestic sheep or goats were not known to occur in HD 210 when such presence could have been connected to the die-off. However, domestic sheep occurred in small flocks on the northern fringe of LRC bighorn range outside of HD 210.

In 2007, 15 apparently healthy bighorn sheep were translocated along the Green River in Utah. All 15 sheep tested negative on serology for *B. ovis*, *B. abortus*, Bluetongue, Infectious Bovine Rhinotracheitis, Bovine Viral Diarrhea Type I and Type II and exposure to *M. ovipneumoniae* (banked serum tested in 2009). Eight sheep (53%) had titers for Anaplasmosis, and 1 (7%) had a titer (1:8) for BRSV. Nine sheep (60%) had titers for PI3, ranging from 1:8 to 1:32. *B. trehalosi* was isolated from 14 (93%) pharyngeal swabs. *M. haemolytica* and *Streptococcus* spp. were both isolated from 7 (47%) swabs. *Staphylococcus* spp. and *Bacillus* spp. were rarely isolated. *M. ovipneumoniae* was not detected by culture on pharyngeal swabs from LRC in 2007, but the samples were not evaluated using PCR techniques. Exposure to *M. ovipneumoniae* was not evident in banked serum recently tested by cELISA. Four bighorn (27%) from LRC had low burdens of coccidia (*Eimeria* spp.). Six (40%) had low burdens of *Nematodirus* spp., and all had low burdens of lungworm (*Protostrongylus* spp.).

Upper Rock Creek (URC)

The URC population was located about 10 miles west of Philipsburg, Montana, in HD 216 (Figure 1). It was a native population that had been supplemented in 1975 with 31 sheep from Sun River, Montana. About 200 bighorns were thought to be in URC before a die-off in 1967 (Berwick 1968). Following that event only 15 were observed on winter ranges, and lamb production was very low for years afterward (Butts 1980). By 1981 the population had rebounded to ≥ 128 sheep. The modern hunting era in URC began in 1979 when 1 license was filled. Subsequently, either-sex license numbers commonly ranged from 8 to 16. Ewe licenses were initiated in 1980 and a range of 5 to 40 such licenses were available through 2009.

The population objective was 300 bighorns (+/- 20%). A record high of 347 bighorns was counted in 2007 and sustained at 342 in 2008 and 2009. Population density prior to the die-off was indexed at ~3.84 bighorns per mi^2 across ~89 mi^2 of occupied habitat. Lamb recruitment in URC averaged 43 lambs:100 ewes and from 1990 to 2009 ranged from 27 to 58. Eight months prior to the die-off, MFWP personnel observed 342 sheep with 32 lambs:100 ewes.

Bighorns were translocated from URC in 1984, 1987, and 1997, totaling 83 bighorns that were removed from this population. A recent herd health baseline was not available. A translocation was planned for 2010, but canceled because of the pneumonia outbreak. Domestic sheep or goats were not known to occur in URC.

Connectedness of Bighorn Populations

Although MFWP personnel managed these 4 populations individually, the pneumonia event refocused our attention on known and suspected connections among these and adjacent satellite populations, known as Bearmouth and Skalkaho (HD 261, Figure 1). MFWP personnel first documented bighorns at Bearmouth and Skalkaho 1 year after translocations in LRC (1979) and the East Fork (1972), respectively. DeCesare (2002) reported seasonal movements of radio-collared bighorns (1 ewe, 2 rams) across I-90 between and within the LRC and Bearmouth populations. Unmarked bighorns also were observed in recent years on Bonner Mountain between Bearmouth and Bonner. Therefore, movement of bighorns between the Bonner and LRC populations is likely.

Movement of bighorns between the LRC and URC populations has not been documented; however, occupied ranges of the 2 populations practically adjoin. In the Bitterroot Valley, a connection between the East Fork and the other populations seems comparatively unlikely, except for the Skalkaho satellite population. The first detection of bighorns in the Skalkaho area coincided with the translocation of bighorns to the East Fork, and DeCesare (2002) documented potential mixing of a radioed Skalkaho ram with East Fork bighorns in the Whiskey Gulch area where the collared ram migrated for a summer.

METHODS

Response Strategies

MFWP employed 3 response strategies to the 4 bighorn sheep die-offs: 1) selective culling─culling of symptomatic sheep, 2) containment zone (CZ) and selective culling─culling of all bighorns in a delineated area (CZ) combined with culling of symptomatic sheep outside the CZ , and 3) limited culling─limited lethal removal of symptomatic animals only for the purpose of diagnostic sampling. The strategy selected depended on the specific circumstances for each population and manifestation of the disease.

Each of the responses involved an initial collection of biological samples to identify pathogens, and MFWP personnel implementing selective culling only in the East Fork and selective and CZ culling in the Bonner population. Personnel dispatched bighorns with firearms and, in rare cases, via chemical immobilization (Bonner population only) by darting sheep from the ground using 570 mg of Telazol® reconstituted with 1.7 ml Xylazine (100 mg/mL) per animal. Personnel then euthanized the animal with Euthasol® at a dose of 1 mL per 4.6 kg of body weight. MFWP personnel initially applied immobilization techniques to bighorns in densely, human-populated areas of Bonner because of concerns of discharging high-powered rifles in the wildland-urban interface. However, the technique was discontinued because of potential complications from long induction times, overall efficiency, and human safety concerns associated with darted sheep evading capture and inadvertently injuring a member of the public or colliding with nearby traffic.

Culling strategies provided a unique opportunity to collect fresh tissue and blood samples during an ongoing pneumonia event. Sample collection occurred in three forms: 1) carcasses were transported to the Wildlife Laboratory (Lab) in Bozeman for necropsy, 2) a mobile lab was established at the culling site and Lab personnel performed thorough necropsies and collected samples, and 3) samples were collected in the field by biologists, Lab personnel and volunteers. Necropsies involved collection of pharyngeal swabs, blood, lung, liver, feces, and lymph nodes, as well as examination for tapeworm and any abnormalities. Pharyngeal swabs were collected using sterile polyester fiber tipped plastic applicator swabs. When the mobile lab was unavailable, biologists and other field personnel conducted tissue collections, which accounted for the majority of those in the Bonner outbreak, but was also used extensively in the other 3 outbreaks. Field personnel were supplied with individual necropsy kits to collect lung, fecal and liver samples, as well as blood and lymph nodes if time permitted. Crews also recorded the date of collection, location, sex and estimated age (in Bonner, ewes older than 4 were classified only as 4+). Each of the necropsy kits was uniquely numbered to maintain sample identification.

Serologic testing was conducted by the Montana Department of Livestock Diagnostic Laboratory in Bozeman, Montana. Pharyngeal swabs were transported in port-a-cul media to Washington Animal Disease Diagnostic Laboratory (WADDL), Pullman, Washington for aerobic and *Mycoplasma* culture. Lung samples were collected and frozen until shipping to WADDL for culture and *M. ovipnuemoniae* testing using PCR techniques. Banked serum from sheep captured in 2007 was submitted to WADDL to test for *M. ovipneumoniae* exposure using a recently developed cELISA. Liver samples were frozen, and a subsample was submitted to South Dakota State University Laboratory for determination of selenium levels. Fecal samples were collected for both lungworm and gastrointestinal parasite evaluation. Analyses of these samples were conducted by Veterinary Parasitology Services, Bozeman, Montana.

Selective culling (East Fork)—On 15 November 2009, hunters reported an injured ram near U.S. Highway 93 four miles north of Sula, Montana. MFWP personnel dispatched the ram and assumed it was injured from a vehicle collision. On 22 November 2009 another group of hunters reported 2 dead rams along U.S. Highway 93 five miles north of Sula. MFWP personnel responded to the scene and collected the carcasses, but these mortalities did not appear to be the result of a vehicle collision. That same day wildlife officials transported the bighorns to the MFWP Wildlife Lab, and the following day Lab officials confirmed the presence of pneumonia.

MFWP staff immediately began to implement the disease outbreak protocol outlined in the Montana Sheep Conservation Strategy (MFWP 2010). We first defined the extent of the outbreak within the East Fork herd and established a geographic area where it appeared that infected sheep occurred. Next, MFWP officials began extensive coordination and communication among field, regional and state wildlife bureau personnel. MFWP personnel developed a field and media response plan and distributed information to local and statewide media outlets. A critical element in communicating with the media sources was to establish a point person to respond to all information requests. As MFWP personnel began to formulate a culling response, we brought local groups of sportsmen and other natural resource agencies into the discussion. This was an important component in building a consensus for a field response to the outbreak and to generate interest in gathering volunteers to assist MFWP staff in field activities.

The 2 most critical components of the culling response were removing all sheep showing clinical symptoms of infection, and obtaining quality tissue and blood samples from those culled sheep. MFWP personnel selectively culled bighorns by using 2 to 3 person teams assigned to specific geographic areas. Teams used various modes of transportation depending on the terrain and access, including stock, motorized, and other non-motorized transportation. Once a team observed a sheep, they determined if it was symptomatic and warranted culling. Clinical symptoms included coughing, shaking head, ears drooping, nasal discharge, stilted gait while walking (goose stepping), walking and suddenly bedding down, bedding down facing a cliff, being solitary, reluctance or inability to move uphill, and grazing an area without any significant movement for an extended period. All teams dispatched sheep using head or neck shots at ranges within 100-yards, unless specific conditions did not allow for such shots; then chest shots at longer distances were permitted. Crews packed out heads of rams that were 2.5 years or older. Carcasses were initially delivered to a mobile lab at the culling site, but sampling transitioned to field collections by biologists, volunteers and lab personnel as the operation progressed.

Sheep exhibiting clinical signs of infection became increasingly difficult to find by mid-December 2009. As a result, MFWP used a helicopter to ferry collection teams to more remote areas that held bighorns and to push sheep uphill as a way of monitoring behavior and increasing the likelihood of discovering sheep in respiratory distress. Several sheep were culled using this method, and during the flights we also observed the carcasses of 6 sheep that were potential pneumonia mortalities. In addition, teams culled 3 adult ewes that appeared healthy to evaluate the effectiveness of the culling, and also to determine if healthy-looking sheep were devoid of infection. Evidence of pneumonia was not apparent during gross field necropsies and lab results confirmed those field observations.

MFWP personnel conducted bi-weekly aerial surveys from late December 2009 through April 2010 to document population trends during the outbreak. These aerial surveys were bolstered by ground surveys during the same time period.

Containment zone culling and selective culling (Bonner)—On 12 January 2010, a local resident in West Riverside reported coughing bighorn sheep in the Bonner herd. MFWP personnel responded within the hour, confirmed there were 5 to 6 potentially sick sheep within a band of 11, dispatched a symptomatic ewe and a male lamb, and transported the carcasses to the MFWP Wildlife Lab. That same evening, the MFWP wildlife veterinarian necropsied the animals and confirmed that the bighorns had pneumonia.

The initial response in West Riverside on 13 January and 14 January 2010 replicated the East Fork selective culling approach. On 14 January 2010, a MFWP wildlife biologist surveyed the Bonner population by helicopter to identify the extent of the outbreak. To prescribe a response strategy specific to the Bonner outbreak, we considered the following factors: 1) the outbreak appeared to be localized, with infected bighorns concentrated just east of Mittower Gulch in West Riverside; 2) the die-off appeared to be in an early stage as the survey revealed symptomatic sheep only in West Riverside, and our first call from the public reported coughing sheep in this extremely visible population on 12 January 2010; 3) due to landscape connectivity within the population and with adjacent populations, the disease could spread quickly from infected bighorns comingling with healthy herd segments, especially since western Montana was experiencing below-average snowfall; 4) access would be challenging because of steep, brushy terrain in the uplands, and many sheep also were residing on numerous, small, private parcels in West Riverside; 5) the Bonner population was highly visible to the public, and any MFWP management actions would be in full view of the public and media; 6.) human safety concerns associated with discharging high-powered rifles in densely developed areas, and 7) the outbreak was occurring during the winter season when bighorn sheep were concentrated on south facing slopes and at lower elevations.

Culling objectives for the Bonner population were 3-fold: to prevent transmission of pneumonia to healthy population segments within the Bonner herd and the nearby Lower Rock Creek population, to dispatch sheep humanely and minimize exposure of animal suffering to the public, and to provide biological samples for diagnosing the disease and pathogens affecting the population. From these objectives, MFWP implemented a more aggressive approach than was applied in the East Fork, and incorporated a combination of culling strategies—containment zone culling and selective culling.

MFWP personnel dispatched all bighorns (both symptomatic and non-symptomatic) within a pre-defined Containment Zone (CZ), and also selectively culled symptomatic sheep outside the CZ.

MFWP personnel defined a CZ as a polygon delineated across a landscape based upon topographical features, known bighorn movements, and flight data of visibly symptomatic sheep. The CZ included the core area containing infected sheep, an outlying area where infected sheep could have comingled with healthy sheep, and about a 1-mile buffer where animals were primarily healthy, but may become infected by any dispersing sheep from the core area. The CZ was a dynamic boundary, defined by field monitoring and altered as necessary to include areas with infected sheep. Outside the CZ, crews observed sheep behavior, and culled those that were symptomatic and any bighorns comingling with them. Crews then reported their findings back to the area wildlife biologist, and if sick sheep were confirmed outside the CZ, the biologist expanded the CZ boundary line. Conversely, if field personnel found only healthy sheep within a segment of the CZ, we readjusted the CZ boundary line accordingly. The overall purpose of the CZ was to contain the pneumonia outbreak to a small portion of the hunting district.

To ensure the public's safety and to decrease the potential for recreationists to displace and disperse bighorns within the CZ, the Lolo National Forest and The Nature Conservancy implemented an emergency resource closure effective 15 January 2010. The closure restricted public use of the CZ and adjacent lands until intensive culling efforts were completed.

The chronology of culling bighorns in the Bonner population occurred as follows: MFWP personnel intensively removed bighorns within the CZ and monitored and dispatched symptomatic sheep outside the CZ for the first 10-days (12 and 22 January 2010); no personnel were on the ground 23 and 24 January to give the sheep a break from the "hunting" pressure; from 25 January through 28 January crews resumed intensive removal of sheep within the CZ, and continued monitoring bighorns on adjacent lands; from 29 January to 5 February, we decreased the number of crews on the ground and the number of days spent in the field; from 6 February – 19 February 2010, we only removed symptomatic sheep from the Bonner population; and from 20 February 2010 onward, MFWP personnel culled sheep only when the public reported seeing an extremely symptomatic animal. During the initial stage of the operation, MFWP personnel delivered carcasses to a mobile lab at the culling site for necropsy and tissue and serum collection by Lab personnel and biologists. As culling activities progressed, MFWP personnel collected tissue and blood samples in the field and then shipped them overnight to the MFWP Wildlife Lab.

Wildlife personnel conducted random ground surveys during March, April and May 2010 to monitor herd health throughout the district, as well as the redistribution and recolonization of bighorns within and adjacent to the CZ. Data collected included the number of sheep observed, classifications, and locations.

Limited culling (URC and LRC)—In early December 2009, a member of the public reported seeing a coughing sheep in the LRC population. MFWP personnel responded on 12 December 2009 and dispatched a ewe, but necropsy results were inconclusive. Other reports followed and on 22 January 2010 MFWP personnel culled a symptomatic ewe and made the first diagnosis of pneumonia in LRC. In the subsequent 10 days, MFWP personnel sampled an additional 9 symptomatic bighorn sheep, all of which were necropsied in the field and showed gross evidence of pneumonia. At that point, we decided to let the disease run its course due to the impracticality and risk associated with culling sheep in extremely steep, snow-covered terrain, as well as hope that spatial segregation of bands would limit the spread of infection. Nonetheless, diagnostic sampling of symptomatic sheep continued, with a total of 19 bighorns collected through 21 February 2010, and another sick ewe was taken on 8 April 2010. Sampling methods in Rock Creek were conducted by MFWP personnel as described for the East Fork and Bonner except the mobile lab was not onsite at any time.

On 29 January 2010 a symptomatic sheep was observed in URC; 3 bighorn were collected the following day and diagnosed with pneumonia. A concerted effort in URC to collect and diagnose sheep resulted in 25 symptomatic bighorn being sampled on 1 day, all of which were necropsied in the field and diagnosed with pneumonia. An aerial survey completed on 8 February 2010 revealed 45% of 174 sheep observed in URC appeared to be symptomatic based on symptoms of respiratory distress. As a result of the high percentage of symptomatic animals, continuous distribution of the herd, and land-owner opposition to culling, the decision was made to let the disease run its course in URC.

Spring Trend Surveys and Lamb Production Monitoring

Post-outbreak population surveys included MFWP's annual, aerial bighorn sheep trend surveys and spring and summer lamb production ground surveys. The MFWP pilot and area biologists conducted trend surveys during optimal observation conditions in a Bell JetRanger helicopter in early spring prior to bighorns moving from their winter ranges. Annual trend surveys provided total, consistent coverage of standardized survey units that incorporated the highest densities of bighorn distribution. Observability varied among habitat types, especially in the Bonner area where bighorns used dense coniferous forests. MFWP has not developed sightability models or indexes for the East Fork, Bonner and Rock Creek populations, but trend data provided information sufficient to determine if population objectives were being met (MFWP 2010).

Biologists conducted spring trend counts on 11 March 2010 in the East Fork, on 23 April 2010 in Bonner, on 23 March 2010 in LRC and on 23 March 2010 in URC. For each of the populations, personnel counted and classified sheep by age class and sex, and rams were classified further as Class I (yearling), II (½ curl to ¾ curl), III (¾ curl to full curl) and IV> (full curl, Geist 1971). The survey units covered core winter/early spring range of each of the populations, including Mittower Gulch east to Wishard Ridge for Bonner, Medicine Tree south and east to Guide-Rye Road for the East Fork, and the entirety of bighorn winter range in LRC and URC from State Highway 38 north to Interstate 90.

To monitor lamb production and potential recruitment into each of the populations, a student conducted ground surveys on foot and by vehicle from May 2010 through August 2010. The student documented and classified the total number of bighorns observed, group sizes and locations, and categorized rams based on horn development. He visually assessed the health of groups by observing sheep, and at times, applying physical stress to the animals. Observations entailed viewing bighorns for 30 to 60 minutes and documenting sheep behavior. Ground herding was conducted to determine whether bighorns would express symptoms of respiratory distress when exerted, and observations of their response were documented.

RESULTS

We observed a reduction of 351 bighorns in annual surveys across the 4 affected populations between 2009 and

2010, a decline of 48.5%. If 2009 data are replaced with more representative surveys from 2008 in Bonner and LRC, then a decline of 55.8%, totaling 470 bighorns was documented in 2010. MFWP culled 236 bighorns, or 50.2-67.2% of the decline indicated by the 2010 and 2008-2009 surveys.

Selective Culling

Culling of 80 bighorns (46 rams, 22 ewes and 12 lambs) accounted for 81.6% of the observed decline in the East Fork population. Fifty-eight percent of the culled animals were rams, and 53% of the rams for which age was estimated were younger than 5.5 years old. Adult ewes 4.5 years or older accounted for 36% of all ewes for which age was estimated. MFWP field crews culled the greatest number of sheep on the 22nd day (8 December 2009) after the initial discovery of the outbreak, with numbers declining thereafter as personnel observed fewer symptomatic sheep (Figure 2). Ground and bi-weekly aerial observations from late December 2009 through April 2010 indicated no major mortality of sheep after culling efforts ceased in early February. Compared with 2009 spring trend surveys, the 2010 East Fork bighorn counts declined by 53%. Ground surveys indicated stable numbers in the East Fork population in the months after the aerial surveys were completed and MFWP personnel did not observe any bighorns with symptoms of pneumonia through August 2010 (except 1 questionable lamb in early August). Ground surveys post-culling documented lamb:100 ewe ratios of 35 (12:34) on 25 May, 62 (21:34) on 15 June, 30 (15:50) on 14 July and 32 (12:37) on 7-8 August 2010.

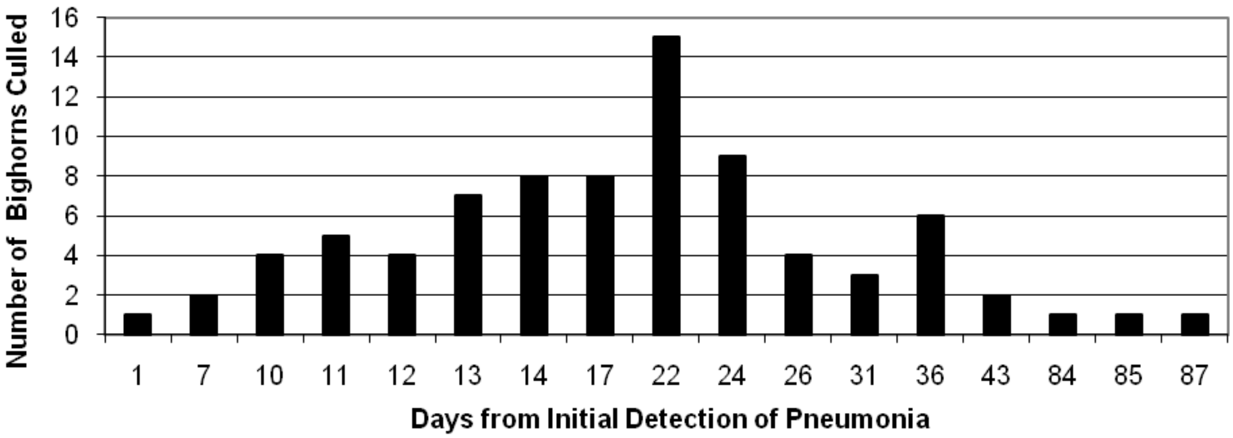

Figure 2. Number of bighorn sheep culled per day from the initial day of detection of pneumonia in the East Fork of the Bitterroot, Montana, winter 2009-2010.

Most sheep necropsied early in the outbreak in East Fork were in good to very good body condition. Typical lesions were severe lung consolidation and fibrinous pleuropneumonia, with the cranioventral aspect of the lung most severely affected.

Most of the East Fork sheep (87.5%) had low titers (1:8 to 1:64) for PI3 and 10% had titers for BRSV (1:8 to 1:32). All sheep were negative on all other serologic tests. Culture results are summarized in Table 1. *M. ovipneumoniae* was detected using PCR techniques in 38/72 (53%) of lung samples from the East Fork. Currently, MFWP Lab personnel are pursuing PCR analysis for detection of *M. haemolytica* in the East Fork lung samples. Preliminary results indicate that *M. haemolytica* may be present in a high proportion of these bighorn sheep lung samples. All but 3 sheep had *Nematodirus* spp. burdens, and 7 of these had high burdens up to 10 times greater than those

Table 1. Aerobic culture results of bacteria isolated from samples collected from bighorn sheep in the East Fork of the Bitterroot, Montana, during the winter 2009-2010 pneumonia outbreak.

Type of Sample	Total Samples	*Pasteurella multocida*	*Mannheimia haemolytica*	*Bibersteinia trehalosi*	*Pastuerella* spp.
Lung	75	41 (55%)	2 (3%)	12 (16%)	0
Swab	37	20 (54%)	5 (13.5%)	26 (70%)	0
Lymph Node	42	26 (62%)	1 (2%)	8 (19%)	1 (2%)
Tonsil	18	7 (39%)	0	15 (83%)	1 (5.5%)

detected in 2007. Sixty-four percent had coccidia (*Eimeria* spp.), and 6 had heavy burdens. Forty percent had lungworm (*Protostrongylus* spp.), nearly all with low burdens. Heavy tapeworm infestation (*Monezia* spp.) was found in several sheep.

All submitted liver samples from the East Fork had liver selenium levels <0.040 ug/g. Normal liver selenium levels have not been established for the bighorn sheep populations involved in these 4 outbreaks. Idaho Department of Fish and Game evaluated liver selenium levels in 8 bighorn populations in Hell's Canyon from 1997-2005. Across populations, liver selenium ranged from 0.03-0.47 ug/g (Cassirer 2005).

A small hobby farm was located near the location of the East Fork outbreak in Sula, Montana. Domestic sheep and goats were among the livestock raised on the property. The owner of the farm allowed MFWP personnel to collect blood samples and pharyngeal swabs from 7 domestic sheep and 2 goats.

One of the 7 domestic sheep had a low titer (1:8) for PI3, but other serologic tests were negative for both domestic sheep and goats. *B. trehalosi* was the most common isolate from pharyngeal swabs of domestic sheep (6/7 or 86% of sheep). *M. haemolytica* was isolated from 3 of the 7 domestic sheep pharyngeal swabs. *Pasteurella* spp. was the only isolate from the pharyngeal swabs of both goats. *M. ovipneumonia* was detected using PCR techniques in 4 of the 7 (57%) pharyngeal swabs from domestic sheep, but not from swabs of goats.

Containment Zone Culling and Selective Culling

MFWP personnel dispatched 99 bighorns and collected 5 additional bighorn that appeared to die of natural causes from the Bonner herd. Of the 104 collected, 64 were ewes, 15 were lambs and 25 were rams. Ages ranged from 0.5 to 9.5 years, with rams younger than 5.5 years accounting for 84% of the total rams collected, and adult ewes 4 years or older accounting for 62% of all ewes for which age was estimated. Most bighorn necropsied early in the outbreak were in good to very good body condition.

The spring trend survey reflected a 68% reduction in the number of bighorns observed in the Bonner Survey Unit, from 94 (53 ewes, 12 lambs, 25 rams) to 30 (15 ewes, 8 lambs, 7 rams). In 2009 there were 47 rams:100 ewes and 23 lambs:100 ewes, but survey results were too low in 2010 to calculate the ratios. Sixty percent of the rams observed in 2009 were ≥ ¾-curl, compared with only 29% in 2010. Culled bighorn rams ≥ ¾-curl accounted for about 36% of all the rams collected.

Serology results from culled bighorns in Bonner revealed that 49% of the sheep had a titer for Anaplasmosis and 8% for Bluetongue. Forty-nine percent had a low titer (1:8 to 1:32) for PI3, and 10% had low titer (1:8 to 1:16) for BRSV. Culture results are summarized in Table 2. *M. ovipneumoniae* was detected by utilizing

Table 2. Aerobic culture results of bacteria isolated from samples collected from bighorn sheep in Bonner, Montana, during the winter 2009-2010 pneumonia outbreak.

Type of Sample	Total Samples	*Pasteurella multocida*	*Mannheimia haemolytica*	*Bibersteinia trehalosi*	*Pastuerella* spp.
Lung	87	2 (2%)	0	11 (13%)	3 (3%)
Swab	5	0	0	5 (100%)	0
Lymph Node	33	1 (3%)	0	4 (12%)	3 (9%)

PCR techniques in 79/87 (91%) of lung samples. Sixty-nine percent of Bonner sheep had low levels of *Nematodirus* spp., while 22% had low burdens of coccidia (*Eimeria* spp.). Seventy-one percent of bighorn sheep from Bonner had lungworm; however, only 2 sheep had high egg counts. Several sheep were infected with both *Protostrongylus spp*. and *Muellerius capillaris*. Liver selenium for sheep from this area ranged from <0.040-0.12 ug/g.

Ground surveys indicated lower, and still declining, numbers in the Bonner bighorns after the aerial surveys were completed, and through August 2010, MFWP personnel continued to observe symptoms of pneumonia in a portion of the population. A ratio of 50 lambs:100 ewes was obtained on 23 June 2010 from 12 bighorns in Bonner, with no documented lamb production outside the CZ. Survival of 2 lambs was documented in August 2010.

Limited Culling

A spring aerial survey of LRC revealed 19 lambs:66 rams:100 ewes with an observed population decline of 43% (201 vs. 114). Diagnostic removal of 19 sheep in LRC (10 ewes, 8 rams, and 1 lamb) accounted for 21.8% of this decline. The average age of bighorns sampled was 4.5 years for both sexes, with the youngest a lamb and the oldest a 6.5-year-old ram. Body condition of bighorns necropsied varied from poor to good. Ground surveys post-culling documented lamb:100 ewe ratios of 29 (4:14) on 11 May, 8 (5:63) on 31 May-2 June, 17 (4:24) on 10 July and 0 (0:29) on 4-6 August 2010. An unverified report from the public of 4 lambs in late August suggested that some lamb survival escaped detection during the previous ground survey.

Sixty-two percent of the sheep sampled from LRC had low titers (1:8 to 1:16) for PI3. Seventy-seven percent had a titer for Anaplasmosis. All other serologic tests were negative. Aerobic culture results are summarized in Table 3. *M. ovipneumoniae* was detected using PCR techniques in 12 of 18 (67%) lung samples, and in 1 of 3 (33%) pharyngeal swabs. Liver selenium for sheep from LRC ranged from 0.0425ug/g-0.132 ug/g, with a mean of 0.080 ug/g. Two (15%) of 13 fecal samples had low burdens of coccidia (*Eimeria* spp.), 9 (69%) had *Nematodirus* spp., and 11 (85%) had lungworm (*Protostrongylus* spp.). Two of the sheep had high lungworm burdens.

During the 2010 aerial survey in URC, the number of observed sheep was 60% less than in 2009, with 136 observed and ratios of 13 lambs:36 rams:100 ewes. Diagnostic collection of 28 bighorns accounted for 13.6% of the total reduction from the 2009 spring aerial survey. Most of the sheep sampled in URC were ewes (19 of 28), but 6 rams and 3 lambs also were taken ges ranged from 0.5 to 8.5 years. Consistent with LRC, summer observations of bighorn lambs declined from a high of 32 lambs:100 ewes to zero (86 bighorns observed in August with no lambs). Ground surveys post-culling documented lamb:100 ewe

Table 3. Aerobic culture results of bacteria isolated from samples collected from bighorn sheep in Lower Rock Creek, Montana, during the winter 2009-2010 pneumonia outbreak.

Type of Sample	Total Samples	*Pasteurella multocida*	*Bibersteinia trehalosi*	*Pastuerella* spp.
Lung	18	12 (67%)	1 (5.5%)	1 (5.5%)
Swab	3	1 (33.33%)	1 (33.33%)	2 (66.6%)
Lymph Node	4	4 (100%)	1 (25%)	0

ratios of 16 (5:32) on 28 May, 32 (21:65) on 20-24 June, and 0 (0:72) on 6-9 August 2010. A local rancher in bighorn habitat reported observing dead lambs over the summer, and MFWP personnel observed symptomatic sheep during ground surveys.

Eighteen of 22 (82%) of URC sheep had low titers (1:8 to 1:32) for PI3. Eight (36%) had low titers (1:16 to 1:64) for BRSV. All other serologic tests were negative. Aerobic culture results are summarized in Table 4. *M. ovipneumoniae* was detected using PCR techniques on all lung samples from URC, and in 14 of 15 (93%) pharyngeal swabs. Liver selenium for sheep from URC ranged from 0.044 ug/g-0.093 ug/g with a mean of 0.0613 ug/g. Fourteen (64%) URC sheep had coccidia (*Eimeria* spp.), 4 of those having heavy burdens. Eighteen (82%) had *Nematodirus* spp., 5 of those having high burdens. Fifteen (68%) of the bighorn had low lungworm burdens.

Table 4. Aerobic culture results of bacteria isolated from samples collected from bighorn sheep in Upper Rock Creek, Montana, during the winter 2009-2010 pneumonia outbreak.

Type of Sample	Total Samples	*Pasteurella multocida*	*Bibersteinia trehalosi*	*Pastuerella* spp.
Lung	29	27 (93.1%)	0	0
Swab	15	14 (93.3%)	5 (33.3%)	1 (6.6%)
Lymph Node	1	1 (100%)	0	0

DISCUSSION

The 2009-10 pneumonia outbreak across western Montana was a dynamic situation, which is continuing and further developing. Results, interpretations and conclusions presented herein are preliminary and not completely informed. However, they reflect our understanding at this time, which we offer for critical review and future reference.

Culling was a management prescription MFWP adopted almost immediately upon first detection and confirmation of pneumonia in the East Fork and thereafter. An essential premise during our culling activities was that pneumonia-stricken bighorn sheep were likely to die from the disease, and in some populations die-offs greater than 90% of the population may occur (MFWP 2010). MFWP benefitted in its decision-making and implementation from having considered and documented the culling strategy shortly in advance of the outbreak, when developing the Montana Bighorn Sheep Conservation Strategy (MFWP 2010). This planning investment was fortuitous and important for sustaining agency commitment and support for the culling effort over the weeks and months when needed.

Local MFWP personnel responded to the first detection of the first outbreak with varying levels of pertinent training and experience. We had the benefit of a wildlife veterinarian on staff and a centralized wildlife research lab, which delivered skills, materials, and expertise to the field within hours of contact. The first diagnoses of pneumonia were made by the wildlife veterinarian personally after sheep carcasses were collected during the day and delivered and necropsied in the lab overnight. These staff and facilities were essential in providing information to guide decisions and to implement field operations until sufficient experience and expertise had been transferred to field staff and managers. We may not have been able to promptly and effectively implement these unscheduled operations without this centralized service, which provided health surveillance and biological sampling skills practiced statewide on a daily basis.

Selective culling sick bighorns appeared to prevent healthy bighorns from contracting pneumonia at multiple geographic scales. Culling was a race to find and intercept each infected bighorn to limit disease transmission to healthy bighorns, with the probability of contact and disease transmission multiplying with increasing numbers of sick animals on the landscape that were possibly interacting with healthy bighorns. In view of that, culling of infected animals may have helped prevent infected bighorns in the East Fork and Bonner populations from coming into contact with neighboring healthy populations in HDs 203, 250 and 261 (Figure 1). Within the infected populations, culling should have reduced the probability that groups of healthy bighorns would be exposed to infected groups by reducing the length of time that symptomatic individuals mingled with non-symptomatic individuals. Within groups, intensive culling, especially in the East Fork, seemed effective in protecting healthy individuals from contact with infected animals, but we cannot be certain that non-symptomatic sheep were not carriers of the pathogen(s).

Determining the extent of the outbreak was critical in developing an effective and successful culling response, but was challenging because infected sheep were not always symptomatic. In the East Fork, the majority of the infected population exhibited discernable symptoms, while those in Bonner appeared more moderately symptomatic. *P. multocida* was commonly isolated from samples from East Fork, LRC, and URC, but rarely from Bonner in 2009-10 (Table 1, 2, 3, and 4). (In 2007, *P. multocida* was not cultured from any pharyngeal swabs in the 3 populations sampled.) We speculate that different pathogens evoke different gradients of symptoms within a population, and that culling strategies and their effectiveness vary depending on the pathogens affecting a population.

Serology of the 4 populations revealed that titers for PI3, BRSV, and Anaplasmosis were common; however titers were consistently low, typically ranging from 1:8 to 1:64. It is not uncommon for a proportion of apparently healthy bighorn sheep to have low titers for these pathogens. The fact that the titers were consistently low suggests there has been some level of previous exposure, but is not indicative of current active infection. Titers do not appear to be higher for bighorn with pneumonia in 2009-10 when compared to visually healthy sheep captured in 2007, including the East Fork population.

*M. ovipneumonia*e was commonly detected using PCR techniques on lung tissue from all populations in 2009-10. All mycoplasma cultures of pharyngeal swabs were negative for sheep captured in 2007 in the East Fork, Bonner and LRC herds. Only the East Fork had any prior evidence of exposure to *M. ovipneumonia* through the testing of banked serum obtained in 2007. Although mycoplasma is extremely difficult to culture, the lack of evidence of exposure on culture or serologic tests suggests that *M. ovipneumoniae* was not present in the Bonner and LRC herds in 2007. Serologic evidence indicates exposure, but not necessarily active infection. The detection of antibodies to *M. ovipneumoniae* in East Fork serum from 2007 suggests that the herd had been exposed to the bacteria; however, no detectable, adverse health effects were observed in the bighorn sheep population prior to December 2009. Although *P. multocida* and *M. ovipneumoniae* were detected during the 2009-10 outbreaks and not cultured from pharyngeal swabs in visually healthy sheep in 2007, we cannot assume that these are the primary agents responsible for the pneumonia outbreaks. Indeed, determining causal pathogens in an epizootic event can be problematic. Recent research has shown that interactions can occur between bacteria and could affect culture results (Dassanayake et al. 2010). These researchers reported that *B. trehalosi* can inhibit growth of *M. haemolytica*, so recovery of *M. haemolytica* from pneumonic lungs by culture could be limited by contact with *B. trehalosi.* This research leads to the question of whether similar interactions occur between other bacterial species.

Our observations that few neonates survived in URC and LRC, and only 2 in Bonner, in the summer following the winter die-off were expected and typical of bighorn die-offs elsewhere (Onderka and Wishart 1984, Coggins and Mathews 1992, Ryder et al. 1994, Aune et al. 1998). Some bighorns ≥ 1-year-old in these populations outwardly exhibited symptoms of pneumonia into August 2010. We speculate that non-symptomatic survivors of the outbreak may have been exposed and carried contagious forms of the causative pathogens, but did not develop fatal infection. As Coggins and Matthews (1992) suggested, maternal ewes appeared to transfer colostral immunity to their lambs, but with a loss of passive immunity over time, neonates developed pneumonia and died shortly afterward. We received reports from the public of numerous dead lambs in URC in summer 2010. The widespread mortality of most lambs in limited culled populations suggests that the pathogens associated with the pneumonia outbreak during the winter persisted in those populations into summer.

Neonates in the East Fork did not exhibit symptoms of pneumonia and they survived into summer at normal rates, which suggests that they did not come into contact with the pathogens associated with the winter pneumonia events. We suggest that the surviving bighorns in the East Fork either did not carry the pathogens that initiated the pneumonia outbreak during the winter or conditions were not conducive for the outbreak to occur, and that culling activities interrupted transmission to these individuals. Although additional testing and monitoring would be required to confirm this, the differing lamb survival rates between the East Fork and Rock Creek populations suggests that the culling effort effectively limited transmission and persistence of pneumonia-causing organisms in that population. We hypothesize that subsequent, annual lamb recruitment in the East Fork population will surpass those of limited cull populations. Unless survival rates should change over the course of the fall, and barring a new introduction of pathogens, we expect the East Fork population to perform as any other healthy bighorn population.

We are hopeful that the benefits of culling in the East Fork will outpace and exceed any disadvantage of having killed symptomatic bighorns that might have survived pneumonia. Bighorn losses were broadly similar across the selective cull, containment zone cull and limited cull populations by March-April 2010. However, adult bighorns in limited cull populations continued dying into August 2010 and produced few surviving lambs, while adults in the East Fork (selective cull) appeared to maintain normal survival rates and normal ratios of surviving lambs. Therefore, under comparable survey conditions we expect annual survey data to show a further measurable decline in March-April 2011 for limited cull populations and a slight increase in the East Fork. To the extent that adult survivorship in subsequent years was reduced by exposure to pneumonia in 2009-10, or that reduced lamb survival persists for 1 or more additional years, we expect population performance in limited cull populations to fall further behind that of the East Fork until the pathogens responsible for lamb mortalities are eliminated from the populations. MFWP personnel will continue to monitor the 4 affected bighorn populations to test these hypotheses.

Aggressive culling in Bonner did not appear to improve survivability of healthy bighorns within the population. Early detection of a pneumonia outbreak is critical to the potential success of culling, and the Bonner outbreak had achieved a greater critical mass of symptomatic bighorns than what MFWP personnel initially identified. Consequently, the CZ was not effective in isolating the outbreak to the West Riverside area. As a result, a higher proportion of the population was culled in Bonner than in the East Fork, and healthy survivors remained at risk of continued contact with symptomatic individuals into the summer. Also, only 2 lambs were observed in Bonner in August 2010.

Nonetheless, culling in Bonner was successful by measures that reflected unique circumstances. Culling allowed MFWP to manage the rate, location and appearance of mortality within and near dense human habitation. We used culling to accelerate the die-off within a defined area of seasonally high bighorn concentrations, with the objectives of removing disease in advance of bighorn immigration and outpacing emigration of infected individuals or groups. Also, accelerating mortality reduced public exposure to the die-off event.

As in Bonner, the pneumonia outbreaks in URC and LRC were already well advanced at the point of first detection. The continuing presence of pneumonia in these populations where limited cull strategies were deployed may be a source of infection for surrounding populations in the future.

Public awareness of pneumonia symptoms in bighorn sheep and the value in reporting them was low when the outbreaks first occurred. Early news reports prompted phone calls from the public about observations made weeks or months earlier, which might have resulted in earlier detections, and even prevention of some outbreaks, had we been notified promptly. Continuing media coverage helped, but fell short of prompting some local residents in bighorn habitat to recognize the importance of reporting their observations. In August 2010, we sent a letter to all bighorn hunting-license holders in western Montana, asking them to watch for and report symptoms immediately to MFWP. Currently, we are seeking other avenues for effectively targeting public awareness and response.

We did not measure public opinion. However, our field operations were not hindered by public opposition and were aided by public support. Numerous private landowners in all 4 study areas allowed MFWP personnel access on or across their properties to dispatch and sample bighorns. One landowner in bighorn habitat voluntarily sold his domestic sheep and goats. A local sportsmen's group publically honored an MFWP biologist with a prestigious award for his work in pioneering the culling effort to save healthy bighorns. Organized groups and members of the general public contributed field assistance. The public respected a closure of public and accessible private land to public recreation within and near the Bonner CZ during culling. Coverage in local newspapers and television was prominent, and we noted letters to editors and internet responses that supported and opposed MFWP's actions. We provided updates and answered questions at regularly scheduled meetings of community groups and others. We do not discount the disappointment, or in few cases, outrage that we had encountered, but generally we worked in an environment of informed public consent, if not support.

We have not demonstrated or dismissed a cause-and-effect relationship between domestic sheep and bighorns during the 2009-10 events. Although recent tests revealed that East Fork bighorns tested seropositive for exposure to *M. ovipneumoniae* in 2007, we cannot conclude they were the source of the bacterium since MFWP personnel did not collect samples in 2007 from the domestic sheep and goats. However, after the 2009-2010 die-off occurred in the East Fork, MFWP personnel received reports of probable comingling occurring between bighorns and domestic sheep and goats over the last several years. In 2009, *M. ovipneumonia*e was commonly detected utilizing PCR techniques on lung tissue from the East Fork population, as well as in pharyngeal swabs from 4 of 7 domestic sheep near the East Fork. Further genetic analysis of the 2009 samples would be required to determine the relatedness of the bacterium identified in both wild and domestic sheep. Tests from samples collected from all 4 bighorn populations for *M. haemolytica* and leukotoxin are pending.

In retrospect, the 2009-10 die-off in western Montana bighorns was instructive not only in its occurrence, but also in its timing of occurrence. For 3 decades preceding the 2009-10 pneumonia outbreaks, 3 of the 4 affected bighorn populations existed in environments that variably included domestic sheep, goats and other pets and livestock, and occasional comingling of bighorns with domestics was reported or suspected. Yet pneumonia, if it occurred, had minor and undetectable effects on these 4 bighorn populations prior to 2009. To date, we are unaware of any particular or substantive change in bighorns or their environment to explain the timing of the pneumonia outbreaks.

We suggest that a point source (or sources) of disease best explains the original coincidence of disease presence, exposure, contraction, and infection in a susceptible bighorn or bighorns, and that our working hypothesis that 2 or more of the outbreaks were related is correct. Similar microorganisms were identified in diseased East Fork and URC and LRC bighorns, which suggests the possibility of a common source for these 3 outbreaks. *P. multocida* rarely was detected from the Bonner samples, suggesting the possibility of a separate source of infection there (Table 2). Inability to isolate an organism by culture is either due to absence of that organism or to problems with sample collection, handling, storage, or culture technique. Tissue collection and handling protocols were very similar among the culling areas and often carried out by the same individuals. It is our contention that any differences that may have existed in sampling protocols do not account for observed differences in *P. multocida* detected between Bonner and other herds. Coincidentally, MFWP received post-hoc reports of bighorns comingling with domestic sheep prior to the Bonner and East Fork outbreaks, but not in URC and LRC. Transmission by bighorns dispersing from the East Fork to URC or LRC seemed unlikely without infecting Skalkaho bighorns along the way; however, rutting behavior could explain such unexpected long-distance movements. Following the initial infection, subsequent transmissions from bighorn to bighorn appeared to occur easily across a variety of habitat conditions and involved bighorns of all ages, body conditions, and parasite loads.

Alternatively, evidence also supports a common source for the Bonner, LRC and URC outbreaks. *M. ovipneumoniae* was detected in all 4 populations and was not found in cultures of previous samples from the same populations, although the detection of *M. ovipneumoniae* antibodies in the East Fork cELISA suggests the bacteria was present in this bighorn population as early as 2007. Other bacteria found in sick bighorns were also present in previous samples from their respective populations. If *M. ovipneumoniae* represented a critical commonality across the 4 affected populations, then the absence of *P. multocida* in the Bonner samples may not indicate a source of infection dissimilar from LRC or URC. This reasoning opens the possibility that the Bonner, LRC and URC die-offs may have been initiated from a common source and spread across these readily connected bighorn populations. Under this hypothesis, the East Fork outbreak could have been a separate event and would be consistent with the lack of pneumonia evidenced in the Skalkaho population in 2010. East Fork bighorns have a history of connection with Skalkaho, and likely would have mixed with Skalkaho bighorns had they dispersed to URC (Figure 1).

Population density has been referenced as a possible contributing factor in predisposing bighorn to pneumonia epizootics (Aune et al. 1998). Three of the 4 affected populations were at or near historic high population levels prior to the outbreaks. However, density dependent stress that would predispose bighorns to infection was not widespread or apparent in lamb recruitment ratios or body condition of culled or sampled bighorns overall. We acknowledge that density may increase emigration rates, which could increase the risk of disease transmission between populations or geographic units within populations. More significant in this study were the extreme within-group densities in affected populations. MFWP personnel observed or received reports of aggregations of over 200 bighorns in URC, over 100 in LRC, and 98 in Bonner in fall 2009. The large group in LRC had gathered around salt blocks placed for horses, and the aggregation in Bonner was within a densely populated residential area. These high within-group densities could greatly increase the rate of disease transmission between bighorns and across populations, and such densities likely played a role in the timing and rapid spread of the 2009-2010 outbreaks. Whether a reduction in population size would result in a reduction in maximum group size is speculative.

MANAGEMENT IMPLICATIONS

Although there can be benefits of maintaining metapopulations, the die-offs in western Montana demonstrated the disadvantage of a connected metapopulation of bighorns should a highly contagious pathogen be introduced. Although each affected population was separated from the others by unsuitable habitat or a gap in bighorn occupancy, the die-off across populations highlighted their seasonal or occasional connectivity. The die-offs redefined our concept of population connectedness to include the immigration or emigration of single individuals between populations, whether or not resulting in genetic interchange. Therefore, the occurrence of domestic sheep and goats or any other possible sources of contagious pathogens in bighorn range or along dispersal routes should be treated as a potential source of infection to the metapopulation as a whole. By this definition and with these current awarenesses, at least 3 of the 4 infected populations in western Montana were connected and should have been managed accordingly.

Full implementation of bighorn management by metapopulation in western Montana would differ from past practices. Avoidance of initial bighorn translocations into questionable anthropogenic environments is the best management alternative; however, in areas where bighorns currently reside or disperse, MFWP should use these case histories to open a dialogue with local landowners and communities to effectively identify and manage anthropogenic risk factors to the health and perpetuation of bighorn sheep populations. Because of the extent of human habitation and domestic sheep and goats within and adjacent to the infected populations, MFWP should manage each of the 4 populations within stringent population objectives with the intent to reduce emigration to connected herds, and bighorn translocations should be considered as a possible alternative to connectedness to maintain genetic diversity.

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Investigation of Nevada's 2009-2010 East Humboldt Range and Ruby Mountain Bighorn Dieoff

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Abstract: Coughing Rocky Mountain bighorn sheep were first reported by sportsmen the second week in December 2009 in the Ruby Mountains. In late December sportsmen again reported coughing and ill bighorn sheep but this time in the adjacent East Humboldt Range approximately 30 miles from the Ruby Mountains core bighorn area. Rut-related ram movement between these 2 ranges mostly likely occurs. Nevada Department of Wildlife (NDOW) quickly confirmed that bacterial pneumonia was present in the bighorn herds in both mountain ranges. The NDOW veterinarian and biologists developed an investigative and surveillance plan to learn the extent of the disease event, and administer an antibiotic treatment to a subgroup of animals. Objectives of the plan were to 1) compare and contrast bighorn sub-herds at different sites within the 2 mountain ranges with animals evaluated for respiratory pathogens and nutritional status (forage quality and trace mineral levels); 2) measure the benefit and effectiveness of the antibiotic Draxxin administered to bighorn sheep as measured by survival, lamb recruitment, body condition, residual lung pathology, and detected pathogens in collared and treated animals vs collared and untreated animals.; and 3) compare and contrast forage, soil, and blood and/or liver selenium levels; pathogen profiles; spring/early summer 2009 precipitation amounts; and forage quality measures among the East Humboldt Range and Ruby Mountain bighorn herds and other bighorn herds in Nevada that were captured in January 2010. During several ground capture events, 31 bighorn were tranquilized and marked between the 2 mountain ranges; (5 with eartags only; 14 in East Humboldts and 12 in Ruby Mountains with radio collars). All 31 animals were administered Banamine (anti-inflammatory) and Vitamin E, with 19 of these treated with the antibiotic Draxxin. An additional 46 bighorn sheep were free-darted with Draxxin. As of late April 2010, 11 radiomarked animals treated with Draxxin have died. All 31 live animals captured tested PCR+ on nasal swabs for *Mycoplasma ovipneumoniae*. *Bibersteinia trehalosi* has been cultured from the majority of the pharyngeal and lung samples with *Mannheimia haemolytica* & *Pasteurella multocida* being cultured at a much lower percentage. As of April 30, a total of 103 bighorn have been found dead in the East Humboldts (summer 2009 population estimate of 180) and 34 in the Ruby Mountains (summer 2009 population estimate of 160). An aerial netgun crew on March 16 attempted to locate and sample a small isolated bighorn group that was apparently unaffected by the disease in the East Humboldts. The crew was only able to locate 1 bighorn sheep. In addition, 3 mountain goats wintering in the same area were captured, sampled, and collared to discern what pathogens they were harboring. There were also 3 bighorn ewes on a distant mountain range that were captured and sampled for pathogen testing that were part of the translocation group (still eartagged) from the East Humboldts in January 2006. All 3 mountain goats and 3 bighorn sheep were PCR+ on nasal swabs for *M. ovipneumoniae.* Vegetation and soil samples have been collected from bighorn winter use areas on various mountain ranges identified in the investigation. Monitoring will occur of surviving ewes this summer to discern lamb birth and follow through until mortality or weaning.

Information was gathered on potential interaction with domestic livestock. No active domestic sheep grazing allotments are present in the East Humboldt's. Hobby flocks have always existed on private lands at the base of the range. Domestic sheep were used on private land adjacent to the USFS boundary the past 2 summers for fuels management with reports from sportsmen, bighorn tagholders, and permittees that domestic sheep were observed beyond the private land boundary in known summer bighorn use areas in late summer 2009. Approximately 2,000 meat goats grazed the southern end of the East Humboldt's on high elevation private lands in 2006, straying was documented, and known contact with at least a single bighorn ram occurred in 2007 (ram euthanized and full necropsy performed). Approximately 19 cattle died in the East Humboldt's in early summer 2009 from pneumonia (confirmed in 1 animal) in proximity to a water tank in the core of the die-off area where rams were observed using this water tank with dead cattle around it.

Within the Ruby Mountains, an active domestic sheep summer grazing allotment has existed since before the first reintroduction of bighorn sheep in 1989. A previous die-off occurred in 1995-1996 where approximately 70-80% mortality occurred.

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Status of Goslin Unit Bighorn Sheep Pneumonia Outbreak in Utah

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Abstract: During the month of January 2010 The Utah Division Of Wildlife (UDWR) found a dead male Rocky Mountain bighorn sheep (*Ovis Canadensis canadensis*) in the Goslin bighorn sheep herd near Flaming Gorge. A field necropsy found evidence of chronic pneumonia. After closer observation we determined that other animals were affected. In February 2010, bighorn sheep exhibiting signs of coughing and lethargy were euthanized by UDWR employees and biological specimens from 16 animals of varying ages were collected. Samples included the cranial and caudal lobes from both lungs, a section of liver, 40mL of blood, and oropharyngeal swabs. We hand delivered samples to the Utah Veterinary Diagnostic Laboratory in Logan, Utah and forwarded some to the Washington Animal Disease Diagnostic Laboratory in Pullman, Washington. Cultural isolates from lung tissue included *Pastuerella multocida* in large numbers from 14 of 16 lung samples. *Arcanobacterium pyogenes* was also isolated in addition to *P. multocida* in 5 of 13 animals. In lung tissue from one animal the only isolates were *Moraxella* spp. in conjunction with *Arcanobacterium pyogenes*. Isolates in lung tissue from one animal contained a Beta-hemolytic strain of *Pasteurella trehalosi* in conjunction with *Arcanobacterium pyogenes* and in one specimen *Arcanobacterium pyogenes* was the only isolate. Lungworm species were not detected through Baermann testing however they were detected histologically in 12 of the 16 animals. Most species were likely *Protostrongylus stilesi,* although, a *Dictyocaulus spp* was detected in one sheep. *Mycoplasma ovipneumonia* was isolated from 8 of 10 lung samples using PCR and was not found in any of the samples through culture. Mineral analysis of the liver samples revealed that most concentrations were within normal levels for Rocky Mountain bighorn sheep. However, 10 of 16 samples had less than normal copper content (normal = 25 to 100 ppm) and 9 of these had suggestive increases in molybdenum. Two additional animals had molybdenum contents at the very high end of normal for other ruminants. Thirteen of 16 samples had low liver selenium content and 8 of these had increased liver zinc. Of unusual note, two of the liver samples also had increased manganese content. In an effort to control the bronchopneumonia outbreak and prevent the bacteria from spreading to larger neighboring bighorn sheep herds, an effort was made to eliminate the entire herd. A total of 51 sheep were culled by UDWR and Wildlife Services employees and it is unknown how many sheep succumbed to the disease.

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Pneumonia in Bighorn Sheep, Lower Gros Ventre Drainage, Wyoming, March 2010

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Abstract**:** In late February/early March 2010, Wyoming Game and Fish Department personnel observed 4–5 bighorn sheep exhibiting signs of pneumonia (i.e., extended coughing, nasal discharge) in a small sub-herd of 50-60 bighorns, on the Lower Gros Ventre River drainage northeast of Jackson Hole. Two ram lambs were euthanized and necropsied on March 9 and 10, 2010. On examination, both animals had 12-20% consolidation in the lower lobes of their lungs, but otherwise appeared to be in good health, with good to moderate body fat deposition. Additional post-mortem examination and diagnostic lab analyses confirmed bronchopneumonia, with *Bibersteinia trehalosi* cultured, and the first instance of *Mycoplasma ovipneumoniae* (via PCR, @ WADDL) documented in a Wyoming bighorn sheep. Subsequent ground monitoring has not indicated additional bighorn mortality in this sub-herd.

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Mycoplasma ovipneumoniae Can Predispose Bighorn Sheep to Fatal *Mannheimia haemolytica* Pneumonia

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Abstract: *Mycoplasma ovipneumoniae* has been isolated from the lungs of pneumonic bighorn sheep (BHS). However experimental reproduction of fatal pneumonia in BHS with *M. ovipneumoniae* was not successful. Therefore the specific role, if any, of *M. ovipneumoniae* in BHS pneumonia is unclear. The objective of this study was to determine whether *M. ovipneumoniae* alone causes fatal pneumonia in BHS, or predisposes them to fatal *Mannheimia haemolytica* infections. We chose *M. haemolytica* for this study because of its isolation from pneumonic BHS, and its consistent ability to cause fatal pneumonia under experimental conditions. Since *in vitro* culture could attenuate virulence of *M. ovipneumoniae*, we used ceftiofur-treated lung homogenates from pneumonic BHS lambs or nasopharyngeal washings from infected domestic sheep (DS) as the source of *M. ovipneumoniae.* Two adult BHS were inoculated intranasally with lung homogenates while two others received nasopharyngeal washings from DS. All BHS developed clinical signs of respiratory infection but only one BHS died. The dead BHS had carried leukotoxin-positive *M. haemolytica* from the onset of this study,

but did not exhibit signs of respiratory infection until after M. ovipneumoniae challenge. The remaining three BHS developed pneumonia and died one to five days following intranasal inoculation with *M. haemolytica*. On necropsy, lungs of all four BHS showed lesions characteristic of bronchopneumonia. *M. haemolytica* and *M. ovipneumoniae* were isolated from the lungs. These results suggest that *M. ovipneumoniae* alone may not cause fatal pneumonia in BHS, but can predispose them to fatal pneumonia caused by *M. haemolytica* infection.

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Mycoplasma ovipneumoniae **as a Primary Agent of Epidemic Respiratory Disease in Bighorn Sheep (*Ovis canadensis*) Commingled with Domestic Sheep (*Ovis aries*)**

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Abstract: Bighorn sheep are threatened by outbreaks of severe respiratory disease, some of which is associated with domestic sheep contact in the wild. This has been reproduced in captivity: cumulatively, 98% of 90 bighorn sheep experimentally commingled with domestic sheep died within 100 days, whereas 91% of 43 bighorn sheep commingled with other domestic animals survived. Our hypothesis is that *M. ovipneumoniae* is a primary initiating pathogen of epidemic respiratory disease in bighorn sheep. We commingled 4 bighorn with 4 domestic sheep that all tested negative for *M. ovipneumoniae*. One bighorn sheep died of acute pneumonia 90 days later but the other 3 remained healthy for >100 days ($P < 0.005$ vs previous commingling experiments). All domestic sheep remained healthy. *Mannheimia haemolytica* was isolated from the lungs of the dead bighorn sheep. We infected one of the domestic sheep with *M. ovipneumoniae* and penned it with one surviving bighorn sheep. The bighorn sheep subsequently began shedding *M. ovipneumoniae* and developed respiratory disease, while the domestic sheep remained healthy. Shortly after the onset of coughing in the first bighorn sheep, *M. ovipneumoniae* was naturally transmitted to the other 2 bighorn sheep located in pens 7 and 12 m distant. These animals developed respiratory disease, while their domestic sheep pen-mates, which also acquired *M. ovipneumoniae* infections, remained asymptomatic. The bighorn sheep were euthanized and necropsies revealed moderate to severe pneumonia, purulent otitis, and sinusitis. Bacterial lung cultures yielded *Bibersteinia* (*Pasteurella*) *trehalosi* and positive PCR tests for *M. ovipneumoniae* were obtained from lungs, sinuses, and middle ears. Histologically, the lung lesions were typical of those reported for mycoplasmal pneumonia in other host species. These results support the hypothesized role of *M. ovipneumoniae* in bighorn sheep respiratory disease outbreaks.

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Transmission of *Mannheimia haemolytica* from Domestic Sheep (*Ovis aries*) to Bighorn Sheep (*Ovis canadensis*): Unequivocal Demonstration with Green Fluorescent Protein-tagged Organisms

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Abstract: Previous studies have demonstrated that bighorn sheep (BHS) die of pneumonia when commingled with domestic sheep (DS). However, these studies did not conclusively prove the transmission of pathogens from DS to BHS. The objective of this study was to determine unambiguously whether *Mannheimia haemolytica*, an important respiratory pathogen of BHS, is transmitted from DS to BHS when they commingle. *M. haemolytica* was obtained from the pharynx of four DS and tagged with a plasmid carrying the genes for green fluorescent protein (*gfp*) and beta-lactamase (*bla)*. Four DS colonized with the tagged bacteria were kept 30 ft apart from four BHS for one month. No symptoms of respiratory disease were observed during this period. The DS and BHS were then allowed to have fence line contact for two months. During this period three BHS contracted the tagged bacteria from the DS. At the end of two months the animals were allowed to commingle. One BHS died on day two, two died on day five, and the fourth one was euthanized on day nine following commingling. Lungs from all four BHS showed gross- and histo-pathological lesions characteristic of *M. haemolytica* pneumonia. *M. haemolytica* isolated from all four BHS were confirmed to be the tagged bacteria from the DS by their growth in ampicillin-containing growth medium, PCR-amplification of genes encoding GFP and Bla, and immunofluorescent staining of GFP. These results unequivocally prove transmission of *M. haemolytica* from DS to BHS which results in pneumonia and death of BHS.

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Snowshoe Hare Abundance Affects Survival of Dall's Sheep Lambs in Alaska

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Abstract: We estimated annual survival of Dall's sheep (*Ovis dalli*) lambs in the central Alaska Range during the peak and subsequent decline of a cyclic snowshoe hare (*Lepus americanus*) population to test whether changes in abundance of hares affect Dall's sheep either negatively by subsidizing predators (apparent competition), or positively by diverting predation (apparent commensalism). The main predators of lambs were coyotes (*Canis latrans*) and golden eagles (*Aquila chrysaetos)*, which rely on hares as their primary food but utilize lambs as an alternate prey. These predators were implicated in 78% of 65 deaths of radiocollared lambs for which cause of death was identified. Annual survival of lambs ranged from 0.15–0.63, and lamb survival was negatively related to hare abundance during the previous year, supporting the hypothesis of predator-mediated apparent competition between hares and sheep. However, because coyote and eagle predation affected lambs but not adult sheep, we observed a positive relationship between abundance of adult sheep and hares. Thus, support for different indirect effects can be obtained from differing types of data, demonstrating the need to determine the mechanisms that create indirect interactions. Long-term survey data suggest that predation by coyotes is limiting this sheep population below levels typical when coyotes were rare or absent. However, periods of reduced predation during years of low hare abundance appear sufficient to prevent a continuing decline in sheep abundance.

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Dall's Sheep Productivity and Survival in the Chugach Range, GMU 13D, Alaska

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Abstract: Dall's sheep populations in parts of southcentral Alaska have declined markedly over the last 20–30 years. This study was designed to 1) obtain baseline demographic information on one of these populations, and to 2) attempt to identify the cause(s) of these declines. Here, I report preliminary results from the first 14 months of study. Thirty-seven adult ewes were captured by helicopter netgunning and radiocollared in March and April 2009. At initial capture, blood samples and nasal and pharyngeal swabs were collected, and body condition assessed. Blood samples were analyzed to determine pregnancy status and the presence of viral diseases. Swabs were cultured for bacteria associated with respiratory disease. Pregnant ewes were monitored daily through May and June of 2009 to determine parturition date, and 25 neonates were captured, weighed, and radiocollared. Eighteen of 25 neonate lambs were female. Adults and lambs were then tracked throughout the year to determine rates and causes of mortality for both groups. Preliminary results from the first year of research show 65% of ewes were pregnant, and 86% of those pregnant gave birth to viable lambs. Survival to April 1, 2010, was 89% for ewes and 52% for lambs. Avalanches, wolverine predation, and an unknown cause accounted for deaths of adult sheep. Twenty percent of lamb deaths were caused by predators, including eagles, brown bears, and an unknown predator, while 24% died from avalanche, disease, malnutrition, or accident. Serum from 34 ewes was tested for viral diseases including PI-3, MCF, BVD, OPP, IBR, BRSV, and bluetongue, but no sheep exhibited positive titers to any of these agents. Nasal and pharyngeal swabs from 36 ewes were cultured for bacteria associated with respiratory disease. *Mannheimia hemolytica* was cultured from 9 of 36 samples, and *Pasturella trehalosi* from 7 of 36 samples. Other variants of *Pasturella* were cultured from an additional 12 of 36 samples. Work is ongoing to determine pathogenicity of *Mannheimia* and *Pasturella* cultures. Thirty-three of the initial cohort of 37 ewes survived to March 2010, and 30 of 33 were recaptured in March of 2010. Eighty-eight percent of ewes were pregnant in the second year of study.

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Use of Highway Corridors by Stone's Sheep Ewes

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Abstract: Although the Sulphur/8 Mile (S8M) Stone's Sheep Project study area in northern British Columbia is largely unroaded backcountry, it includes a portion of the Alaska Highway, a major transportation route with traffic volumes estimated at 1,200–1,300 vehicles per day. Stone's sheep (*Ovis dalli stonei*) are commonly observed on the highway and mortality due to vehicles has been recorded. The full impact of highway-related mortalities on Stone's sheep demographics is unknown but likely underestimated. Wild sheep using highway corridors may be more vulnerable to vehicle collisions than other large mammals because of their gregarious nature, strong affinity for salts, and apparent reluctance to leave licking sites even in the presence of vehicles or other disturbance. Further, vehicle collisions with wild sheep are less likely to be reported than those with larger mammals because they often cause little or no vehicle damage and therefore do not result in insurance claims. To better understand risk of Stone's sheep mortality associated with use of highway corridors and identify opportunities for mitigation, we used GPS radiocollar data from Stone's sheep ewes monitored between 2005 and 2009 to determine location, frequency, timing and duration of highway use. We also analyzed movement patterns between seasonal ranges and highway corridors to identify patterns of highway use versus highway crossings. Remote cameras established in 2009 were used to estimate frequency of Stone' sheep occurrence at one common crossing point on the Alaska Highway. Data obtained from the BC Ministry of Transportation and the Insurance Corporation of BC were used to identify frequency and timing of reported vehicle collisions with wild sheep. These data are intended to inform management plans to reduce highway-related mortality of Stone's sheep.

KEY WORDS Stone's sheep, British Columbia, seasonal movements, highway corridors, mortality, management strategies, *Ovis dalli stonei.*

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Using Distance Sampling to Estimate Dall's Sheep Abundance in Gates of the Arctic National Park and Preserve, Alaska

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Abstract: Historically, management of Dall's sheep populations in Alaska has depended on minimum count surveys for population assessment. Sheep movement and differences in survey coverage between years can result in highly variable counts, making trend analysis difficult. Additionally, these techniques can require an input of time and money that may be unrealistically high, especially when estimates for large areas, such as national parks, are necessary. Dall's sheep were selected by the National Park Service Arctic Network as an important species for long-term monitoring in Gates of the Arctic National Park and Preserve (GAAR), Noatak National Preserve and Kobuk Valley National Park. The sheer size of this region precludes minimum counts as an effective tool to monitor park-wide abundance. In 2009, we tested distance sampling as an alternative approach for estimating sheep abundance within GAAR. A set of 20km transects (n=316) was generated systematically throughout all potential sheep habitat in GAAR (27,934 km^2). We fit Bayesian models to the survey data using WinBUGS, resulting in an abundance estimate of 8,564 (95% CI: 6,586 to 11,130) sheep in GAAR in 2009. This is the most viable park-wide estimate of Dall's sheep abundance for GAAR since the early 1980's, and we intend to refine methods in 2010 to improve survey efficiency and precision of estimates. Our preliminary findings suggest that distance sampling is a practical and efficient alternative to minimum counts for monitoring Dall's sheep populations and can provide precise estimates of abundance over large areas.

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Evaluating Survival and Home Range Use of Dall's Sheep in Lake Clark National Park and Preserve, Alaska

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***Abstract*:** In Lake Clark National Park and Preserve (LACL), Dall's sheep (*Ovis dalli dalli*) reach the southwest extent of their current geographical range. Sheep are an important resource in LACL, providing excellent opportunities for wildlife viewing by visitors and hunting by sportsmen and local residents. Sheep have been monitored in LACL by aerial surveys, providing estimates of population size and density. Estimates have shown dramatic fluctuations among years and regions in both metrics. To better understand the factors contributing to population variability, a study was initiated to determine survival rates and identify range use patterns of sheep throughout LACL. Between 2005 and 2007, 26 ewes and 14 rams were captured using net gun and fitted with GPS radio-collars. Fourteen of 40 sheep died during the study. Annual survival of ewes ($\geq$2 years of age) was 0.77$\pm$0.09 and 0.85$\pm$0.08 for 2005-06 and 2006-07, respectively. Survival of rams was 0.75$\pm$0.13 in 2005-06 and 0.82$\pm$0.12 in 2006-07. Survival was not significantly different between sexes or years. Mortalities occurred during 5 months of the year, with April and May accounting for 64% of all mortalities. Eleven of the 14 mortalities occurred within the segment of the population nearest the geographical boundary of sheep range. Home ranges of sheep (surviving $\geq$ 6 months) averaged 133.4$\pm$16.0 km^2 (MCP-Minimum Convex Polygon) in LACL. Ram home ranges (156.5$\pm$17.5 km^2) were larger than ewes (121.3$\pm$22.5 km^2), but were not significantly different. The subpopulation of sheep near the geographical boundary had significantly smaller (*P=0.045*) home ranges (90.7$\pm$14.7 km^2) than sheep from the central region (168.1$\pm$23.5 km^2). Smaller home ranges and increased mortality may be indicators of habitat limitations for Dall's sheep on the periphery of their range.

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WAFWA Wild Sheep Herd Health Monitoring Recommendations

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***Abstract*:** Bighorn sheep (*Ovis canadensis*) populations throughout western North America have suffered historic or recent declines. Mortality events in many bighorn populations were associated with recurrent outbreaks of pneumonia and occasionally other diseases. Periodic disease outbreaks in bighorn populations can contribute to instability and potentially to local extinction. Although apparently spared from disease outbreaks thus far, thinhorn sheep (*O. dalli*) are susceptible to respiratory and other pathogens that cause epidemics in bighorns, and their populations would be harmed by disease introductions. Consequently, preventing epidemics and minimizing their severity or impacts are universal management goals for North American wild sheep species. The paper outlines principles, guidelines and minimum recommendations for key elements of wild sheep herd health monitoring and management that can be practically applied across herds and jurisdictions. The intent is not to prescribe a comprehensive set of actions or activities for all agencies or for use in all management situations, but to provide guidance in assessing and monitoring herd health as an essential element of wild sheep management in North America.

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Diagnosis of *Mycoplasma ovipneumoniae* in Bighorn Sheep

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Abstract: Respiratory disease continues to cause very significant morbidity and mortality in wild populations of Bighorn sheep (*Ovis canadensis*). Although fatal pneumonia is typically associated with various species of *Pasteurella*, *Bibersteinia*, and *Mannheimia*, the role of these agents in the initiation and/or the spread of disease is unclear. Epidemiologic data implicate domestic sheep (*Ovis aries*) as the direct or indirect source of the contagious component of Bighorn sheep pneumonia. Recent studies have strongly correlated *Mycoplasma ovipneumoniae*, an organism endemic in domestic sheep, with respiratory disease outbreaks in Bighorn sheep. An obstacle to testing the hypothesis that *M. ovipneumoniae* is a primary pathogen of epidemic bighorn respiratory disease is the difficulty in accurately detecting this organism and differentiating it from other mycoplasmas. This presentation will review the optimal sampling, laboratory testing, and strain typing methods for detecting *M. ovipneumoniae*.

Mycoplasmas are bacteria that are common commensals of the mucous membranes of most vertebrates. While most are non-pathogenic, others can be primary or opportunistic pathogens and cause significant diseases. Multiple mycoplasma species are often present in an animal, requiring that any mycoplasma isolates be accurately speciated. Mycoplasmas differ from other bacteria in that they lack cell walls, and are thus sensitive to desiccation and osmotic changes and do not persist well outside of their hosts. They are also very small with limited genetic coding potential and metabolic capabilities, and thus require a large number of nutrients be provided from their environment. These physical and biochemical properties of mycoplasmas mean that special care is needed to maintain optimal viability during transport the laboratory, and that once in the laboratory mycoplasmas are highly fastidious, slow and often very difficult to grow, and exhibit limited biochemical reactivity that can be used to identify/speciate them.

For the detection of *M. ovipneumoniae*, in live sheep nasal swabs are more rewarding than oropharyngeal swab samples (both can be collected and pooled as one sample). In clinically affected sheep at necropsy, tissue samples or exudates from sites with lesions, including the lungs, middle ear canals, and paranasal sinuses are preferable. Although swabs can be used, tissues or exudates (several grams or milliliters, respectively) are preferable from necropsied animals. Swabs made of wood and/or cotton should be avoided as these can be inhibitory to mycoplasma. In our experience, the ideal transport media appears to be one of the growth broths normally used for mycoplasma culture. Alternatively, transport systems specifically formulated for mycoplasma can be used. The least desirable, although these often work, are the standard bacterial transport systems used for detection of *Pasteurella*. In all cases, samples should be kept cool and shipped to laboratory as soon as possible – optimally, by the next day.

M. ovipneumoniae is particularly challenging to isolate and identify in the laboratory. While *M. ovipneumoniae* will grow relatively well in a number of mycoplasma growth broths, they often do not grow on agars of the same formulations. This has created a problem since the typical indicator of a culture being designated positive or negative is visible growth on the agar plate – thus, this procedure will give a high percentage of false negatives. For this reason, WADDL is now detecting growth of *M. ovipneumoniae* by performing PCR on the broth cultures. This method is giving much more consistent results. At this time, PCR for *M. ovipneumoniae* done directly on clinical samples (i.e. without initial broth culture amplification) has not been validated and is not offered by WADDL. Another consideration when interpreting *M. ovipneumoniae* culture results is there often are multiple mycoplasma species present in the sample and that grow in the broth, but only the non-*M. ovipneumoniae* isolates grow on the agar plates. In our experience with domestic and Bighorn sheep, the most common such mycoplasma is *Mycoplasma arginini*. Thus, isolates from agar plates, for example to be used to bank isolates or for other studies, need to be re-isolated and verified as *M. ovipneumoniae*.

Serologic testing for antibodies to *M. ovipneumoniae* can also be used to detect infections based upon host response to infection. Serological testing has advantages over agent detection by PCR in that chronic, previous infection status can be identified even in the absence of active shedding of bacteria. A disadvantage of serologic detection of *M. ovipneumoniae* is that an antibody response may take 7-10 days after infection to be at a high enough level to detect and early infections can be missed. Several antibody tests have been developed by WADDL, including an Indirect Hemagglutination Test (IHA) and a Competitive ELISA (cELISA). The IHA test used initially has now been discontinued due to difficulties with test standardization and performance. Although the IHA appeared to give accurate results for negative and high-titer positive tests, there was less accuracy with low titer positive test results. The IHA test was replaced with the cELISA in the Spring of 2010. Development and initial validation of the new *M. ovipneumoniae* cELISA is now complete, and appears to be much more reliable. Despite the improved methods for detecting *M. ovipneumoniae* antibody, it is still very important to realize that the current antibody testing is validated only for detecting infection in herds, not individual animals. For example, antibody testing should not be used to assess the status of individual animals, and the status of a herd should be interpreted with caution if it only contains a single positive animal.

Strain typing of *M. ovipneumoniae* isolates from Bighorn sheep is possible and can potentially provide important epidemiologic information about the origins and transmission dynamics within and between animals. A number of molecular methods have been used for typing isolates from domestic sheep, and can successfully discriminate isolates from different origins and within affected flocks of sheep. These same methods can also likely be used for Bighorn sheep isolates and provide important epidemiologic information about the origins and transmission dynamics within and between animals. The method currently being evaluated by Washington State University is sequencing of the intergenic spacer region of the ribosomal gene complex. Initial results indicate that this method has good discriminatory power for *M. ovipneumoniae* isolates, and also has the advantage that it does not require isolation and extensive amplification of isolates.

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Pasteurella/Mannheimia/Bibersteinia Culture and Strain Typing (Serotyping, Biotyping, Genotyping)

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Abstract: Bacteria in the family Pasteurellaceae, e. g. *Pasteurella multocida*, *Mannheimia* spp. and *Bibersteinia trehalosi* are some of the most often-encountered organisms in ruminant nose, pharynx and lungs. They are often considered primary or opportunistic respiratory pathogens capable of causing pneumonia in cattle, wild and domestic sheep, and other ruminants. Culture, strain typing and taxonomy of these organisms to determine pathogenicity and transmission among and between species have been the object of a multitude of approaches. Culture results depend upon the types of growth media employed, the culture conditions, and the familiarity of the technologists performing the culture. Perhaps more important are the ways in which the samples are collected, handled and shipped, as these organisms are rather fragile and do not survive long outside of a living host.

Previously, strains in the genera *Mannheimia* (formerly *Pasteurella*) and *Bibersteinia* (formerly *P. trehalosi* or *P.* Type T) have been identified with serological typing developed using isolates from domestic ruminants. While serology is not always clear with all isolates from domestic animals, it has been widely used. Serology has also been coupled with biochemical tests to determine species and biotypes. Unfortunately, these techniques much less successful with Pasteurellaceae isolated from wild ruminants, such as bighorn sheep. Additional biochemical profiles (biovariants) have been developed to better differentiate the wildlife strains.

Newer DNA-based technology can also be employed in many different ways to genotype strains. Some of these attempt to analyze the entire genome (chromosome, plasmid), and others target specific genes, or parts of genes, mostly using polymerase chain reaction (PCR). Direct sequencing of PCR products is also commonly used, especially in determining bacterial species present from either culture or non-culture based techniques.

All of the various approaches have both strengths and weaknesses. In most instances the most effective protocol will utilize several approaches, beginning with the quickest and cheapest (such as biochemical profiling) and progressing through the more complicated and expensive ones. The extent to which strains are scrutinized will depend upon their importance, time and labor availability, and budgets.

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Molecular detection and serology of *Mannheimia / Bibersteinia / Pasteurella* in the lungs of pneumonic bighorn sheep.

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***Abstract**:* Pneumonia caused by members of the Family *Pasteurellaceae* has played a significant role in the decline of free ranging bighorn sheep (*Ovis canadensis*, BHS) populations in North America. *Mannheimia haemolytica* consistently causes fatal bronchopneumonia in BHS under experimental conditions. However, *Biberstenia trehalosi* and *Pasteurella multocida* have been isolated more frequently than *M. haemolytica* from pneumonic lungs of BHS. This has led to the misconception that *M. haemolytica* may not be the primary bacterial pathogen of this deadly disease in BHS. A recent study by us has revealed that *B. trehalosi* and *P. multocida* can outgrow and inhibit *M. haemolytica* growth. The objective of this study was to detect the presence of *M. haemolytica* in the pneumonic lungs of BHS that died in the recent outbreaks in Western United States. We obtained pneumonic lung tissue of BHS from three States. Since *M. haemolytica* was not isolated from the great majority of these specimens by culture-dependent methods, we developed a culture-independent method for the detection of *M. haemolytica*. Total genomic DNA from lesional tissues was extracted and species-specific PCR assay was performed. This assay detected the presence of *M. haemolytica* in cases where the culture-dependent methods failed to detect this organism. We have also developed a multiplex PCR assay to detect *M. haemolytica*, *B. trehalosi* and *P. multocida* simultaneously. The leukotoxin (Lkt) produced by *M. haemolytica* is the primary virulence factor of this organism. Lkt-neutralizing antibody titer in the BHS is an indicator of infection of these BHS with Lkt-positive *M. haemolytica.* Therefore we also determined the Lkt-neutralizing antibody titer of serum samples from diseased BHS by MTT dye reduction cytotoxicity inhibition assay. Serum titers of most of the animals were between 1:200 and 1:800. These results indicate the involvement of *M. haemolytica* in bronchopneumonia in free-ranging BHS.

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Dispersal patterns of the North American mountain goat (*Oreamnos americanus*)

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KEYWORDS: Mountain goat, dispersal, population genetics

Abstract: The mountain goat (*Oreamnos americanus*) is an alpine specialist endemic to the mountains of western North America. We examined the spatial genetic structure and dispersal patterns of mountain goats spanning their entire native range using microsatellite and DNA sequence data. We identified 30 cross-assigned individuals, which are defined as individuals with the genetic signature of one subpopulation that were physically found in another. This suggests long-distance contemporary dispersal is important for colonization and maintenance of genetic diversity in mountain goats. In addition, there was no sex-bias in dispersers. Closer examination of dispersers across the range and at Caw Ridge, Alberta, revealed they had significantly less genetic diversity than residents. This finding may have important evolutionary and ecological consequences which will be discussed.

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Developing a management plan for mountain goats in British Columbia

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Abstract: A management plan for the mountain goat (*Oreamnos americanus*) in British Columbia was completed in 2010. The purpose of the plan was to provide science-based advice to the province to help ensure mountain goats are conserved in perpetuity. The Province of British Columbia is responsible for the management of mountain goats within its boundaries and guidance is required to help inform appropriate management actions. Approximately one half of the world's mountain goats are found in British Columbia, therefore the province has a global responsibility to ensure their long-term persistence. The management goal for mountain goats in British Columbia is to maintain viable, healthy and productive populations of mountain goats throughout their native range in British Columbia. Management objectives include (1) to effectively maintain suitable, connected mountain goat habitat; (2) to mitigate threats to mountain goats; and (3) to ensure opportunities for non-consumptive and consumptive use of mountain goats are sustainable. Recommended management actions include ways to mitigate threats and specifically address issues pertaining to habitat, harvest, disturbance and access. Harvest recommendations focus on sustainable harvest rates of 1–3% of the population depending upon population size. Populations with less than 50 adults should have no harvest. Harvest of female mountain goats should be minimised because of their low reproductive rates, through education and changes in regulation. Mountain goats react more strongly to human disturbance and may be more sensitive to sustained muscle activity than most ungulates, particularly from the extreme physical exertion and stress caused by helicopter disturbance. Therefore, it is recommended that helicopters have a 2,000 m horizontal and 400 m vertical separation from all mountain goat habitat. A habitat risk matrix is provided as a key habitat recommendation and provides advice on the relative risk of physical disturbance to vegetation in and adjacent to important habitat for mountain goats. Increased access to mountain goat habitat can have implications to all forms of management and there is a need for integrated management decisions that capture all forms of resource development and recreational activities. Finally, there is a need for research to fill data gaps on mountain goats in British Columbia that could help address management decisions to benefit the conservation of the species.

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Modified Clover Trap for Capturing Mountain Goats in Northwest British Columbia

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Abstract: Safe, humane, and effective capture methods are a critical component of mountain goat (*Oreamnos americanus*) research and management. Clover traps are widely used as an effective method for ground capturing mountain goats. The traps, which consist of a metal frame covered with heavy mesh netting, are simple to use, require only 2 people to operate, and can be used in a wide range of terrain, including open alpine ridges. Combined with a skilled capture and handling crew, use of the clover trap can also minimize adverse capture effects such as stress and physical injury. This paper discusses our experience using clover traps to capture mountain goats in Northwest BC and a number of design improvements made to improve trap efficacy. During capture, periods of snow, sleet and very strong winds were frequently experienced. During these periods, failed captures were frequently reported (i.e. goats entering traps were not captured, as confirmed by observations or tracks). Failures appeared to be due to freezing or icing of the trap mesh, the trap release mechanism (a snap-trap), or the trap door drop-bar. Improvements were subsequently made to both the trap-release mechanism and the vertical uprights of the door frame to minimize failed captures. We present an evaluation of these improvements in terms of capture efficacy and discuss other critical factors that influenced capture success in our work.

KEY WORDS British Columbia, clover trap, mountain goat, *Oreamnos americanus*, trigger release, wildlife capture.

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The safe, humane and efficient capture of wildlife is essential to many research and management programs. Several methods exist for capturing mountain goats (*Oreamnos americanus*), including traps (i.e. box traps [McBeath 1941], Stephenson box traps [Rongstad and McCabe 1984], and clover traps [Clover 1956]), nets (i.e. drop nets [Ramsey 1968], and aerial net-gunning [Barrett et al. 1982]), or ground or aerial darting (Crockford et al. 1957). Which method is utilized is dictated by a range of factors such as terrain, financial cost, selectivity of the method, project timelines, and project objectives (Peterson et al. 2003). Although net-gunning is often the most cost-effective method to capture goats, ground based capture is frequently required. For example, our broader study centered on investigation of the interactions between heli-skiing and mountain goats, and the study objectives necessarily precluded aerial-based capture of goats.

Clover traps are a ground-capture method that has been used successfully in a range of mountain goat research and management efforts (Rogers 1960, Hebert et al. 1971, Rideout 1974, Festa-Bianchet and

Côté 2008, L. Ingham, Columbia Basin fish and wildlife compensation program, personal communication). Compared to traditional wooden box traps, clover traps are lighter and more maneuverable, appear more likely to be used by wary animals, and pose less risk of injury to struggling wildlife (Vercauteren et al. 1999). Clover traps can also be used in a wide range of habitats that are prohibitive of other capture methods, including open alpine ridges (Thompson et al 1989). Clover traps also allow for processing of animals without the use of immobilizing drugs, a particular benefit in mountain goat capture due to the negative effects that drugs have been shown to have on kid abandonment rates and the fecundity of young nannies (Côté et al. 1998).

Despite these advantages, several limitations of the clover trap must also be taken into account to ensure both the safety of captured animals and efficacy of the traps. Goats captured in clover traps are exposed both to predators and sources of disturbance while entrapped; as such, traps must be monitored regularly to reduce the risk of capture stress or predation (Vercauteren et al. 1999). In regards to capture efficacy, the conventional rat-trap trigger system (Clover 1956) has been criticized for leading to excessive false releases due to non-target animals and weather effects, and preventing the simple adjustment of the trip-wire tension and position, which also leads to increased rates of both false and missed captures (Rideout 1974, Vercauteren et al. 1999). Finally, the mesh on the sliding trap door can become frozen to the doorframe uprights in times of adverse weather, preventing the door from fully closing and, thereby, resulting in missed captures (Jex 2008).

We used clover traps to capture mountain goats in the Coast Mountains of Northwest British Columbia (56°18', 57°02' N; 129°14',130°32' W). Clover traps were chosen as a practical capture method, as traps had to be set on open alpine ridges, and broader study objectives necessitated a ground, rather than aerial, capture method. Further, clover traps could be easily positioned and set by the 2-person capture crews. Here, we review the challenges experienced during our capture efforts, and make suggestions pertaining to trapping techniques and trap design, both of which increase animal safety and capture efficiency in areas having inclement weather.

STUDY AREA

Captures were carried out in the Skeena Mountains of the Coastal Mountain range in Northwest British Columbia with a protocol approved by the University of Northern British Columbia's Animal Care and Use Committee. This area is influenced by both arctic and coastal climate systems; as such, periods of severe wind, sub-zero temperatures, freezing rain, and snowfall occurred throughout the summer capture sessions. Capture sites were situated on open alpine ridges and plateaus above rugged cliff terrain. Elevation of capture sites ranged between 1500 and 1800 m.

METHODS AND DISCUSSION

We set clover traps along trails in areas of observed high goat use. Pre-baiting of sites for one year prior to trapping was found to be essential for trap success, as it allowed mountain goats to become familiar with bait locations and become accustomed to entering the traps. Trap placement was also an important factor in trapping success, because animals would dig for remnant salt from previous years rather than enter traps for bait salt if traps were not placed in the exact previous location. Salt blocks were placed between the trip-line and the back of the trap, and at least 25 cm from the sides and back of the trap to avoid animals accessing salt from outside. Traps were anchored in place using stakes of rebar and heavy gauge rope to secure the four corners of the traps. The metal frame and nylon mesh of the clover traps were conventional in size to those used for capturing deer: ~91 cm (3 feet) wide by ~122 cm (4 feet) high by ~152 cm (5 feet) long, with the trap frame composed of ~2.2 cm (7/8 inches) diameter steel pipe (Figure 1).

Figure 1. Photograph showing the modified clover trap *in situ* in the Skeena Mountains, northwest British Columbia, Canada.

Traps were checked visually a minimum of 2-3 times per day, as well as a daily manual test of the release mechanism to ensure that it was functioning properly. When visual monitoring was not possible due to weather, traps were checked remotely using a VHF radio collar (alarm collar) fitted to the trap. The magnet silencing the alarm collar was attached to the sliding bar of the door so that when released, it would pull off the magnet and the alarm collar would begin to transmit. This remote monitoring system ensured that traps fitted with collars could be checked constantly, thereby reducing the risk of capture stress, predation, or nanny-kid separation which may result from an animal being trapped for an extended period of time. This remote alarm system also helped ensure crew safety, as traps could be checked in white-outs, wind storms, and at other times when crew safety may have been compromised by doing a manual trap check. The only disadvantage to the alarm collar system were occasional “false alarms” when the tape holding the magnet onto the collar would fall off, often due to the combination of sub-zero temperatures and precipitation. A solution to this may be holding the magnet onto the collar with an elastic band, rather than tape.

Trap modification 1: Archery trigger release system

Our trigger release system consisted of a trip string (18-kg-test fishing line) tied to a stake approximately 45 cm forward from the back of the trap with the string tied approximately 45 cm above the ground (Figure 2). The trip line was then brought around an opposing stake on the opposite side of the trap, and attached to the trigger of the modified archery release (typically Cobra Pro Archery Release, Cobra Manufacturing Co, Inc. Bixby, OK). The line was either tied to a three-way fishing swivel with one arm of the swivel attached with tygon tubing to the trigger of the release, or directly to the trigger with a loop in the line and additional tape (Figure 3).

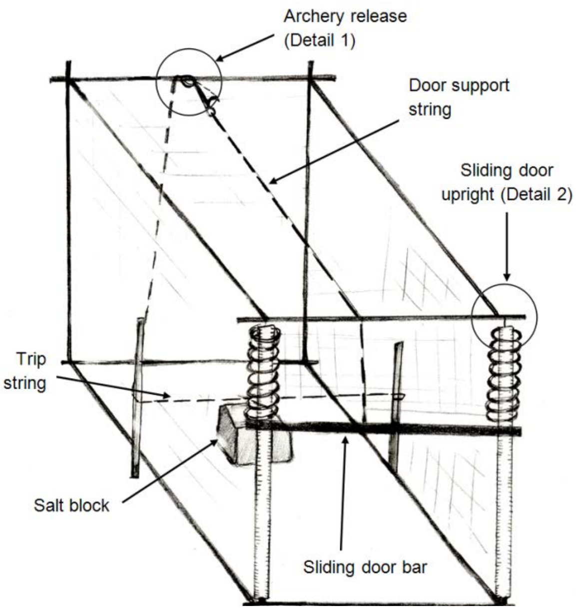

Figure 2. Configuration and major components of the modified clover trap design used in the Skeena Mountains, northwest British Columbia, Canada.

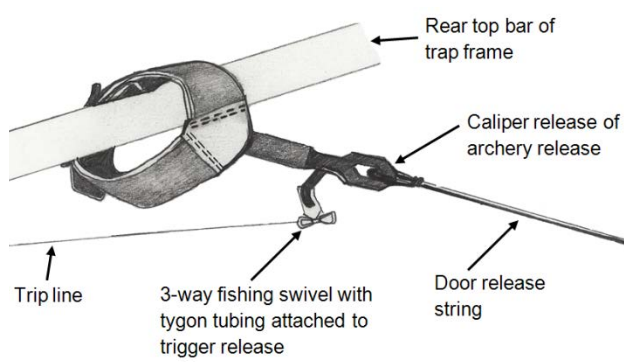

Figure 3. The archery release trap door trigger system of the modified clover trap used in the Skeena Mountains, northwest British Columbia, Canada.

The trap was set by holding the string for the sliding mesh door in the caliper head of the archery release. When a goat entered the trap to access salt and made contact with the trip-string, the trigger of the archery release was pulled back, releasing the door string from the caliper head, and normally capturing the goat.

This release system, devised by Jex (2008), proved to be a more reliable, easily adjustable, and lower maintenance alternative to the conventional rat-trap release system. When using the conventional system, crews often observed either false releases or signs of missed capture (goat tracks and sign in open traps) during times of freezing weather and precipitation. Although these problems were not completely eliminated by the archery release, (components were still somewhat prone to effects of ice accumulation and heavy winds) they were considerably reduced. The minor disadvantage of the archery release system is the financial cost of the trigger components relative to the conventional rat-trap system; archery releases used for the traps cost approximately $40 USD. Considering the time, effort, and expense that is required in mountain goat capture efforts, however, this increased cost is easily offset by the increased capture efficacy of modified traps.

Trap modification 2: Weather-proof Sliding Door. Our sliding door was modified by the fitting of 1” diameter polyvinyl chloride (PVC) pipe to the vertical uprights that the guide the sliding mesh door (Jex 2008). The fabric loops of the mesh door that thread through the vertical uprights were also replaced with heavy gauge metal rings ~0.6 cm (¼ inch) thick and ~5 cm (2 inches) in diameter (Figure 4).

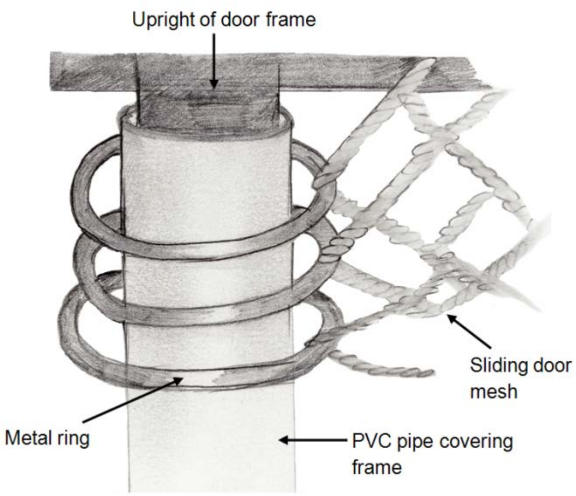

Figure 4. The sliding trap door of the modified clover trap used in the Skeena Mountains, northwest British Columbia, Canada.

In traps with conventional uprights, capture crews reported that ice accumulation would cause the mesh of the sliding door to become frozen to the uprights, thereby preventing the door from closing upon release of the trigger system, and allowing animals to escape. The modifications made to the sliding door system were effective in preventing freeze-up of the sliding door system, and thereby improving the reliability of the system in adverse weather. A potential concern, however, is that the colour and brightness of the PVC pipe may have deterred some animals from entering the trap, as it seemed to be used less often than the unmodified traps with plain metal doorframes (Jex 2008). A possible way to mitigate this problem would be covering the PVC in a darker fabric tape or matte paint or to use a black acrylonitrile butadiene styrene (ABS) covering.

MANAGEMENT IMPLICATIONS

The modifications made to the conventional clover trap, in addition to the use of an alarm collar signalling capture, minimized the disadvantages associated with conventional clover traps, namely concerns of exposure of entrapped animals and unreliable release systems. Modifications resulted in a more reliable trap, which was easier for crews to set and adjust, and yielded improved capture success rates, particularly in times of adverse weather conditions including high winds, freezing rain, or snow. The modifications listed are relatively cost efficient, simple to make, and were found to have a considerable positive effect on capture success in adverse weather. Although capture efforts of this project focused solely on mountain goats, the modifications made would be equally successful in capture programs of other ungulate species requiring the use of clover traps.

ACKNOWLEDGMENTS

We thank several individuals from the B.C. Ministry of Environment, in particular Doug Heard, Rick Marshall, George Schultze, Len Vanderstar, and Glen Watts as well as all the other goat trappers and collar retrievers. Without their guidance, hard work, and sense of humour and adventure, this project wouldn't have been possible. Also, a huge thanks to the pilots at Highland Helicopters, Altoft Helicopter Service, and Lakes District Air. Last but certainly not least, we thank the guides and pilots at Last Frontier Heliskiing for all their enthusiasm in being a part of this project.

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An ongoing assessment of Mountain Goat – Heliskiing interactions in Northwest British Columbia

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Abstract: Studying the effects of helicopter activity on mountain goat behaviour and habitat-use patterns is a high priority for research in BC due to expanding backcountry recreation. Previous research has identified short-term responses of mountain goats to helicopters; however, whether these short-term responses result in longer-term responses, such as habitat selection or range-use changes, is unknown. We are examining these medium-term responses by simultaneously monitoring movements of 21 female mountain goats equipped with GPS collars and helicopter activity (tracked by100-m GPS data) within a heliskiing tenure (and nearby control area) in northwest BC. Comparing helicopter activity to animal location data, we are examining whether individual animal's seasonal movement rates, range-size and resource selection patterns are related to measures of heliskiing activity (i.e., helicopter overflights and landings, skiing) that they are exposed to. Specific anomalous movements of animals (longer than average movements or movements that extend outside established winter range) are also being analysed to determine if they are associated with specific heliskiing events. By utilizing GPS collar technology, this project will allow us to quantify changes in behaviour at a scale not limited to the perceptual range of the observer. As such, this project is providing information integral in determining a more realistic disturbance space, and thus, more relevant operating guidelines.

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Nutrition and reproduction of mountain goats in coastal Alaska.

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Abstract: Understanding characteristics of nutrition and reproduction is critical for interpreting variation in demographic processes of mountain ungulates. This occurs because nutritional condition is often positively correlated with reproductive performance which, in turn, influences population dynamics. In this study, data collected during a 5-year research project on radio-marked mountain goats (females, n = 65, males, n = 78) in coastal Alaska are used to characterize patterns in diet composition, over-summer body mass gain and age-specific reproductive performance. In addition, costs of reproduction were assessed by contrasting differences in body mass and rump fat thickness between adult females with and without kids at heel. Overall, findings indicate that summer diet composition is dominated by sedges, lichens, forbs and ferns while winter diets were composed primarily of conifer needles (western hemlock), shrubs and lichens, in order of decreasing preference. Between August 1-October 15, mountain goats gained body mass at a high rate (males: 0.58 lbs/day; females: 0.40 lbs/day) relative to overall body mass (body mass on August 1st: males, mean = 260 lbs; females, mean = 160 lbs) suggesting the importance of summer range conditions in the annual nutritional cycle of mountain goats. Within this context, female mountain goats experience a significant nutritional cost of reproduction such that females with kids at heel were both lighter and had less rump fat than those without kids at heel. Overall, annual kid production ranged between 58-62% for adult females; no animals less than 4-years old had young. When comparing females for which kid production was determined during subsequent years, reproductive pauses were observed in 60% of cases (n = 68). In a broad context, these findings provide an overview of the nutritional and reproductive status of mountain goats in coastal Alaska. Specifically, these data offer insight into the linkage between nutrition and reproduction in alpine ungulates and pose important questions about the importance of summer range conditions and reproductive costs on population productivity and resilience.

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Rocky Mountain Goat Trap and Transplant Program and Survival of Transplanted Kids in Oregon

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Abstract: Reintroductions of mountain goats (*Oreamnos americanus*) into the Elkhorn Mountains of Northeast Oregon have established a source population for other releases in Oregon. We captured 157 goats during 9 captures from 2000 to 2009. Reintroductions have established breeding populations and natural dispersion is being reported throughout Northeast Oregon. While release efforts have resulted in established populations, survival of released kids has been low. Later capture date and release methodology changes have increased kid survival. Managers need to be aware that capture and transplant programs are successful at establishing breeding populations but survival of released kids is low.

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GIS mapping of North American wild sheep translocations.

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Abstract: At the 10th Biennial Symposium of the Northern Wild Sheep and Goat Council (1996 in Silverthorne, Colorado), a workshop was held to exchange, verify, and update transplant records for wild sheep in 18 central and northern states, provinces, and territories, excluding desert bighorn sheep states. Biologists from state/provincial/territorial wildlife management agencies compared donor and recipient transplant records for wild sheep, as far back as records were available. Tabular summaries were included in the 10th NWSGC Proceedings. In winter 2005-06, transplant actions for each state/province were preliminarily entered into a Geographic Information System (GIS), to graphically depict inter- and intra-state/province/territory translocation of wild sheep. Individual maps were drafted for each state, province, and territory, as were composite maps for wild sheep translocations across central/northern U.S. and Canada. An interim presentation on this mapping effort was given at the 16th NWSGC Symposium in Midway, Utah, and at the 2009 Desert Bighorn Council meeting in Grand Junction, Colorado. The WAFWA Wild Sheep Working Group continues to make progress on this mapping effort. Once concluded, and inclusive of desert sheep translocations, these GIS maps/databases should provide a valuable framework and an historic record for future genetic review, population implications, possible disease analysis, and other management strategies relative to wild sheep transplants across western North America.

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History of Bighorn Sheep in the Sun River Area, Montana

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***Abstract*:** The Sun River bighorn sheep herd (Hunting Districts 421, 422, 423 & 424) has consistently been one of the largest and most robust native herds within Montana. Early European settlement records indicate bighorn sheep presence in the upper Sun River drainage area as early as 1866, although it is reasonable to assume that bighorn sheep have inhabited the upper Sun River drainage for at least the last two centuries. By the early part of the 20th century, bighorn sheep numbers in this as well as many other areas were dramatically reduced. The causes most often cited were contact with domestic sheep, range competition from livestock and other big game animals, contraction of diseases, and subsistence hunting. There have been four recorded die-off events for the Sun River herd (1924-25, 1927, 1936 and 1983-84). During the 1930s bighorn sheep numbers in the Sun River area began to recover due to the reversal of the previously noted conflicts. Herd reestablishment was due to natural production, survivorship and recruitment. Current (spring 2010) population surveys place Sun River sheep at over 900 animals (ram:ewe:lamb = 66:100:28). Translocation efforts along with hunting are the two primary tools utilized to help manage population growth. Trapping and translocation of bighorn sheep in Montana began in 1922 and has resulted in a total of 2,752 sheep transplants used for restoration of historically occupied sheep habitat or augmentation of existing herds. Of these, 1,197 sheep or 47% have come from the Sun River area, which has been used as a source population for 34 different locations (31 different locales within MT and 3 other states). There have been two transplants of bighorn sheep into the Sun River area (1 ram in 1944 and 22 of various age and sex in 1999). Since 1955, there have been 2,902 sheep hunting licenses given in this area (1,723 ram or either-sex licenses and 1,179 ewe licenses) with an overall success rate of 74% (85% on ram or either-sex licenses and 58% on ewe licenses).

KEY WORDS bighorn sheep, Sun River, translocation, hunting, research, disease.

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The first recorded European explorations of the Sun River country were by Lewis and Clark in June of 1805, however, no bighorn sheep observations were noted. Rocky Mountain bighorn sheep presence in the upper Sun River drainage was first reported in 1866 (Couey 1950). Earlier reports exist in other locations within the Rocky Mountains and it is reasonable to assume that bighorn sheep presence in the Sun River country has been persistent for at least the last two hundred years. Similar to other wild sheep populations, around the turn of the 20th century sheep numbers in this area declined likely due to contact with domestic sheep (and subsequent disease), range competition from livestock and other big game (primarily elk), and subsistence hunting. However, due to the natural topography of the area and the ability for sheep to separate themselves from other livestock and big game concentrations, bighorn sheep populations did not suffer complete eradication. Unverified reports of good numbers of sheep were noted in 1908 and 1910 in two different locations within the Sun River area (Couey 1950).

In 1913, there were 6,500 cattle and horses and 5,500 domestic sheep permitted to graze on forest service lands in the Sun River area (Picton et al. 1975). In 1929, the Gibson Irrigation Dam (and Reservoir) was completed effectively blocking primitive access to the upper Sun River country. Due to this new barrier along with support from local sportsmen, livestock use of this area was gradually reduced. By 1934 nearly all livestock grazing had been discontinued. Today, only two relatively small seasonal horse grazing allotments exist in the upper Sun River drainage. Cattle grazing continues in other portions of currently occupied sheep habitat in the area, but there is no domestic sheep presence in the vicinity of suitable bighorn sheep habitat.

Beginning in the 1930s sheep numbers in the area were recovering and the first successful translocation effort in this area was accomplished in 1942. Other than an approximate 30-50% herd die-off in 1983-84, bighorn sheep in the greater Sun River area have continued to flourish.

LOCATION

The upper Sun River drainage and surrounding occupied sheep habitat is located in west central Montana along the eastern edge of the Rocky Mountains known as the Sawtooth Range (Figure 1). The area lies approximately 60 miles south of Glacier National Park and on the east edge of the Bob Marshall Wilderness. This area is comprised of bighorn sheep hunting districts (HD) 421, 422, 423 and 424. Together, these HDs represent just over 2,949 km² of land with approximately 855 km² (30%) currently occupied by bighorn sheep during at least some portion of the year. Just over 90% of the occupied sheep habitat is public land (U.S. Forest Service, Bureau of Land Management, or Montana Fish, Wildlife and Parks). Although < 10% of existing occupied sheep habitat is private, these lands are important, especially during winter.

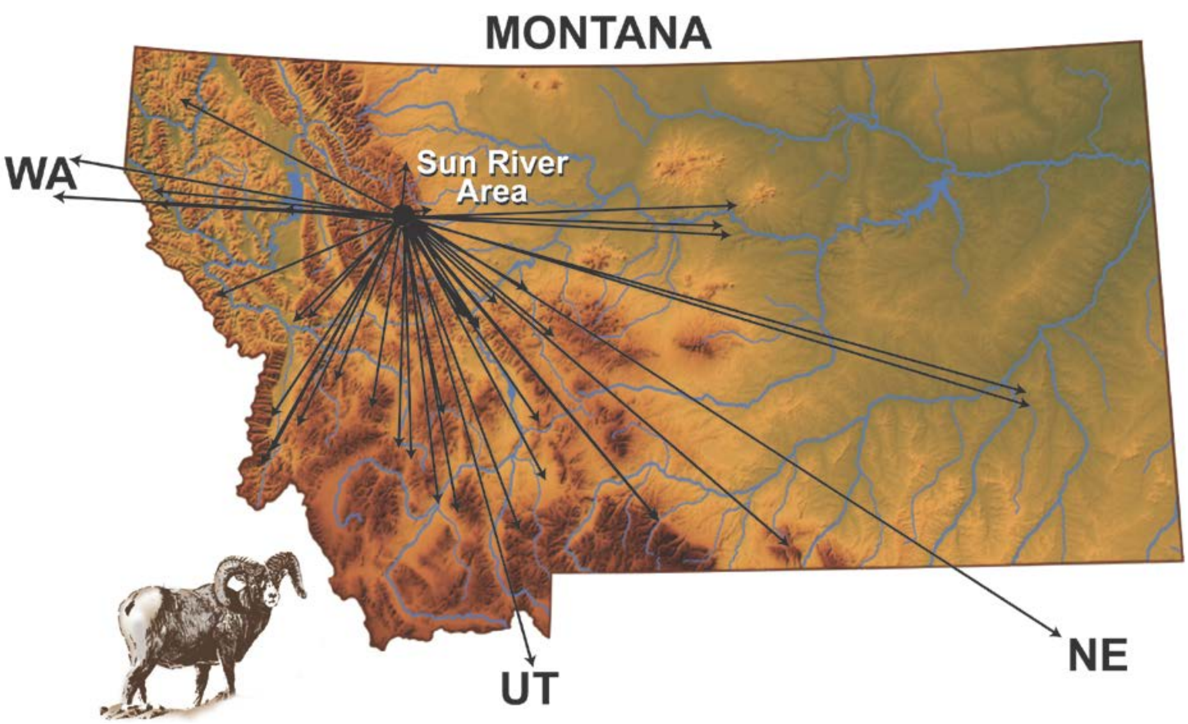

Figure 1. Map of Montana portraying location of the Sun River area and approximate locations to which Sun River sheep have been translocated, 1942 – 2009.

POPULATION HISTORY

The earliest recorded survey of bighorn sheep in this area was in 1941, with an observed number of 161 sheep (Couey 1950). In 1943 there was an estimated 280 sheep inhabiting the area with approximately 63% of these sheep in the upper Sun River drainage and the others occupying the surrounding areas (Couey 1950). By the mid 1950s sheep observations (minimum counts) in the area grew to nearly 400, and by the early 1970s observations further increased to between 700 and 800 animals. Although an approximate 30-50% die-off (some areas were harder hit than others) occurred during 1983-84, by the fall of 1986 surveys placed total observed sheep at not less than 780 individuals. The most recent (spring 2010) survey yielded observations of not less than 933 observed animals. An average of 461 sheep were observed during late fall rut surveys from 1955-2009. Average lamb:ewe and ram:ewe ratios from the same time period are 44:100 and 53:100, respectfully.

The overall population management objective for HD's 421, 422, 423 and 424 is to be at or near 800 sheep observed during spring/fall surveys. Current overall lamb production appears to suggest population maintenance rather than significant growth at 28 lambs:100 ewes. Ram numbers remain strong at 66 rams:100 ewes. Continued hunter harvest and translocation efforts are important to help manage population growth.

DISEASE AND DIE-OFF

There have been four bighorn sheep die-offs recorded in this area in the last century. The first die-off occurred during 1924-25 with an estimated population loss of 70%. Forage competition with other big game (elk) and livestock was thought to be a major contributing factor. Other smaller die-offs were recorded in 1927 and 1936, but the magnitude is unknown. Field diagnosis of some of the dead sheep in the 1924-25 and 1927 die-offs indicated pneumonia as the cause of death (Marsh 1938). The last major die-off occurred during 1983-84, with an estimated loss of 30-50% of the population. Estimates vary because certain areas within the greater Sun River region had higher losses than others. The latter die-off was primarily caused by bronchophneumonia complicated by pulmonary nematodiasis. While we will never know the true origin of the disease, one plausible scenario consists of a disease outbreak that started in the spring of 1983 at Crowsnest Pass-Waterton Lakes National Park, Canada, worked its way south through Glacier National Park and eventually down the eastern flank of the Rocky Mountain Front and the Sun River region (Montana Fish, Wildlife & Parks 1984). With the exception of a small transplant in 1999, all population growth post die-off has been the result of natural production, recruitment, and immigration.

TRANSLOCATION

One tool commonly utilized to help manage highly productive sheep herds is trapping and translocating sheep. Since 1942, sheep from the Sun River area have been used as a source for restoration of historically occupied sheep habitat or augmentation of existing herds. In the early years of such efforts, there were three different permanent sheep traps (Scattering Springs, Ford Creek, and Castle Reef) placed in strategic areas for capturing sheep. There was also an additional mountain goat trap in the Deep Creek area that was occasionally used for capturing bighorn sheep. These traps proved to be very effective and were used for nearly 60 years. Although the remnant sheep traps are still present, current capture efforts are completed via helicopter net-gunning which has significantly improved the efficiency of such efforts.

Over the last 68 years, trapping and translocating sheep from the Sun River area has been completed in 33 different years (sometimes more than once per year). Sun River sheep were moved to 31 different locations within Montana (some areas have received multiple augmentations), and 3 other states (Fig. 1). In total, 1,197 individual sheep have been trapped and translocated from the Sun River area (47% of all MT sheep augmentation and/or restoration transplants) (Carlsen et al. 2010). In addition, there are seven areas that at some point have received Sun River sheep and have since further been used as a source herd (n=806 or 32% of all transplants statewide) to augment sheep to other areas (Carlsen et al. 2010). Through these restoration efforts, Sun River sheep have been directly or indirectly involved with 79% of all Montana sheep augmentation and/or restoration efforts.

There have been only two translocations during which sheep were released into the Sun River area. In 1944 and for unknown reasons, one ram from southwest Montana was released in Sun Canyon. In 1999, in an effort to help boost existing sheep numbers in the Deep Creek area (16 km north of the Sun Canyon), 22 sheep of various age and gender were translocated from the Bitterroot Mountains, Montana. Ewes (wearing neck-bands and ear tags) from the 1999 translocation are still occasionally observed.

HUNTING

In addition to trapping and translocation efforts, another important facet to sheep management in the Sun River area is hunting. From 1912 to 1952, there was no hunting season for bighorn sheep in the Sun River area. From 1953 until 1974, ram hunting seasons were permitted (bighorn sheep hunting district 42). Starting in 1974, licenses were changed to either-sex (ES) hunting, and for the first time a separate and limited number of ewe hunting licenses were available. It was not until 1975 that bighorn sheep Hunting Districts 421, 422, 423, and 424 were established.

Since 1955, there have been 2,902 sheep hunting licenses awarded in this area (1,723 ram or ES licenses and 1,179 ewe licenses) with an overall success rate of 74% (85% on ram or ES licenses, and 58% on ewe licenses). Since 1976, the average age of all harvested rams is 7.4 years.

Bighorn sheep hunting in the Sun River area remains as popular as ever. Current hunter drawing odds for ES sheep licenses vary from 0.59% to 1.22%, depending on the hunting district. In contrast, adult ewe hunting opportunity drawing odds are significantly better and vary from 62.5% to 83.3%. Similar to other areas, ES hunting opportunity has become very restrictive over time. Typically after many years of applying for an ES license, hunters that are successful in the drawing have high expectations of harvesting a trophy quality ram.

RESEARCH

Part of the history of bighorn sheep in this area is its contribution to research efforts. Since 1966, there have been 5 MS theses completed on Sun River bighorn sheep biology and ecology. One of the more significant results of this research was the development of the current four sheep hunting districts. Even today, current management practices (i.e., overall population objectives) are based on some of the research findings from the late 1960s and 1970s (Schallenberger 1966, Erickson 1972, Frisina 1974). Other research (Andryk, 1983, Schirokauer 1996) has contributed to our knowledge the effects of habitat alteration on bighorn sheep inhabiting the Sun River area.

SUMMARY

Through hunting, translocation efforts, research, and general wildlife viewing, this herd has established its importance both locally and nationally over the past seven decades. Continued management and cooperation with public and private landowners, as well as finding a balance between translocation efforts and hunting, will be important in the future to help keep healthy numbers of sheep in the Sun River country.

ACKNOWLEDGMENTS

The information gathered and summarized in this manuscript is presented in recognition of all the good biologists, conservationists and sportsman that have worked and lived in the Sun River Country. This short summary is a testament to their work and emphasizes the desire to continue to maintain a healthy and robust population of bighorn sheep in the Sun River area.

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Implementation of the Montana Bighorn Sheep Conservation Strategy

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Abstract: Montana Fish, Wildlife and Parks (FWP) recently completed a Conservation Strategy for bighorn sheep which was approved the FWP Commission January, 2010. This is Montana's first comprehensive planning effort for bighorns and includes a thorough discussion of the history of bighorn sheep in Montana including translocation efforts and the role that hunting has played in managing bighorns. Functional implementation is the primary challenge in utilization of any planning document. Implementation of the strategy is focused on monitoring and management of populations, health and habitats. Population monitoring to determine numerical status has been adequate and no major changes are being proposed. Management of populations consists of setting objectives and managing for those objectives through hunting and translocation efforts. Adaptive processes for determining the number of licenses issued for rams and ewes have been developed that provide for harvest levels designed to meet numerical objectives. Establishing 5 new populations over the next 10 years is one of 11 statewide objectives in the strategy and will be facilitated, in part, by a GIS modeling effort to identify suitable habitats. Health monitoring and management will continue with many established efforts such as collecting biological samples from sheep during translocation efforts. New direction to determine health of populations may include genetic sampling looking at genetic status of small/isolated populations determining the need for possible augmentation. Genetic sampling will also be pursued to look at structure and genetic status of metapopulations. Efforts to improve separation of wild sheep and domestic sheep/goats are on-going and will be emphasized to protect new and existing populations from potential disease transmission. Most bighorn sheep habitat in Montana occurs on land managed by the Forest Service and Bureau of Land Management and FWP relies on partnerships with these and other land managing agencies and private landowners to effectively manage habitat for bighorns. Monitoring and management of populations, health and habitat are not independent aspects of managing bighorn sheep but must be integrated to maintain viable populations of bighorns. A risk assessment for each population is underway to determine the status of these 3 factors for each population and will help prioritize management actions for bighorn sheep on a statewide basis.

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Perceived Threats to Wild Sheep: Levels of Concordance Among Western States, Provinces, and Territories

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Abstract: In 2008, representatives of 19 states, provinces, or territories that are members of the Western Association of Fish and Wildlife Agencies informally ranked 7 perceived threats to the conservation of wild sheep from greatest to least concern. Statistical analyses indicated significant concordance among respondents when all responses were considered simultaneously ($P < 0.001$), but there was little agreement among representatives from areas inhabited by thinhorn sheep ($P \approx 0.23$). I failed, however, to reject the null hypothesis of no agreement among states inhabited primarily by desert bighorn sheep ($P \approx 0.02$) or Rocky Mountain bighorn sheep ($P < 0.001$). Further, when within-group and between-group rankings were considered simultaneously, the null hypothesis of no agreement among participants representing areas inhabited by desert bighorn sheep or Rocky Mountain bighorn sheep again was not rejected ($P < 0.001$). Categories of threat considered in this analysis were preliminary in nature and not mutually exclusive and, thereby, confounded interpretation of results. Thus, I suggest further refining the list of threats with which wild sheep are faced, and combining those issues into fewer categories of risk.

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Historic Bighorn Sheep Disease Outbreaks in Western North America and Mountain Sheep Extirpation from Oregon

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Abstract: Bighorn sheep were abundant in Western North America prior to settlement. The common reported reasons for population declines and extinctions were unrestricted hunting, overgrazing by livestock and disease. D isease outbreaks decimating bighorn sheep herds were reported in the Tarryall/Kenosha Colorado herd as early as 1885. Montana reported die offs in the Southern Rocky Mountain front between the 1920's and 1930's.

In Oregon, bighorns were extirpated from Central and Eastern Oregon by the 1920's, in all but the Wallowa Mountains. A state wildlife refuge was established in the Wallowa Mountains to protect the small bighorn herd, however large numbers of domestic sheep were allowed to graze the same area. Between 1911 and 1920, over 10,000 sheep grazed the Standley Allotment alone. Field notes from Oregon State College Cooperative Wildlife Research Unit technicians conducting surveys in 1939 and 1941 found no evidence of surviving bighorns. Charles Seeber spent summers in the Wallowa Mountains from 1887 to 1946. He reported that "mountain sheep used to be very numerous in the area (the Wallowa Mountains) until domestic sheep were brought in."

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British Columbias Use of Ecological Goods and Services Payments as a Tool For Separating Wild Sheep From Domestic Sheep and Goats

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Abstract: British Columbia's Wild and Domestic Sheep Seperation Program's goal is to mitigate the disease risks to wild sheep from domestic sheep and goats, and prevent future disease-related losses. The provincially coordinated program focuses on all regions containing wild sheep populations in British Columbia, Canada. The East Kootenay and South Okanagan bighorn populations have suffered pneumonia related die-offs with mortality rates up to 60-75%. One of the causes of the die-offs may have been infectious disease transmission from domestic to bighorn sheep. All populations have recovered to some degree but some have recovered more rapidly than expected, with high lamb recruitment. The Program began with the assessment of habitat quality and quantity, bighorn carrying capacity, animal health and morphology, location and movement, population dynamics and exposure risks to domestic sheep and goats. This information is used to develop a suite of options to mitigate the risks of disease transmission from domestic sheep and goats to wild sheep. Educational programs involve communication with landowners on short-term solutions (such as double fencing, guard dogs, etc.) and working with governments towards longer-term solutions (resolutions, bylaws etc.). This paper focuses on developing and evaluating another solution; the use of ecological goods and services payments as a tool for separating wild sheep from domestic sheep and goats. Since the initiation of the Program, no new cases of pneumonia have occurred in bighorns in the Project areas.

Key Words: bighorn sheep, British Columbia, disease transmission, domestic sheep, ecological goods and services payments.

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Utilizing Wildlife Forensics to Protect Natural Resources: A Case Study in Catching a Bighorn Sheep Poacher

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***Abstract*:** Illegal take of trophy big game species reduces the legal hunting opportunities for the general public on already small populations. In addition to being highly valued as watchable wildlife, sales of big horn special tags & permits funds big horn sheep conservation efforts throughout North America. The value of these animals and limited hunting opportunity leads some to attempt to take these trophies through less than legitimate means. In 2008, Idaho Conservation Officers received information about a potential illegal harvest of a trophy ram from the Salmon River drainage. This case study describes the criminal and forensic investigation that lead to the prosecution and felony conviction of the poacher.

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Developing a Non-Invasive Technique to Estimate Population Size of Bighorn Sheep in Rocky Mountain National Park Using Fecal-DNA

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Abstract: Developing non-invasive techniques to study large mammals is the goal of many wildlife managers and researchers. Handling ungulates causes stress to animals and risk to humans. In certain places, such as Rocky Mountain National Park (RMNP), Colorado, flying helicopters to radio tag or mark ungulates in wilderness is heavily scrutinized. The development of viable alternatives is needed. Based on research and modeling by McClintock (2006), the bighorn sheep population on the east side of RMNP (Mummy Range) is predicted to become extirpated by 2020 if the rates of decline observed during the study continue. It is unclear whether these declines have continued between McClintock's last field season in 2004 and the present time. Thus bighorn sheep population monitoring in RMNP is a high priority, and population and density estimates are essential for successful management and conservation of the species. In order to avoid capturing and marking bighorn sheep, we are conducting a study to develop a non-invasive population estimation technique using fecal DNA. Mark re-capture models will be used to estimate parameters such as population size and survival, where the "mark" will be an individual animal's DNA. If this technique is viable and less costly (and less risky) than traditional aerial helicopter monitoring, RMNP managers may be able to determine trends in bighorn sheep and other wildlife populations, which would inform a variety of management decisions. We are beginning the second year of this 2-year study. After first year analyses, it is clear that the method has validity, and preliminary analysis indicates that the herd has not declined further since the McClintock study.

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Demographic Response to Experimental Genetic Management in Bighorn Sheep Herds in Oregon

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Abstract: Steens Mountain and Leslie Gulch populations of bighorn sheep (*Ovis canadensis*) in Oregon were experimentally augmented in 2000 and 2001, respectively, with ewes from the Santa Rosa Mountains population of Nevada, a herd with higher genetic diversity. The intent of these augmentations was to reverse declining trends in herd productivity through increases in genetic diversity. In this research we investigated the demographic response of the Steens Mountain, the larger Steens metapopulation, and Leslie Gulch California bighorn sheep herds to experimental genetic management. We evaluated pre- and post-augmentation demographic trends using several metrics derived from yearly herd inventory data. Our results suggest that both the Steens Mountain and Leslie Gulch herds exhibited demographic changes after augmentation. Steens Mountain changed from strongly declining in numbers to a more stable pattern whereas the Leslie Gulch population metrics increased substantially over the full course of our study. The responses we observed indicated that inbreeding depression potentially played a role in previous downward trends of our study populations, but further research will be necessary to assess this hypothesis.

KEY WORDS bighorn sheep, genetic management, genetic rescue, population dynamics

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Genetic management, defined as management action intended to increase genetic variability, of wild populations has been called the "…greatest unmet genetic challenge in conservation biology" (Frankham et al. 2002, p. 362). However, there are strikingly few examples of genetic management in the literature and even fewer reports of genetic management resulting in the genetic rescue (i.e., increased genetic diversity and a response in some demographic parameter; Thrall et al. 1998) of wild populations. Madsen et al. (1999) reported the rescue of a population of adders (*Vipera berus*) in Spain after the addition of 20 individuals from more genetically-diverse stock and Westemeier et al. (1998) reported increased reproductive fitness in a remnant population of greater prairie chickens (*Typmanuchus cupido pinnatus*) after augmentation with individuals from several large, more genetically diverse populations. The results of the genetic management of the Florida panther (*Puma concolor coryi*) also has received much attention, with some authors pointing to evidence portraying the management action as a success (Pimm et al. 2006) while others have expressed doubts about some (Creel 2006) or most of that evidence (Maehr et al. 2006). In the most comprehensive record of a population's response to augmentation, Hogg et al. (2006) documented genetic rescue in a long-term study of Rocky Mountain bighorn sheep (*Ovis canadensis canadensis*) in Montana, USA.

Although an ample body of theoretical work suggests that restoring gene flow to small, isolated populations via genetic augmentation has benefits in terms of the maintenance of genetic diversity and the avoidance of inbreeding depression (e.g., Whitlock et al. 2000, Ingvarsson and Whitlock 2000), empirical examples of such outcomes are few and generally have not accounted for the effects of unmeasured variables by studying replicate populations (Ball et al. 2000, Keller et al. 2001, Saccheri and Brakefield 2002, Schönhuth et al. 2003, Vilà et al. 2003). That is, successful genetic management resulting in the genetic rescue of a wild population has not been demonstrated in an experimental framework. This is surprising given the widespread use of translocation as a tool in wildlife management (Fischer and Lindenmayer 2000) and the numerous opportunities that exist to experimentally evaluate genetic and demographic responses to augmentation within managed wildlife populations resulting from this type of translocation (e.g., Mock et al. 2004).

Whittaker et al. (2004) describe such an experimental framework using bighorn sheep (*O. c. canadensis*; formerly recognized as California bighorn sheep *O. c. californiana*) in Oregon. After documenting poor productivity (<20 lambs:100 ewes) and population-specific numerical declines along with no indication of disease related die-offs, Oregon Department of Fish and Wildlife (ODFW) conducted a genetic analysis of some of that state's bighorn sheep herds (Whittaker et al. 2004). They evaluated measures of genetic diversity among 5 herds in Oregon (Hart Mountain, Aldrich Mountain, Lower John Day River, Steens Mountain, and Leslie Gulch; Figure 1) and those of the Santa Rosa Mountains herd of Nevada to determine if the observed declines could be due to inbreeding depression (Whittaker et al. 2004). This research revealed that the Oregon herds exhibited significantly lower levels of genetic diversity when compared to that of the Santa Rosa Mountains herd of Nevada. Inbreeding depression was suspected as the causal mechanism behind the decline in productivity of the Oregon herds because most have a lineage tracing back to the original translocation of 20 sheep to Hart Mountain, Oregon in 1954 (Coggins et al. 1996). As a consequence of this research, experimental augmentations of the Steens Mountain (N = 16 in 2000) and Leslie Gulch (N = 15 in 2001) populations of bighorn sheep in Oregon were carried out using sheep from the more genetically-diverse Santa Rosa Mountains herd (Whittaker et al. 2004).

Our investigation centers on these augmentations as examples of attempted genetic management in the wild. Using annual herd inventory data (e.g., counts, population size estimates, and lamb/ewe ratios) collected subsequent to and after the experimental augmentations were performed, the goal of this research was to evaluate whether there was a demographic response by these herds after experimental genetic management. Specifically, our objective was to determine if a genetic rescue effect could have occurred as a result of our experiment by comparing and contrasting population trends within the Steens Mountain and Leslie Gulch bighorn sheep herds before and after their respective augmentation events.

METHODS

Study Area

Steens Mountain, located in Harney County, Oregon, is a fault-block upheaval

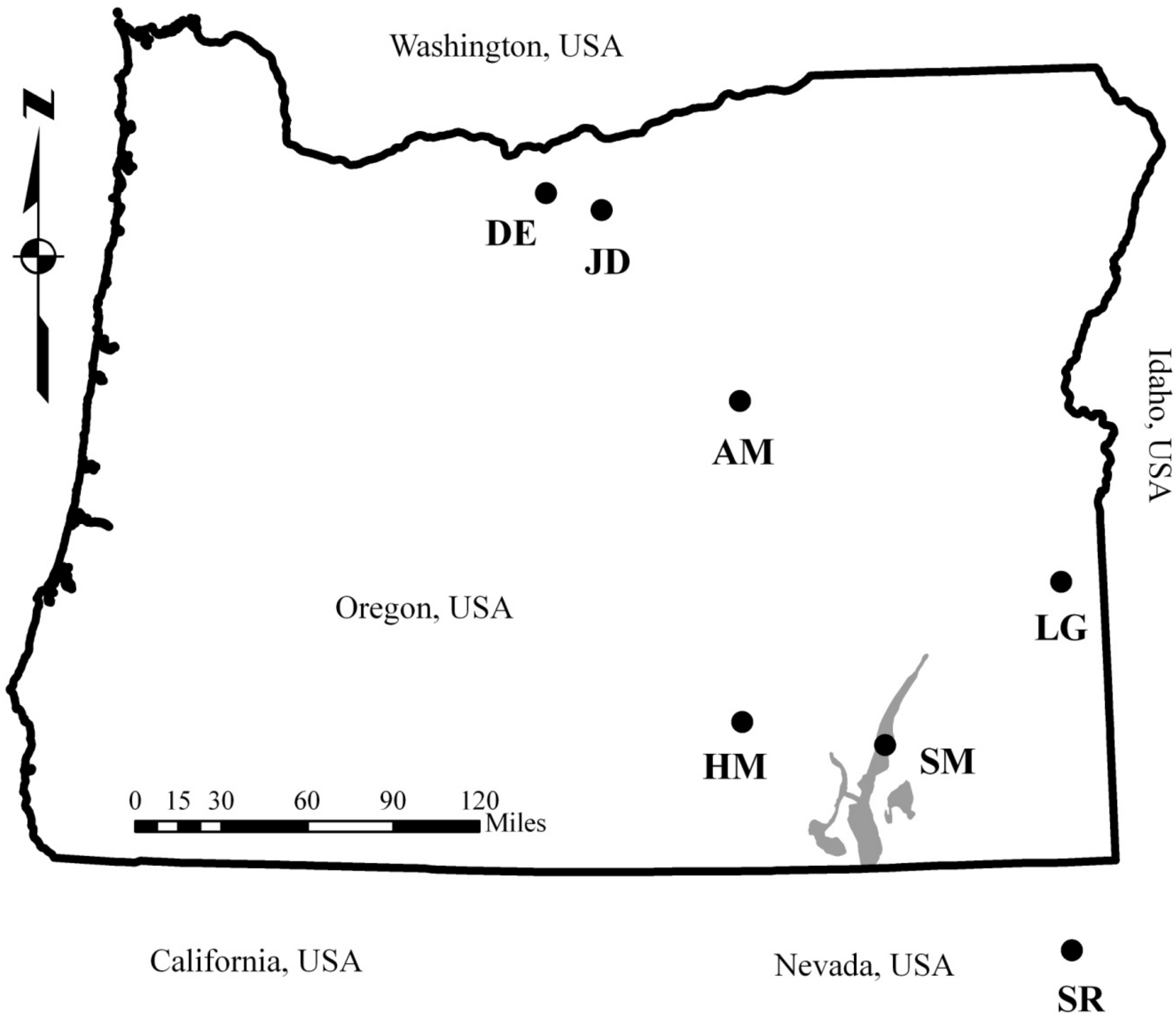

Figure 1. Bighorn sheep populations sampled as part of our larger genetics study. Oregon populations were Aldrich Mountain (AM), Deschutes River (DE), Hart Mountain (HM), Lower John Day River (JD), Leslie Gulch (LG), and Steens Mountain (SM). The Nevada population was Santa Rosa Mountains (SR). The shaded area surrounding Steens Mountain bounds the larger Steens metapopulation.

that rises nearly a vertical mile from the surrounding landscape (Whittaker et al. 2004; Figure 1). Bighorn sheep primarily occupy the more-vertical, east face of the mountain. The herd was established from two translocations of 4 and 7 bighorn sheep from Hart Mountain in 1960 and 1961, respectively (Coggins et al. 1996). By 1985 the Steens Mountain herd had reached numbers large enough to permit its use a source herd for reintroductions and augmentations elsewhere in Oregon (ODFW 2003). Subsequent natural range expansion and additional ODFW translocations (Coggins et al. 1996) around the mountain proper have resulted in a metapopulation-like configuration of herds around Steens Mountain (larger Steens metapopulation; Figure 1). Peripheral populations currently include: Andrews Rim, Alvord Peaks, Heath Rim, Lone Mountain, Mickey Butte, North and South Catlow Rims, Palamino Canyon, Pueblo Mountains, Squaw Creek, and Stonehouse Canyon (Table 1). In 2000, 16 additional bighorn females were translocated to Steens Mountain proper from the Santa Rosa Mountains of Nevada in an attempt to increase genetic diversity in the Steens Mountain herd (Whittaker et al. 2004).

Table 1. Year established or first inventoried, and release size for subpopulations comprising the larger Steens metapopulation of California bighorn sheep.

Population	Year	N	Source Population
Steens Mountain	1960	4	Hart Mountain
	1961	7	Hart Mountain
Andrews Rim	1998		Range expansion
Alvord Peaks	1991		Range expansion
Heath Rim	1996		Range expansion
Lone Mountain	1992	15	Hart Mountain
Mickey Butte	1995		Range expansion
N & S Catlow Rims	1989	17	Hart Mountain
Palamino Canyon	2004		Range expansion
Pueblo Mountains	1976	16	Hart Mountain
	1980	7	Hart Mountain
	1983	17	Hart Mountain
Squaw Creek	1993	17	Hart Mountain
Stonehouse Canyon	1996	18	Lower John Day[1]

[1] Bighorns in the Lower John Day herd originate from 2 translocations: 1989 from Hart Mountain and 1990 from Williams Lake, B.C., (the source herd for Hart Mountain).

Leslie Gulch is a rocky gorge that connects to the larger Lower Owyhee River canyon and is located in Malheur County of eastern Oregon (Figure 1; Whittaker et al. 2004). Bighorn sheep were established in Leslie Gulch with a translocation of 17 sheep from Hart Mountain in 1965 (Coggins et al. 1996). Similar to Steens Mountain, Leslie Gulch eventually contained enough sheep to be included as an additional source herd for bighorn sheep restoration efforts in Oregon (ODFW 2003). In 2001, the Leslie Gulch herd received an additional 15 bighorn females translocated from the Santa Rosa Mountains of Nevada in an attempt to increase genetic diversity (Whittaker et al. 2004).

Experimental Design

Three population-level metrics were available from yearly ODFW winter bighorn sheep herd inventories: 1) total number counted during classification surveys (i.e., minimum number alive), 2) population size estimates derived from ODFW population models (POP-II; Bartholow 1995), and 3) lambs:100 ewes defined as the number of lambs counted divided by the number of ewes counted multiplied by 100. Total number counted and population size estimates were intended to index population abundance whereas lambs:100 ewes was interpreted as an index of herd productivity. Inventories of Steens Mountain and the larger Steens metapopulation were based on counts from the ground, whereas data from Leslie Gulch were based on inventories conducted via helicopter (ODFW 2003).

We used inventory data from 1992-2009 for Steens Mountain and 1994-2009 for Leslie Gulch (Table 2). Separately, we combined data from Steens Mountain proper and its peripheral populations within years from 1992-2009 to represent the larger Steens metapopulation (Table 2). Peripheral populations were included in analyses if population metrics were available for ≥1 year before and after augmentation (i.e., the population was well established). Of the 11 peripheral populations evaluated in the larger Steens metapopulation, 8 met this criterion: Andrews Rim, Alvord Peaks, Lone Mountain, Mickey Butte, North and South Catlow Rims, Squaw Creek, and Stonehouse Canyon. It should be noted that these data sets are imperfect; they were collected by ODFW personnel when and where time and funds allowed. Consequently, the data set contained many missing values, and to minimize bias associated with incomplete counts, population size estimates were

Table 2. Oregon Department of Fish and Wildlife (ODFW) inventory data for the Steens Mountain, Steens Metapopulation, and Leslie Gulch herds. Total count = number counted during classification surveys; N-hat = population estimate derived from ODFW population models; Lambs:100 = (number of lambs counted)/(number of ewes counted)* 100. Total count and N-hat were summed for all sub-populations in the Steens Metapopulation whereas Lambs:100 is the mean across sub-populations. Pre- and Post- indicate data available for pre- and post-augmentation series.

	Steens Mountain						Steens Metapopulation[a]						Leslie Gulch					
	Total Count		N-hat		Lambs:100		Total Count[b]		N-hat[b]		Lambs:100[b]		Total Count		N-hat		Lambs:100	
Year	Pre-	Post-	Pre-	Post-	Pre-	Post-	Pre-	Post-	Pre-	Post-	Pre-	Post-	Pre-	Post-	Pre-	Post-	Pre-	Post-
1992	168				25		79.5 (4)				40.0 (4)							
1993	167		250		19		86.5 (4)		128.8 (4)		36.4 (4)							
1994																		
1995	61		225		16		46.5 (6)		90.8 (6)		32.3 (6)		137		160		17	
1996	56		225		11		29.7 (7)		95.8 (6)		22.8 (7)		116		150		19	
1997	132		200		27		53.7 (7)		85.0 (8)		45.8 (7)		92		125		7	
1998	132		185		26		61.0 (9)		80.9 (9)		43.1 (9)		92		125		24	
1999	129		185		22		56.3 (9)		87.2 (9)		37.2 (9)		107		125		24	
2000	137		185		17		50.8 (9)		86.1 (9)		34.6 (9)		105		125		33	
2001		97		185		40		57.8 (4)		130.0 (4)		36.8 (4)	132		160		21	
2002		143		195		21		53.1 (7)		83.1 (8)		20.9 (7)						
2003		122		195		31		64.1 (7)		106.7 (9)		35.7 (7)						
2004		135				23		66.0 (9)				24.1 (9)		194				38
2005		91				32		59.0 (8)		135.0 (2)		26.1 (8)		232				42
2006		84				30		55.0 (7)		135.0 (2)		32.6 (7)		170		250		40
2007		62		175		27		58.6 (8)		145.0 (7)		39.6 (8)		235				24
2008		66				23		45.3 (7)				29.8 (7)		224				21
2009		59				35		51.3 (8)		100.1 (7)		32.8 (8)		197				47

excluded from our analyses if they were equal to the total number counted in that year.

Data Analysis

Population-level metrics were analyzed separately for Steens Mountain, the larger Steens metapopulation, and Leslie Gulch. We used simple linear regression to calculate the slopes of our estimates of total count, population size, and lambs:100 ewes through time (i.e., years) using the procedures outlined in Robbins et al. (1986). Balanced (total number of years) pre- and post-genetic augmentation time series were regressed separately for each study area (Robbins et al. 1989). For example, data from Steens Mountain proper were split into two, 9-year data series: before (1992-2000) and after (2001-2009) augmentation. Likewise, the data from Leslie Gulch were analyzed separately as data series before (1994-2001) and after (2002-2009) augmentation. Because not all populations in the larger Steens metapopulation were inventoried every year, annual estimates of each of the demographic variables for this herd complex were corrected by taking the sum of population estimates divided by the number of populations inventoried within each year. We used simple linear regression on the 3 corrected population metrics in balanced pre- (1992-2000) and post- (2001-2009) augmentation series as described previously for Steens Mountain proper.

We used Student's t-tests to evaluate the null hypothesis of no difference in slope coefficients between pre- and post-augmentation regressions (Zar 1999, p. 360) of each of the 3 population metrics independently for Steens Mountain proper, the larger Steens metapopulation, and Leslie Gulch. If regression slopes for any population metric did not differ between pre- and post-augmentation series, we also used Student's t-tests to evaluate the null hypothesis of no difference between pre- and post- regression elevations (i.e., we tested for vertical separation of the regression series) for that metric following Zar (1999; p. 364).

Further, in order to evaluate trends for each demographic metric over each full time series, we constructed regression models using the entire data sets for each herd (i.e., 1992-2009 for Steens Mountain proper and the larger Steens metapopulation and 1994-2009 for Leslie Gulch) using total counts, population size estimates, and lambs:100 ewes in separate models. All regression models were constructed using lm in R (R Development Core Team 2008) and the raw data for each regression we conducted were plotted using SigmaPlot version 10.0 (Systat Software, Point Richmond, CA, USA). We used $\alpha = 0.05$ as our level of statistical significance for all analyses.

RESULTS

Overall, only 3 of the 17 pre- and post-augmentation regressions (one regression was not conducted due to insufficient data) exhibited slope coefficients that were significantly different from zero (Table 3; Figure 2). In addition, we detected only 1 significant difference between pre- and post-augmentation regression slope coefficients across the 8 comparisons evaluated (Table 3). Population size estimates for Steens Mountain proper decreased less severely after genetic augmentation than was the trend prior to augmentation (P=0.04; Table 3, Figure 2). The explanatory power of the pre and post-augmentation models we evaluated ranged from >91% to <0.001% of the total variance explained by the models (Table 3). In particular, our regressions of numbers of lambs:100 ewes over years had exceptionally low explanatory power, with an overall average R^2 value across all pre- and post- time series combined of less than 0.07 (Table 3). Therefore, plots of the relationships between total counts and estimated population sizes relative to time are provided for all three data sets (Steens Mountain proper, the larger Steens metapopulation, and Leslie Gulch; Figure 2) while those involving lambs:100 ewes were excluded. We detected no significant differences in the regression elevations for any of the pre- and post-augmentation comparisons evaluated (Table 2).

Seven of the 9 models conducted using data from the full time series exhibited significant trends (i.e., slope coefficients $\neq$ 0; Table 3). The sheep population on Steens Mountain proper decreased in both total count and population size estimates over the period from 1992-2009, although lambs:100 ewes increased slightly over the same time period. All three population metrics (total counts, population size estimates, and lambs:100 ewes) increased significantly in the Leslie Gulch herd during approximately the same time period (1994-2009; Table 3, Figure 2). However, only the data for total counts exhibited a significant temporal trend in the larger Steens metapopulation: decreasing over time after the data were standardized to account for the number of populations inventoried in each year (Table 3; Figure 2).

DISCUSSION

Both the Steens Mountain and Leslie Gulch populations of bighorn sheep appeared to exhibit changes in some demographic parameters after augmentation, but the form of these potential responses to experimental genetic management differed between the populations. At Steens Mountain, we detected a change from a strong declining trend in population size estimates prior to augmentation to a relatively stable population size after augmentation. The standardized data from the larger Steens metapopulation followed a pattern similar to that of Steens Mountain, but, unlike the herd on the mountain proper, we were unable to assign statistical significance to the

Table 3. Population metrics for the Steens Mountain, Steens Mountain metapopulation and Leslie Gulch bighorn sheep herds in Oregon pre- and post- genetic augmentation. Total Counted = number counted during classification surveys; N-hat = ODFW modeled population estimates; lambs:100 = Lambs per 100 ewes. For Steens metapopulation, we calculated the average value among all populations for which the metric was reported in each year. To calculate full trends we combined pre- and post- data. The different slopes column contains p-values indicating a difference between pre- and post-augmentation trends. The different elevations column contains a p-value from secondary hypotheses tests indicating differences in regression elevations if regression trends did not differ. Our α for all tests was 0.05. Significant values are in bold.

	Total Counted										
	Pre-			Post-			Full				
Study Site	Slope	R^2	p-value	Slope	R^2	p-value	Slope	R^2	p-value	Diff. Slopes	Diff. Elev.
Steens Mountain	-2.676	0.031	0.675	**-9.233**	**0.639**	**0.010**	**-3.898**	**0.280**	**0.029**	0.347	0.388
Steens Metapopulation	-3.463	0.291	0.168	-1.190	0.260	0.161	**-3.055**	**0.233**	**0.050**	0.356	0.885
Leslie Gulch	-0.786	0.009	0.839	1.600	0.014	0.827	**9.581**	**0.717**	**< 0.001**	0.771	0.168
	N-Hat										
	Pre-			Post-			Full				
	Slope	R^2	p-value	Slope	R^2	p-value	Slope	R^2	p-value	Diff. Slopes	Diff. Elev.
Steens Mountain	**-10.25**	**0.916**	**< 0.001**	-2.530	0.483	0.305	**-4.641**	**0.646**	**0.003**	**0.044**	-
Steens Metapopulation	**-5.321**	**0.623**	**0.035**	1.644	0.043	0.656	2.011	0.173	0.138	0.127	0.453
Leslie Gulch	-1.786	0.050	0.630	-	-	-	**8.690**	**0.502**	**0.049**	-	0.167
	Lambs:100										
	Pre-			Post-			Full				
	Slope	R^2	p-value	Slope	R^2	p-value	Slope	R^2	p-value	Diff. Slopes	Diff. Elev.
Steens Mountain	-0.014	< 0.001	0.987	-0.250	0.012	0.779	**0.700**	**0.253**	**0.040**	0.846	0.159
Steens Metapopulation	0.134	0.003	0.900	0.450	0.039	0.610	-0.393	0.085	0.255	0.817	0.342
Leslie Gulch	2.036	0.307	0.196	-0.971	0.030	0.741	**1.583**	**0.434**	**0.014**	0.372	0.304

difference of estimated population size trends from sharply decreasing pre-augmentation to a more neutral pattern after augmentation. Over the course of our full time series, both Steens Mountain and the larger Steens metapopulation trended downward in the total number of sheep counted and the average number of sheep counted per herd during inventories, respectively. A slightly different pattern emerged in the full time series of population size estimates: Steens Mountain again trended downward overall, but average population size estimates for the larger Steens metapopulation were statistically stable over time. In fact, though both of our abundance metrics decreased over the full course of the study, the metapopulation maintained a large number of bighorn sheep overall ($\widehat{N}$ = 701 in 2009).

The spatial dispersion of mountain sheep populations is defined by the patchy distribution of the rugged habitat on which they depend (Geist 1971). These disjunct populations are subject to relatively common extinctions (Berger 1990, Torres et al. 1994), but individual movements between local populations also are common (Schwartz et al. 1986, Bleich et al. 1996). Steens Mountain contains the most sheep of any herd in the larger Steens metapopulation, and, while we would not have expected a metapopulation level response to the augmentation of one population to emerge within the time frame of our study, a continued decline of inventory metrics for the mountain proper may have presaged the natural extinction and recolonization profile symptomatic of true metapopulations (Hanski and Gilpin

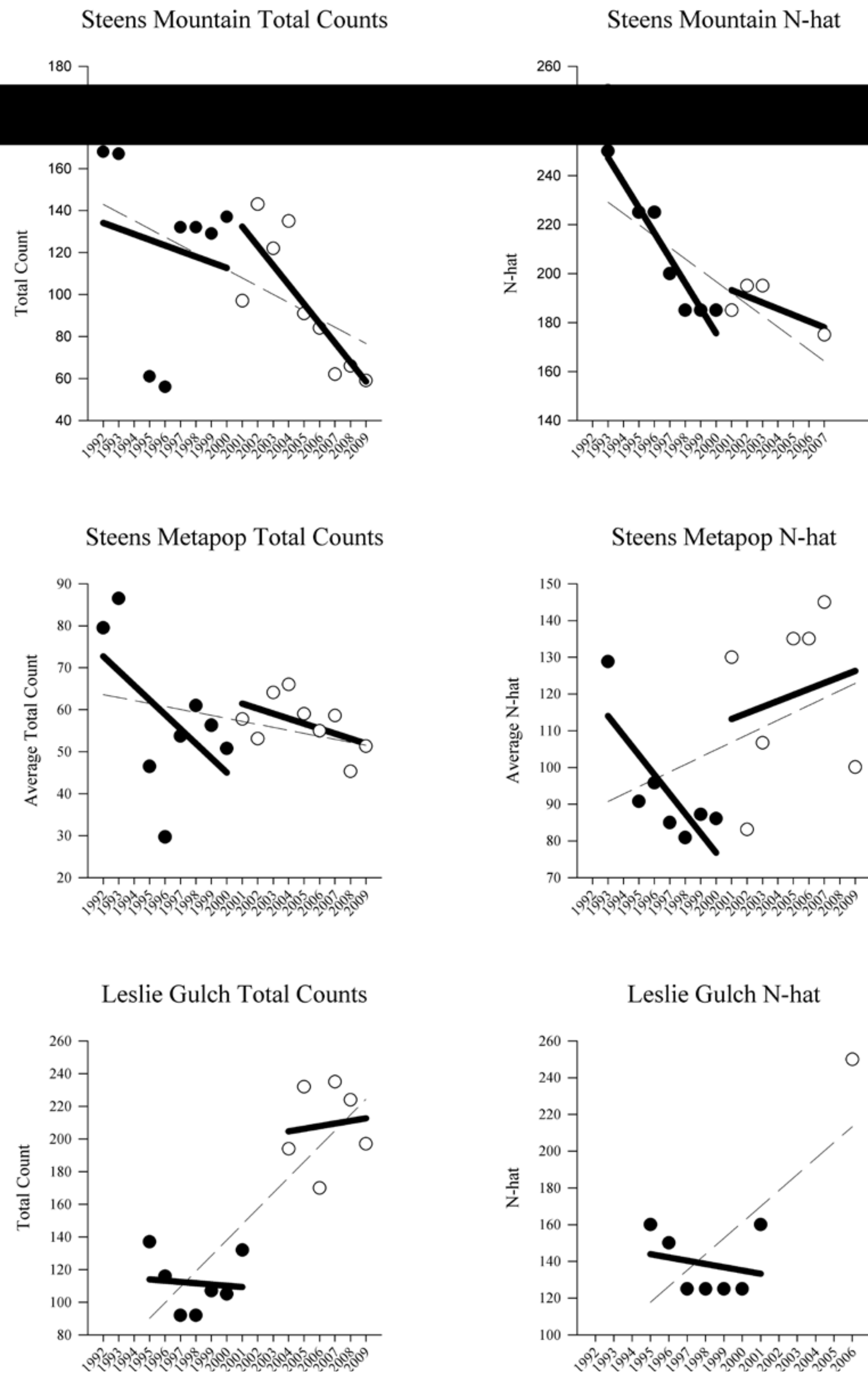

Figure 2. Trends in total count and population size (n-hat) for the Steens Mountain, Steens metapopulation, and Leslie Gulch bighorn herds pre- and post- genetic augmentation. Solid lines represent pre- and post-augmentation regressions whereas hashed lines represent regressions including the full time series.

1997). Alternatively, the change we documented from strongly declining population sizes to a more neutral trend at Steens Mountain suggests that the genetic augmentation could have stabilized the population. This demographic change was possibly aided by the increasing trend in lamb production we observed over the full course of the study. However, understanding how a response by one herd will influence population trends in the metapopulation as a whole will require much longer time series of herd inventory data.

In contrast to the neutral trend exhibited by the Steens Mountain herd after augmentation, all available population metrics for the Leslie Gulch herd (total counts, populations estimates, and lambs:100 ewes) exhibited significant positive trends over the full time series (1994 to 2008; Fig. 2), indicating strong recruitment after experimental genetic management in this herd. Although none of the pre- and post-augmentation data series exhibited significant trends or different elevations, we suspect this was the result of a lack of power due to the small number of data points available for each of these models. The extent of the change exhibited by the Leslie Gulch herd after experimental genetic management was evident in the series of population size estimates: the most recent estimate ($\widehat{N}$ = 250), from 2006, was 56% larger than the last estimate prior to augmentation ($\widehat{N}$= 160 in 2001). While it is probable that other unmeasured variables were also involved in this increase, we expect that the augmentation played at least some role in driving the increased abundance of bighorn sheep in Leslie Gulch. In fact, genetic analyses revealed strong integration of augmented genotypes into both Steens Mountain and Leslie Gulch herds approximately one generation post-augmentation (Z. Olson, unpublished data), which indicates successful breeding among augmented ewes and survival of the resulting offspring. Thus, the changes exhibited by our study populations after their respective augmentations, although manifesting differently in Steens Mountain and Leslie Gulch, potentially were affected by the experimental genetic management.

There are a number of plausible mechanisms by which the change in demographic parameters exhibited by the Steens Mountain herd could have differed from that of the Leslie Gulch herd. For example, fewer transplanted ewes from the genetic augmentation could have integrated reproductively at Steens Mountain than in Leslie Gulch. Lower rates of reproductive integration could have occurred because of different reproductive success due to stress from the initial capture and release (e.g., Pelletier et al. 2004) or because of mortality after the transplant. However, the translocated ewes for both herds were subjected to similar capture conditions and radio-tracking after the augmentation indicated that no immediate mortality was evident for the augmented individuals of either herd (D. G. Whittaker, unpublished data). Nor were there obvious climatic differences (i.e., mean average temperature and precipitation) between pre- and post-augmentation periods for either Steens Mountain or Leslie Gulch (data not shown). In terms of resource availability, Leslie Gulch received 11 guzzlers designed to increase the availability of water in bighorn habitat since 1980, although the installation dates did not correspond with the augmentations in this study (i.e., two were installed in 1980 and the remaining nine were installed since 2004; S. Torland, unpublished data).

Different rates of predation between Steens Mountain and Leslie Gulch also could have led to different responses by the populations to augmentation. While it is unlikely that smaller predators such as coyotes (*Canis latrans*), golden eagles (*Aquila chrysaetos*), and bobcats (*Lynx rufus*) affect the growth of Oregon's bighorn sheep populations (Lawson and Johnson 1982), cougars are known to be efficient predators of bighorn sheep (ODFW 2003). This is particularly true where individual cougars have specialized in preying on bighorns (Festa-Bianchet et al. 2006). However, cause-specific mortality based on radiotelemetry from Steens Mountain and Leslie Gulch after augmentation has not indicated disparate levels of cougar predation between the herds (D. G. Whittaker, unpublished data). Further, we found no difference in the number of cougars killed (as a simple index of abundance) on Steens Mountain (N = 12) and in Leslie Gulch (N = 8) from 2005-2008 (ODFW 2009; χ^2 = 0.800, df = 1, P = 0.371). These data suggest that cougar abundance and resultant predation are not likely the driving factors causing differing responses to augmentation by the bighorn sheep on Steens Mountain and in Leslie Gulch. While there can be little doubt that physical and environmental differences exist between the Steens Mountain and Leslie Gulch study areas, our study design was uniquely capable of documenting population level changes around a single, definite commonality between the populations: our experimental genetic augmentations.

Our results are not confirmatory, but we can infer from the demographic changes we observed in Steens Mountain and Leslie Gulch after experimental genetic management that inbreeding depression could have played a role in the declines reported previously for those herds (Whittaker et al. 2004). Inbreeding depression results from matings between related individuals which increases the chance that offspring from such matings will express deleterious traits and have reduced viability (or reduced fitness; Ralls et al. 1988, Keller and Waller 2002, Slate et al. 2004). In the case of wild populations, there was considerable debate as to whether inbreeding depression could have demonstrable impacts on populations (Lande 1988, Caro and Laurenson 1994). Nevertheless, more recent evidence from a variety of wild populations suggests that the effects of inbreeding may be more common in the wild than previously suspected (Keller and Waller 2002).

While demographic evidence of a response to genetic management may be indicative of a reduction in inbreeding depression due to the influx of new genetic diversity, further evidence is necessary to support this hypothesis before conclusions can be drawn about the success of experimental genetic management in 2 herds of bighorn sheep in Oregon. We are conducting further research using molecular markers to investigate the genetic contribution of the translocated females at Steens Mountain and in Leslie Gulch, and this should provide us with a more direct measure of reproductive integration. If the responses we observed were due to factors other than inbreeding depression, we would expect the demographic response to have come from some segment of the whole population, including at least some of those lineages present before the augmentation. Alternatively, if the response of bighorns in the Steens Mountain and Leslie Gulch herds was the result of a genetic rescue effect, we would expect the demographic response to be driven mostly by the progeny of the translocated individuals. Our forthcoming investigation should further elucidate the role that inbreeding depression played in the previous declines observed in the Steens Mountain and Leslie Gulch herds of bighorn sheep.

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A Genome Wide Set of SNPs Detects Population Substructure and Long Range Linkage Disequilibrium in Wild Sheep

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Abstract: Single nucleotide polymorphisms (SNPs) provide several advantages over other genetic markers including: abundance in the genome, distribution in both expressed and intronic sequences, and ease of genotyping through automation. Therefore, SNPs are fast becoming the genetic marker of choice for addressing a wide variety of evolutionary and population genetic questions. However, the development of large scale SNP resources for wild species is still in its infancy. Cross-species utilization of technologies developed for their domestic counterparts has the potential to unlock the genomes of organisms that currently lack genomic resources. Here we apply the OvineSNP50 BeadChip, developed for domestic sheep, to two related wild ungulate species: the bighorn sheep (*Ovis canadensis)* and the thinhorn sheep (*Ovis dalli*). Over 95% of the domestic sheep markers were successfully genotyped in bighorn sheep while over 90% were genotyped in thinhorn sheep. Pooling both species we found 868 SNPs distributed on all autosomes and the X-chromosome. This panel of SNPs was able to discriminate between the two species, assign individuals to their population of origin, and detect substructure within a population corresponding to known family groups. Further application of these markers to multiple populations holds the prospect of dramatically informing and enhancing existing management strategies that currently rely on demographics and population structure estimates inferred from a few neutral markers.

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Evolutionary History of North American Wild Sheep: Morphometric and mtDNA Analyses

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***Abstract**:* Since this research was discussed at the meeting 4 years ago, the first author has added a significant number of samples to the DNA sequence data bases of two mtDNA genes (control region and ND5), and increased the amount of ND5 sequence by 50%. Additional samples were chosen to fill in geographic gaps in the data for the desert and Rocky Mountain region. Samples also were chosen to allow comparison of phylogenetic analyses based on sequence and RFLP data. The latter were developed in the 1980s by Rob Ramey and Gordon Luikart, and we were able to develop sequence data from a wide sampling of the same DNA samples they used. Cranial morphometric analyses have found 5 defensible groups of sheep in North America: 2 thinhorn subspecies and 3 bighorn subpspecies. However, phylogenetic analyses of mtDNA sequences indicate a complex evolutionary history that results in trees that do no coincide entirely with the morphometric data. For instance, morphometrically there is one well-defined group of Rocky Mountain bighorn, but there are two mtDNA clades of Rocky Mountain bighorn sheep. To complicate this further, 2 of 3 distinct mtDNA lineages of thinhorn sheep are on the bighorn sheep clade, including a group from the Brooks Range. This complex pattern reflects a phenomenon known as cytonuclear dissociation or mtDNA capture, which results from directional hybridization events associated with habitat and climate change. Yet further complicating this is strong evidence of 2 colonizations of North America by Siberian Snow Sheep. I will discuss how well RFLP data elucidated these complex patterns and the limitations of mtDNA analyses in general relative to taxonomic divisions, given the potential problem of cytonuclear dissociation.

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Status of the Mummy Range Subpopulation of Bighorn Sheep *(Ovis canadensis)* at Rocky Mountain National Park, Colorado

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***Abstract*:** In 2009 a report was completed to review the history of bighorn sheep in Rocky Mountain National Park, to compile existing research, data and information with emphasis on Mummy Range herd, to identify gaps and/or inconsistencies in knowledge regarding that subpopulation, to potentially clarify those inconsistencies and gaps with current literature on sheep populations from across North America, and to identify management considerations and future research for the Mummy Range subpopulation of bighorn sheep at Rocky Mountain National Park. Existing data was compiled to assess mineral use and deficiencies, habitat use, dietary information, disease, and the role of transplants/removals, interspecific interactions, genetic exchange, and human disturbances on sheep productivity and survival. Synthesis of research on sheep biology, physiology, behavior, and management appear to support priority areas identified at a workshop of key stakeholders held in February 2008 as well as identify other research that may warrant consideration – especially with regard to the band of sheep along the Mummy Range. Though numerous stressors exist and are further complicated by the removal of 135 animals over eight years, reported population estimates over time indicate that age/sex ratios may be relatively stable throughout the Mummy Range. Continued caution is encouraged, however. Numerous opportunities exist to expand current research or further analyze available data to fill gaps in knowledge that may lead to better understanding of potential threats to this herd.

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Estimating Survival Rates of Reintroduced Bighorn Sheep Before and After Exposure to Domestic Sheep

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Abstract: Much has been written regarding the consequences of bighorn sheep (*Ovis canadensis*) and domestic sheep interactions. Penned and field studies have documented bighorns dying shortly after exposure to domestic sheep; however, debate surrounding this controversial topic still exists. From 2000 to 2009, the Utah Division of Wildlife Resources has conducted 11 translocations and released 249 bighorns (143 collared females) onto four mountain ranges in northern Utah. We used Program MARK to estimate monthly survival rates (S) of bighorns before and after contact with domestic sheep. We investigated how disease contracted through interaction with domestic sheep influenced bighorns that were released at different times and from different source populations. In each population, we considered bighorns initially reintroduced as resident animals, whereas bighorns released in subsequent years were considered augmented animals. We observed bighorns interacting with domestic sheep in three populations (Rock Canyon, Mount Nebo, and Mount Timpanogos). Survival for resident and augmented bighorns in Rock Canyon was $S = 0.986$ before exposure to domestic sheep and decreased significantly for resident ($S = 0.778$), but not for augmented bighorns ($S = 0.974$) after exposure. Bighorns on Mount Nebo experienced similar results; survival for resident and augmented bighorns was $S = 0.996$ before exposure to domestic sheep and decreased to $S = 0.750$ for resident and $S = 0.985$ for augmented bighorns after exposure. Although we documented bighorns interacting with domestic sheep on Mount Timpanogos, survival remained constant ($S = 0.983$) for resident and augmented bighorns before and after exposure. To our knowledge, bighorns on the Stansbury Mountains never interacted with domestic sheep, and survival was constant ($S = 0.997$) throughout the study for resident and augmented animals. Our results indicate that disease did not spread uniformly throughout populations of bighorns, because resident bighorns suffered greater mortality after contact with domestic sheep than augmented bighorns. Additionally, our data indicate that not all interactions between bighorns and domestic sheep were fatal, but when dieoffs occurred, they were acute. Finally, our results re-emphasize the importance of spatial separation between bighorn sheep and domestic sheep.

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Comparative Studies of Sympatric Bighorn Sheep and Mountain Goats in the Greater Yellowstone Area

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Abstract: Mountain ranges of Montana and Wyoming within the Greater Yellowstone Area (GYA) comprise one of the core ranges for bighorn sheep in North America. Following mountain goat introductions in the Montana and Idaho portions of the GYA from the 1940s through the 1960s, there has been a progressive increase in the abundance and distribution of non-native mountain goats. Mountain goats and bighorn sheep now share seasonal ranges in many parts of the GYA, but little is known about competitive interactions between these two mountain ungulates. The limited information available indicates potential for dietary overlap in some seasons and behavioral dominance of goats over sheep when foraging in the same areas, which suggests that bighorn sheep may be sensitive to inter-specific competition. In addition, bighorn sheep are well known for their sensitivity to a variety of diseases that can cause episodic die-offs that result in substantial population reductions. Though mountain goat populations do not appear to be susceptible to disease die-offs to any appreciable extent, mountain goats are effective hosts for a variety of parasites and pathogens that may also infect bighorn sheep. Thus, information regarding potential competition, disease transfer, and/or displacement of bighorn sheep by mountain goats is a key issue for natural resource managers in this region. We have initiated a 5-year research effort to address these biological questions and will report our initial efforts to consolidate all mountain goat and bighorn sheep records for the GYA to better understand mountain goat range expansion from the initial introduction sites and current seasonal distributions. These data were used to evaluate published habitat models for both species and the development of new habitat models for mountain goats in the GYA to help predict future distributions of mountain goats as this species continues to expand its range.

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Winter Tick Infestation and Associated Hair Loss on Stone's Sheep in Northern British Columbia

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Abstract: Stone's sheep (*Ovis dalli stonei)* at low elevations along the Williston Reservoir in northern British Columbia exhibit hair loss in late winter similar to that seen in moose (*Alces alces*) affected by winter ticks (*Dermacentor albipictus*). We conducted 80 examinations of 43 Stone's sheep in the Dunlevy and Schooler herds, 63 on sheep wintering at low-elevation (700–1,200 m) and 17 on sheep wintering at high-elevation (1,400–1,900 m) in March/April between 1999 and 2004. We classified tick-associated hair loss into five categories based on affected proportion of the torso: None (<1%), Very Low (1-5%), Low (6-15%), Moderate (16-30%), and High (>30%). We found the incidence and degree of winter tick infestation and tick-associated hair loss in late winter varied by Stone's sheep migratory type, showing a relationship with seasonal elevation use by Stone's sheep during the critical tick life stages. The probability of tick-induced hair loss in sheep decreased with increasing elevation, with late winter hair loss generally highest in Low Resident sheep (year-round residents at low elevation), lower in Migratory sheep (those that descended from high elevation habitat to low elevation winter ranges after 31 October), and absent in High Resident sheep (year-round alpine residents). Lambs were more affected by ticks than adult sheep. Rocky Mountain elk (*Cervus elaphus*) introduced to the area in the mid-1980's are the most abundant ungulate in the area, and likely the primary host for winter ticks. Spatial overlap of sheep and elk occurred in both spring, when engorged adult female winter ticks drop off their ungulate hosts to lay eggs on the ground, and fall, when winter tick larvae are seeking new hosts. The common use of grassland and deciduous habitat classes by elk and sheep during these seasons likely results in ticks being shared between species. Although it appears that both sheep and elk are perpetuating the winter tick cycle in the area, given the degree to which Stone's sheep are tied to specific localized escape terrain features it is possible that the sheep/tick cycle could now be self-supporting without secondary hosts. While our study confirmed the presence of winter ticks and tick-associated hair loss in sheep using low elevation winter ranges, we did not find evidence of direct mortality or serious population level impacts resulting from tick infestation.

Key words: *Dermacentor albipictus,* hair loss, low elevation, mortality, *Ovis dalli stonei*, Stone's sheep, winter range, winter ticks

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Using Microsatellites to Identify Mountain Goat Kids Orphaned During Capture and Translocation Operations

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Abstract: We used molecular markers to test the hypothesis that orphaned mountain goat (*Oreamnos americanus*) kids were driving recent observations of kid mortality in translocated groups in Oregon. To address this hypothesis we collected genetic samples (N = 55) during 3 years of mountain goat captures (2007-2009) in the Elkhorn Mountains of Oregon. Using genotypes from these samples at 12 microsatellite loci, we conducted parentage analyses and estimated relatedness within each year's translocation group to identify kids without a mother. Based on the results of our parentage analyses, 6 of 15 kids were assigned to potential mothers with a level of confidence < 80%, levels at which the validity of the assignment is questionable. Using the more liberal assignments based on maximum likelihood estimates of relatedness, 3 of 15 kids could not be assigned to a mother within their capture group. Therefore, at least 3 kids (20% of 15 total) but as many as 6 kids (40%) were orphaned as a result of translocation operations. In addition, at least 4 but as many as 6 candidate mothers that were not assigned to a kid were lactating at the time of capture. Thus, orphaning of mountain goat kids may have occurred as a result of mothers being transported without their offspring as well as through offspring being transported without their mothers. Our results indicate that biologists conducting translocations of mountain goats should anticipate some orphaning as a result of capture operations.

KEY WORDS *Oreamnos americanus*, orphans, parentage analysis, reintroduction, relatedness, mountain goat, supplementation, translocation.

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Translocations are a commonly used tool in the conservation and management of wildlife species (Griffith et al. 1989, Fischer and Lindenmayer 2000). Many large fauna in North America have benefitted from reintroduction campaigns with success stories including white-tailed deer (*Odocoileus virginianus*; DeYoung et al. 2003), Rocky Mountain elk (*Cervus elaphus*; Hicks et al. 2007), and bighorn sheep (*Ovis canadensis*; Krausman 2000). Although reintroduction programs have re-established populations of many species to areas throughout their historic ranges, the success of individual reintroductions often is not assured (Risenhoover et al. 1988, Fischer and Lindenmayer 2000).

Of the factors affecting the success of reintroductions, the size of translocated groups has been shown to have a dramatic impact on population persistence (Forsyth and Duncan 2001). Large group sizes hasten the growth of populations away from small population sizes, effectively buffering them from the negative effects of demographic and environmental stochasticity (Lande 1988), Allee effects (Deredec and Courchamp 2007), and inbreeding and genetic drift (Lacy 1987, Keller and Waller 2002). All of these processes affect small populations more than large populations (Pimm 1991) and could potentially act to create an extinction vortex (Gilpin and Soulé 1986). Thus, improvements in the efficiency of translocations, either in terms of increasing the group size associated with translocations or by improving survival of translocated individuals, can improve the success of supplementations or reintroductions (Rhodes and Latch 2010).

Oregon Department of Fish and Wildlife (ODFW) has been conducting mountain goat (*Oreamnos americanus*) translocations since 1950, when the first successful reintroduction of mountain goats to Oregon took place in the Wallowa Mountains (Coggins et al. 1996). Since that reintroduction Oregon's mountain goats have increased in number to over 800 animals (Myatt 2010), due in large part to a translocation campaign intended to restore goats to their historic range across the state (ODFW 2003). However, during recent capture efforts, ODFW biologists noticed poor kid survival after translocation (Myatt et al. 2010). One hypothesis proposed to explain high kid mortality after translocation was that translocated groups could include orphaned kids. Due to the logistical challenges associated with staging capture operations in the alpine environment that mountain goats inhabit (e.g., poor access), goat captures in Oregon occur during times of year when kids are dependent on their mothers (Rideout and Hoffmann 1975). Thus, orphaning could occur if dependent kids are captured and translocated without their mothers in the group or vice versa.

Identifying the prevalence of orphans resulting from mountain goat capture operations is important because it is likely that orphaned kids exhibit poor survival in translocated groups. While understanding that there is an ethical obligation to improve kid survival after translocation, from a biological perspective orphaning of goat kids could also effectively reduce translocation group size: a critical component in the long-term success of reintroductions and supplementations. In addition, recent simulations have predicted that juveniles in reintroductions may be even more valuable than adults in terms of population persistence when genetics and demography were considered simultaneously (Robert et al. 2004). Alternatively, the negative aspects of orphaning mountain goat kids may not be restricted to the reintroduced population. Although productivity is expected to be reduced in the source population due to the export of captured individuals, further reduced productivity could occur if capture operations orphan kids at the site of capture by translocating their mothers.

In this study we used a suite of microsatellites, a type of molecular marker that is hyper-variable and biparentally-inherited, to address the hypothesis that mountain goat capture operations resulted in the orphaning of goat kids. We used parentage analysis and estimates of relatedness derived from our suite of molecular makers to assign kids in each capture group to candidate mothers. Thus, kids that we could not assign to a mother likely would be orphans. The specific objectives of this study were to 1) identify the proportion of goat kids captured without their mother as a result of translocation operations, and 2) identify the proportion of lactating mothers captured and translocated without an associated kid during capture operations.

STUDY AREA

Mountain goats were captured at Goodrich Lake in the Elkhorn Mountains of northeastern Oregon. The Elkhorns, a part of the larger Blue Mountains, are located immediately west of Baker City, and rise approximately 5,000 ft from adjacent Baker Valley (Johnson 2004). A population of mountain goats was re-established in the Elkhorns through reintroduction efforts in 1983-1986 that involved 21 goats translocated from Idaho, the Olympic Peninsula of Washington, and Misty Fjord in Alaska (Coggins et al. 1996). The Elkhorn population has increased steadily since reintroduction: 301 goats were counted during the 2010 herd inventory conducted by ODFW (Myatt 2010). As such, the Elkhorn population has been valuable as a source for mountain goat translocations in Oregon since 2000.

METHODS

Field Methods

Goats were captured using a drop-net once each July from 2007-2009. The net was baited with salt and dropped on a group only when we noted no other goats in visible range of the net. Groups were observed for a considerable amount of time in order to ensure that nanny-kid groups were not accidentally separated when the net was dropped. Once captured, we blindfolded and hobbled goats prior to recording their sex, age, and lactation status if applicable. We tagged all individuals with uniquely numbered ear-tags and some received radio-collars as part of a larger study of goat movement behavior and survival. Tissue samples were collected from each goat for genetic analysis using a 6.3-mm (i.e., 0.25-inch) ear punch, and sampling equipment was sterilized between each use to avoid cross-contamination. Each sample was stored in a 2 mL screw-top vial filled to 1 mL with desiccant beads. The vials were shipped immediately to the genetics lab at Purdue University where full desiccation of the sample was ensured before samples were stored at -80° C until DNA extraction.

Laboratory Methods

Genomic DNA was extracted using a modified ammonium acetate protocol (see Fike et al. 2009). Quality of the extracted DNA was assessed visually using gel electrophoresis prior to DNA quantification on a NanoDrop 8000 spectrophotometer (Thermo Scientific, Waltham, MA, USA). Genomic DNA was stored at -80° C after an aliquot of working stock was diluted to 20 ng/µL.

From each sample we used polymerase chain reaction (PCR) to amplify 13 microsatellite loci (Table 1). These loci were chosen from a suite of those used in previous mountain goat studies based on their level of polymorphism and ease of amplification in our lab. The PCR amplification of genomic DNA was carried out in 10-µL reactions which consisted of 20 ng DNA template, 0.25 µM of each primer, 0.2 mM of each dNTP, 1.25 mM $MgCl_2$, 1× reaction buffer (10 mM Tris-HCL, 50 mM KCL, 0.05 mg/µL BSA), and 1 unit of *Taq* DNA polymerase. We used the following thermocycler profile for all loci: 94 °C for 2 min; 30 cycles of 94 °C for 30 sec, locus-specific annealing temperature (Table 1) for 15 sec, and 72 °C for 15 sec; then 72 °C for 10 min and a final extension at 60 °C for 45 min. PCR amplification products were

Table 1. Microsatellite loci used in this study were genotyped in 55 mountain goats captured in the Elkhorn Mountains of northeastern Oregon during 2007-2009. Listed for each locus are number of alleles (A), annealing temperature (T_A), observed (H_O) and expected (H_E) heterozygosity, and a test of Hardy-Weinburg proportions (F_{IS}) with its associated p-value.

Marker[a]	Primer Sequence (5' → 3')	Allele size range (bp)	A	T_A (°C)	H_O	H_E	F_{IS}	P
LS15[4]	F: gtagaaacccctaaagattc R: ctgagtgttaattttctatcct	98-116	5	60	0.661	0.638	-0.036	1.000
OarCP26[2]	F: gcctaacagaattcagatgatgttgc R: gtcaccatactgacggctggttcc	129-148	3	64	0.500	0.434	-0.169	1.000
BM121[1]	F: tggcattgtgaaaagaagtaaa R: actagcactatctggcaagca	162-176	6	60	0.893	0.774	-0.215	0.013
INRA3[7]	F: ctggaggtgtgtgagccccattta R: ctaagagtcgaaggtgtgactagg	201-228	5	64	0.625	0.651	0.133	0.530
BM203[1]	F: gggtgtgacattttgttccc R: ctgctcgccactagtccttc	244-277	3	64	0.278	0.522	0.673	<0.004
RT9[8]	F: tgaagtttaatttccactct R: cagtcactttcatcccacat	129-137	4	55	0.786	0.679	-0.222	0.247
BM4028[1]	F: acggaagcagcatctcttac R: atggaaacatggtctcctgc	148-150	2	64	0.109	0.167	-0.040	1.000
INRA11[6]	F: cgagtttctttcctcgtggtaggc R: gctcggcacatcttccttagcaac	193-207	5	64	0.429	0.629	0.191	0.375
BM1818[1]	F: agctgggaatataaccaaagg R: agtgctttcaaggtccatgc	243-248	3	60	0.093	0.09	-0.020	1.000
BMS599[5, b]	F: agtaggagctgtcttctgtggc R: gtcactgggacttctctgagc	166-172	6	64				
MCM527[3]	F: gtccattgcctcaaatcaattc R: aaaccacttgactactccccaa	165-169	2	64	0.536	0.502	-0.198	0.450
BMC5221[1]	F: agcaaggagaacaggcattc R: cttctttggcagcacagtttc	185-215	7	64	0.875	0.754	-0.144	0.721
BM1225[1]	F: tttctcaacagaggtgtccac R: acccctatcaccatgctctg	278-290	5	64	0.696	0.665	-0.034	0.604

[a]Originally described in [1]Bichop et al. (1994), [2]Ede et al. (1995), [3]Hulme et al (1994), [4]Maddox et al. (2000), [5]Stone et al. (1995), [6]Vaiman et al. (1992), [7]Vaiman et al. (1994), and [8]Wilson et al. (1997)

[b] Locus BMS599 was difficult to score and was removed from all analyses

electrophoresed at the Purdue Genomics Core Facility on an ABI 3730xl automated sequencer (Applied Biosystems, Carlsbad, CA, USA). The electrophoretic data were imported into GeneMapper version 3.7 (Applied Biosystems) where fragments were sized based on internal ROX size standards (DeWoody et al. 2004). We used the following methods to ensure the quality of our microsatellite dataset: (i) allelic standards were included for each locus in each submission to the core facility, (ii), an experienced researcher independently scored each locus/sample combination to assess genotyping error rates, and (iii) all ambiguous or low-quality genotypes (signal strength <100 in GeneMapper) were re-amplified to confirm the genotype.

Data Analysis

We used program CREATE version 1.33 (Coombs et al. 2008) to facilitate data conversion for all analyses. We tested for locus-specific deviations from Hardy-Weinberg equilibrium (HWE) using Fisher's exact tests and for pairwise deviations among loci from linkage equilibrium in GENEPOP version 4.0 (100,000 steps in the Markov chain; 100 batches with 1000 iterations; Raymond and Rousset 1995). We used only genotypes from adult goats (i.e., > 1 year old) in these tests to avoid violating assumptions associated with sampling across generations. Deviations from equilibrium expectations were assessed for significance after correction for multiple tests using Bonferroni's method (Rice 1989). Using the full dataset, we calculated the number of alleles, observed heterozygosities, and expected heterozygosity for each locus in program GENALEX version 6.3 (Peakall and Smouse 2006). Because there is some uncertainty involved in the assignment of offspring to parents when the sample of candidate parents is incomplete or when using a finite number of molecular markers (Glaubitz et al. 2003, Jones and Ardren 2003), we used 2 methods to identify mountain goat orphans from our genetic data.

First, we conducted parentage analysis using program CERVUS version 3.0 (Kalinowski et al. 2007) to identify likely mother-offspring dyads within each capture group. Separate analyses were conducted for each group (i.e., goats captured in 2007, 2008, and 2009), but genotype frequencies were simulated using the full dataset. Within each capture group we identified offspring as goat kids (i.e., goats < 1 year old) and candidate mothers as nannies ≥ 2 years old. Within CERVUS, we simulated 10,000 offspring genotypes with the proportion of loci mistyped set to 1.0%. The sampling rate was set to 80% based on the observations of field personnel.

CERVUS uses simulated genotypes to create a critical likelihood value (critical ΔLOD; where a LOD score is the logarithm of the likelihood ratio) beyond which there is some level of confidence in a mother-offspring dyad. Briefly, LOD scores are calculated for the most-likely candidate mother and the second most-likely mother for each offspring. Then, the difference between the ratios is compared to the critical ΔLOD in order to assign confidence in the pairing (Marshall et al. 1998). In this study, assignments were made at a relaxed level of 80% confidence and a strict level of 95% confidence which are standard for the program. Loci exhibiting a heterozygote deficit were excluded from this analysis. Although there are many causes of heterozygote deficiency, null alleles are particularly problematic in parentage analysis (Dakin and Avise 2004).

The second method we used to identify goat orphans was via maximum likelihood estimates of relatedness calculated in program ML-Relate (Kalinowski et al. 2006). Offspring and candidate mothers were defined as above within each capture group. ML-Relate produces a matrix containing the most likely of 4 relationship categories for each pair of individuals (i.e., unrelated, half-sib, full-sib, or parent-offspring). Thus, to identify putative goat orphans, we recorded all offspring lacking a parent-offspring assignment to any candidate mother in their capture group. Then, for those putative orphans, we specifically tested any assigned relationship to a candidate mother (i.e., at the half-sib or full-sib level) to determine if that relationship was statistically more likely than a parent-offspring relationship (using the specific hypothesis test option with 100,000 simulated genotypes in ML-Relate). Putative orphans with statistical support for each of such assignments were considered true orphans. Because ML-Relate is capable of adjusting its simulation to accommodate null alleles where they have been identified *a priori* (Kalinowski et al. 2006), loci exhibiting heterozygote deficits were retained in this analysis, but were flagged as potentially harboring null alleles.

Although mountain goat kids usually remain close to their mother for the first year of life (Rideout and Hoffmann 1975), it is possible for capture operations to orphan kids at the site of capture by translocating a mother without her kid as opposed to translocating a kid without its mother. We identified potential instances of orphaning at the site of capture by noting lactating candidate mothers that remained unassigned to a kid from our analyses.

RESULTS

We successfully extracted genomic DNA from all mountain goat samples (N = 55). Cohort size was 19 in 2007 including 5 kids and 10 candidate mothers (i.e., nannies > 2 years old), 19 in 2008 including 6 kids and 8 candidate mothers, and 17 in 2009 including 4 kids and 5 candidate mothers. One microsatellite locus, BMS599, was difficult to score and was excluded from all analyses. Our genotyping error rate for the remaining 12 loci was < 0.5 % overall and our missing data rate was < 4.0 % for each locus (i.e., 2 missing genotypes) and was < 1.0 % overall. Locus BM203 exhibited a significant deficit of heterozygotes ($P < 0.004$, Table 1). Thus, we excluded this locus from analyses in program CERVUS, but retained it for our analyses using program ML-Relate after we flagged the locus as potentially harboring null alleles. No pair of loci deviated from linkage equilibrium after corrections for multiple tests (i.e., all $P > 0.0003$).

Parentage analysis allowed us to assign 3 of 5 offspring to mothers in the 2007 group, 3 of 6 offspring to mothers in the 2008 group, and 3 of 4 offspring to mothers in the 2009 group with confidence exceeding the relaxed assignment threshold of 80% (Table 2), which is a standard threshold for the program and commonly used in parentage studies (e.g., Richardson et al. 2001). Thus, our analysis revealed the potential for 2 orphans in the 2007 group, 3 orphans in the 2008 group, and 1 orphan in the 2009 capture group. These numbers should be interpreted with caution as the likelihood scores used to calculate confidence in CERVUS are dependent on the relative strength of evidence for other candidate mothers. For example, assignments with < 80% confidence can indicate 1) that the assignment was truly unlikely (i.e., that the offspring was an orphan), or 2) that the second-strongest candidate mother was also likely to be the true mother. Thus, these results likely represent the maximum number of orphans in each group.

All mother-offspring dyads identified in program CERVUS were nominally identical to those we identified using the maximum likelihood estimates of relatedness in program ML-Relate (Table 2). However, this analysis revealed 5 putative orphans rather than the 6 identified using parentage analysis (Table 2). Further simulations indicated that 3 putative orphans had statistical support for status as true orphans (Table 3). Therefore, a minimum of 3 mountain goat kids were captured as orphans during 3 years of capture activities.

Based on our parentage analyses, additional potential orphaning occurred at the site of capture in 2008 (N = 4) and 2009 (N = 2) when candidate mothers were identified as lactating but remained unassigned to offspring in the capture group (Table 2). Based on our more liberal estimates of relatedness, potential orphaning at the site of capture similarly occurred in 2008 (N = 2) and 2009 (N = 2). No

Table 2. Assignments of offspring to candidate mothers using parentage analysis (CERVUS) and estimates of relatedness (ML-Relate) derived from genetic data. Samples were obtained from 3 years (2007-2009) of capture operations in Oregon's campaign to restore mountain goats to their historic range in the state.

	CERVUS						ML-Relate	
Year Offspring	Candidate mother	Lactation status[a]	Loci compared (mismatching)		Pair ΔLOD[b]	Pair confidence	Candidate mother	Relation[c]
2007								
RMG10	RMG1	NL	11	(0)	6.07	> 95%	RMG1	PO
RMG11	RMG3	L	11	(0)	3.73	80-95%	RMG3	PO
RMG12	RMG6	NL	11	(0)	4.52	80-95%	RMG6	PO
RMG14	RMG17	NL	11	(0)	0.40	< 80%	RMG17	FS
RMG15	RMG16	unk	11	(0)	0.99	< 80%	RMG16	PO
	RMG4	NL				Unassigned		
	RMG5	NL				Unassigned		
	RMG13	NL				Unassigned		
	RMG19	unk				Unassigned		
	RMG20	unk				Unassigned		
2008								
RMG21	RMG36	L	10	(0)	1.76	< 80%	RMG36	PO
RMG27	RMG24	L	11	(0)	2.28	< 80%	RMG24	PO
RMG28	RMG25	L	11	(0)	2.95	80-95%	RMG25	FS
RMG29	RMG26	L	11	(1)	0.20	< 80%	RMG26	HS
RMG30	RMG36	L	11	(0)	4.51	80-95%	RMG36	PO
RMG31	RMG32	L	11	(0)	5.28	> 95%	RMG32	PO
	RMG22	NL				Unassigned		
	RMG23	NL				Unassigned		
	RMG33	L				Unassigned		
2009								
RMG40	RMG2778	L	11	(0)	4.88	80-95%	RMG2778	PO
RMG41	RMG2279	L	10	(0)	3.33	80-95%	RMG2279	FS
RMG42	RMG2284	L	11	(0)	3.16	80-95%	RMG2284	PO
RMG43	RMG2279	L	10	(0)	-0.11	< 80%	RMG2279	HS
	RMG2282	L				Unassigned		
	RMG2288	NL				Unassigned		

[a]NL= not lactating, L = lactating, or unk = no data

[b]Critical ΔLOD (logarithm of likelihood ratio) was 5.02 for strict (95%) and 2.57 for relaxed (80%) confidence

[c] Most likely relationship: U = unrelated, HS = half-sib, FS = full-sib, and PO = parent-offspring

Table 3. P-values from simulations conducted in ML-Relate to test if the most-likely relationship (i.e., half-sib or full sib) of putative orphans and candidate mothers was significantly more likely than that of a parent-offspring relationship. P-values < 0.05 indicate support for the half-sib or full-sib designation and that a parent-offspring relationship was not likely. Putative orphans with statistical support for each such relationship were considered true orphans.

Putative Orphan	Candidate Mother			
2007	RMG3	RMG6	RMG13	RMG17
RMG14	Half-sib	Half-sib	Full-sib	Half-sib
	<0.001	<0.001	<0.001	0.030
2008	RMG25	RMG33	RMG36	
RMG28	Full-sib	Full-sib	Full-sib	
	0.061	<0.001	<0.001	
	RMG26			
RMG29	Half-sib			
	<0.001			
2009	RMG2279			
RMG41	Full-sib			
	0.057			
	RMG2279	RMG2288		
RMG43	Half-sib	Half-sib		
	0.029	<0.001		

potential orphaning at the site of capture was apparent in the 2007 group (using parentage analyses or estimates of relatedness), although 2 candidate mothers were assigned to offspring even though they were not lactating at their time of capture (Table 2).

DISCUSSION

Mountain goat kids were captured without their mothers at surprisingly high rates: at least 3 kids (20% of 15 captured overall), and potentially as many as 6 kids (40%), were orphans in their translocated groups across 3 years of captures in Oregon. Biologists often strive to achieve the highest, logistically-feasible number of animals in their translocation efforts to maximize the positive effects of supplementation on target populations (Van Houtan et al. 2009) and/or to bolster the ability of introduced populations to resist stochastic demographic processes and avoid potential Allee effects (Deredec and Courchamp 2007, Armstrong and Seddon 2008). Large translocation groups also are a viable strategy to combat reductions in genetic diversity often associated with reintroduction programs (DeYoung et al. 2003, Mock et al. 2004, Hicks et al. 2007, Rhodes and Latch 2010). Thus, it is possible that orphaned goat kids are reducing the effectiveness of expensive capture operations by reducing the size of translocation groups. However, in a concomitant, independent assessment of kid mortality after translocation using radio-collared kids from this study, ODFW biologists identified near complete kid mortality after translocation possibly as a result of kids being separated from their mothers during their release (Myatt et al. 2010). Therefore, while orphaning of mountain goat kids during translocation operations likely reduced the probability of kid survival and, thus, the effectiveness of translocation efforts, other factors such as release method may supersede the impacts of orphaning on kid survival in some instances.

In addition to goat kids being captured without their mothers, another concern associated with capture operations is translocating mothers without their offspring. Mountain goat kids typically are weaned in September (Rideout and Hoffmann 1975) and capture-related orphaning during earlier phases of development undoubtedly increases the risk of kid mortality. The potential for orphaning at the site of capture – identified as lactating candidate mothers that were unassigned to offspring – was evident in 6 of 23 possible assignments (i.e., 26%) from our parentage analysis and 4 of 23 possible assignments (17%) from our more liberal estimates of relatedness. While the prevalence of lactating females that were not assigned to an offspring could track the true rate of orphaning at the site of capture, it is possible that some portion of these candidate mothers experienced kid mortality prior to capture operations, had not yet stopped lactating, and that the true rate of orphaning at the site of capture was slightly lower.

Lactation status failed to predict offspring assignment twice in the 2007 capture group, where candidate mothers identified as not lactating in the field were assigned to offspring. These assignments (supported in both cases by both our analytical approaches) may be indicative of imperfect assessment of lactation status in the field, but could also evidence mothers weaning offspring earlier than has been previously reported (i.e., July as opposed to September; Rideout and Hoffman 1975). Further research will be necessary to address this issue, but these cases may serve to highlight the imperfection of physiological cues that prevent biologists from identifying orphaned goat kids in the field.

Estimates of parentage and relatedness derived from genetic data have found a variety of uses in the field of wildlife management (DeYoung and Honeycutt 2005). Herein we applied parentage analysis and estimates of relatedness to a novel problem in mountain goat management in which we identified offspring without mothers and lactating females without offspring in translocated groups using microsatellite markers. If orphaning reduces kid survival as we would expect, our study could indicate that these translocated groups of mountain goats are effectively smaller than they seem. Biologists should consider the potential effects of orphaning, and the potential for kid mortality independent of orphaning, on translocation group sizes when designing future mountain goat reintroductions and supplementations.

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Re-introduction of California Bighorn Sheep (*Ovis canadensis californicus*) Into the Hellsgate Game Reserve and Addressing Management Needs of Existing Bighorn Sheep Within the Omak Lake Game Reserve on the Colville Reservation

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Abstract: Among the native bighorn sheep that were extirpated during the 1900's were herds that historically occurred within the boundaries of the area now known as the Colville Indian Reservation. The Traditional Territories of the Twelve Tribes of The Colville Confederated Tribes (Chief Joseph Nez Perce, Palus, Moses/Columbia, Wenatchi, Entiat, Chelan, Methow, Southern Okanogan, Nespelem, San Poil, Colville, and Lakes) would have included populations of both Rocky Mountain Bighorn Sheep and California Bighorn Sheep.

The existing California bighorn sheep (*Ovis canadensis californicus*) occurring within the Omak Lake Game Reserve on the Colville Reservation have remained un-hunted, yet stagnant with observed numbers never exceeding 20 animals since the early 1980's. Free-ranging domestic sheep and goats, and the increased potential for disease transmission to occur in their presence, has limited the possibility of augmentation to increase genetic variation or improve population composition. In 2009 and 2010 a total of eight bighorn sheep were captured in the Omak Lake Game Reserve, and fitted with 5 VHF and 2 GPS collars, to establish home range analysis, habitat selection and primary cause of mortality. Blood samples, fecal samples, pharyngeal swabs, and ear swabs were collected from six of the Omak Lake bighorn sheep for genetic analysis, bacteriology, parasitology, and toxicology. In an effort to re-establish a healthy population of bighorn sheep on the Colville Reservation and to provide a source herd for future augmentation of the Omak lake bighorn population, eighty-five California bighorn sheep in four captures were transplanted into historical range in the Hellsgate Game Reserve in 2009 and 2010. Bighorn sheep transplanted into the Hellsgate Game Reserve were released in suitable habitat at two locations approximately seven river miles apart that have experienced varying levels of fire frequency. The first release site experienced a wildland fire event in 2005 and the second release site has not burned for several decades. Twenty three of the transplanted Hellsgate bighorn sheep were fitted with VHF collars and two with GPS collars to measure the possible responses of transplanted bighorn sheep in similar habitats with varying fire frequency using home range analysis, habitat selection, population composition, and cause of mortality.

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Habitat Use of Translocated Bighorn Sheep (*Ovis canadensis*) in North-Central Wyoming: Does Source Herd Matter?

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Abstract: A common strategy to conserve bighorn sheep (*Ovis canadensis*) populations is translocation into historically occupied ranges. However, many translocations have resulted in herds with low productivity, potentially due to a mismatch between source habitats and novel habitats where translocations occur. We evaluated the spatial association and habitat use patterns of bighorn sheep from three source populations that were translocated into the same habitat in Devil's Canyon, Wyoming. We used global positioning system (GPS) locations collected from sheep originating from elsewhere in Wyoming (n=9), Oregon (n=6), and Montana (n=11). Wyoming sheep were translocated in 1973 and thus were considered residents, whereas Oregon and Montana sheep were recent translocations, beginning in 2004 and 2006 respectively. We modeled the relative probability of use for each group as a function of habitat attributes using resource selection functions. Habitat associations suggested that inter-herd differences existed for several habitat attributes, indicating that the three source herds used the same novel habitat in different ways. However, spatial association analysis revealed that rams and ewes from the three groups frequently came into contact during the breeding season, due to large movements by rams. Study findings suggest that cultural differences among translocated source herds influence habitat use but not interbreeding and gene flow.

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Evaluation of the Use of the Escape Terrain and Buffer Model to Depict Northwestern Nebraska's Bighorn Sheep Habitat

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Abstract: The natural range of bighorn sheep (*Ovis canadensis*) historically extended eastward into parts of North Dakota, South Dakota, and Nebraska. Audubon's bighorn (*O. c. auduboni*) historically occurred in this area, but were extirpated in the early 1900s. In 1981, the Nebraska Game and Parks Commission transplanted six Rocky Mountain bighorn sheep (*O. c. canadensis*) into the Pine Ridge region of Nebraska, an escarpment of the Black Hills of South Dakota, in an effort to reestablish this species to the landscape. Since that time, three additional herds have been established in Nebraska. One additional herd was added to the Pine Ridge, and two herds were established in the Wildcat Hills, which lie approximately 100 km southwest. Nebraska's bighorn sheep population currently is estimated at 300 individuals. Systematic monitoring of these herds through radio-telemetry has led to a wealth of data regarding their population dynamics, herd health, and landscape use. We used Zimmerman's (2008) Escape Terrain and Buffer Model (ETBM), which places a 300m buffer around areas with a slope ≥40°, derived from a Digital Elevation Model (DEM) at 10-meter resolution to define suitable bighorn sheep habitat in Nebraska. Zimmerman's 2008 study found that the ETBM model is a better predictor of low-elevation bighorn sheep habitat use than traditional models, which generally use a lower limit of 27° for its slope cutoff and 30-meter DEMs. Preliminary tests of a subset of Nebraska's bighorn sheep population showed that 305 of 394 locations, or 77.4%, fell within available habitat defined by the ETBM. Additional locations from Nebraska's bighorn sheep population will be used to determine the validity of this model for predicting suitable bighorn sheep habitat.

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Evaluating Dietary Shifts of Bighorn Sheep (*Ovis Canadensis*) Before and After Use of the Sheep Lakes Mineral Lick, Rocky Mountain National Park, Colorado

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Abstract: Recent efforts at Rocky Mountain National Park (ROMO), Colorado, focus on the Mummy Range subpopulation of Rocky Mountain bighorn sheep (*Ovis canadensis canadensis*) because of increased human activity in the region of the Sheep Lakes mineral site. There is concern because the sheep have to cross a heavily traveled road to get to the Sheep Lakes mineral lick. Previous studies indicate bighorn sheep use the mineral lick, but the importance and use of the Sheep Lakes mineral lick is not thoroughly understood.

The proposed study aims to supplement available dietary information with ongoing field and laboratory studies to provide a thorough analysis of dietary status and limitations of lactating bighorn sheep in the Mummy Range of ROMO. Specifically, the potential role of the Sheep Lakes mineral lick for lactating ewes will be addressed. Fecal samples and vegetation samples before and after use of the lick will be collected in two field seasons, and laboratory analyses of the samples will determine concentrations of minerals. The proposed study will aid in management of visitors and bighorn sheep around Horseshoe Park at ROMO.

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Habitat Selection of Bighorn Sheep at Radium Hot Springs, British Columbia

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Abstract: Bighorn sheep (*Ovis canadensis*) habitat quality and availability near Radium Hot Springs, British Columbia have been affected by urban development, recreation, forest in-growth, and prescribed fire, among other factors. I analysed sheep location data in order to improve understanding of sheep habitat use and to identify important management considerations in relation to land use planning, human activity, and vegetation management. I compiled radio-collar Global Positioning System (GPS) data from a sample of 62 sheep, with each sheep collared for 8 to 12 months between 2002 and 2009. I used these data to generate separate resource selection functions (RSFs) for summer and winter. During summer, sheep selected habitats that were characterised by open forest structure, high elevation, and terrain complexity. During winter, sheep did not usually select habitats within or near escape terrain, but selected habitats that were characterised by open forest structure, low elevation, and low slope angle. Slopes selected by males in winter averaged 15.4^{o} ($\pm 0.33^{o}$), while those selected by females averaged 9.2^{o} ($\pm 0.21^{o}$). Males selected steeper terrain than females year-round (2.9^{o}, $\pm 0.34^{o}$, $t = 8.70$, $P < 0.001$), and in all months except May and June when females were travelling to or occupying lambing range. Several sheep management issues arise out of the tendency of the Radium Hot Springs herd during winter to occupy flat, valley floor habitats within or in close proximity to human developments. These include high rates of sheep-vehicle collisions on highways, habituation resulting from use of urban habitats, and increased sedentary behaviour.

Key words: bighorn sheep, British Columbia, GPS, habitat selection, *Ovis canadensis,* radio-telemetry, Radium Hot Springs, resource selection

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The Short-Term Effects of Wildfire on Sierra Nevada Bighorn Sheep

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Abstract: We studied changes in forage and habitat selection by Sierra Nevada bighorn sheep (*Ovis canadensis*; hereafter Sierra bighorn) for two years after the Seven Oaks wildfire. Forage biomass initially decreased but by the second year post wildfire had recovered to be equal to areas that had not burned. The amount of high quality forage available to bighorn initially decreased but plants within the burn had a 4% increase in crude protein for the duration of the study. In addition forage quality in the burned areas tended to be greater than unburned areas because the forage class composition within burns was forb dominated while areas outside the burn were shrub dominated. We assessed the effect of these changes in forage availability on Sierra bighorn with fecal measures of nitrogen and diet composition. We found no change in fecal N between Sierra bighorn in burned and unburned areas but there was a shift in diet composition; Sierra bighorn from burned areas had more forbs in their diet than Sierra bighorn from unburned areas. Sierra bighorn habitat selection was dominated by selection to be near escape terrain. We also found selection for grasses and forbs and this selection tended to be higher in winter than spring and highest in the first winter after the Seven Oaks Wildfire. It is during this winter of 2008 that Sierra bighorn had the largest exposure to lion use, indicating a forage predation tradeoff. It is likely that Sierra bighorn were driven by selection for forage and this led them into areas of high lion use. In general when in areas of higher lion use, Sierra bighorn showed increased selection to be near escape terrain and for visibility. It is unknown how effective these anti-predatory strategies were. We predict that as the forage in the burn increases beyond that of unburned areas (as it appears to be on a trajectory to do) that the benefits of the burned area will be twofold: increased forage quantity and quality and decreased exposure to areas of high lion use because forage will be readily available.

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Poor Population Performance of California Bighorn Sheep on Hart Mountain National Antelope Refuge

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Abstract: In 1995 the end of winter population of California bighorn sheep on Hart Mountain National Antelope Refuge (HMNAR) was estimated at 600 individuals. By 2003 this population was estimated at 300 individuals and lamb recruitment during the period was adequate to maintain the population. For a 4 year period beginning in January, 2004 we radio marked and monitored 49 adult bighorn (12 rams and 37 ewes) to determine cause of adult mortality, measure lamb production and recruitment, monitor herd health, and measure sex and age specific survival. Two rams died due to capture related injuries and 3 collars failed, therefore survival analysis was based on 44 individuals. Nineteen bighorn died during the study resulting in annual survival estimates of 0.832 and 0.897 for adult males and adult females, respectively. Cougar predation or probable cougar predation accounted for 63.2% of all mortalities. Exposure to disease and blood chemistry values did not differ from historic values measured at HMNAR.

KEY WORDS: California bighorn sheep, cause of mortality, Oregon, survival

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California bighorn sheep (*Ovis canadensis californiana*) were extirpated in Oregon by 1912. In 1954 California bighorn were successfully reintroduced to Oregon when 22 sheep were trans-located from Williams Lake, British Columbia, Canada, to Hart Mountain National Antelope Refuge (HMNAR). By 1992 the herd was estimated to be 600 individuals. With this increase, HMNAR has served as the primary source herd for California bighorn in Oregon and from 1969–2003 673 bighorn were moved from HMNAR to start new herds in Oregon, Nevada and Idaho.

By 1996 the herd had started to decline and in 2004 the population was estimated to be 300 individuals (Oregon Department of Fish and Wildlife, unpublished data). During the period of decline lamb ratios were high enough ($\bar{x}$ = 39.8 lambs:100 adult females, range 21-61) that the population should have increased or remained stable. With adequate lamb ratios, we hypothesized that the decline was due either to an increase in adult mortality, or to emigration. Our objectives were to:

1. Measure age and sex specific adult survival.
2. Determine causes of adult mortality.
3. Measure lamb recruitment.
4. Monitor herd health.

STUDY AREA

The study area encompassed 185.2 km^2 which is the entire bighorn range on HMNAR and included the west escarpment of Hart Mountain and Poker Jim Ridge (Figure 1). Elevations ranged from 1,385 m in the Warner Valley to 2,467 m on Warner Peak. Extensive cliffs and steep talus slopes provided escape terrain throughout the range. Vegetation was shrub-steppe typical

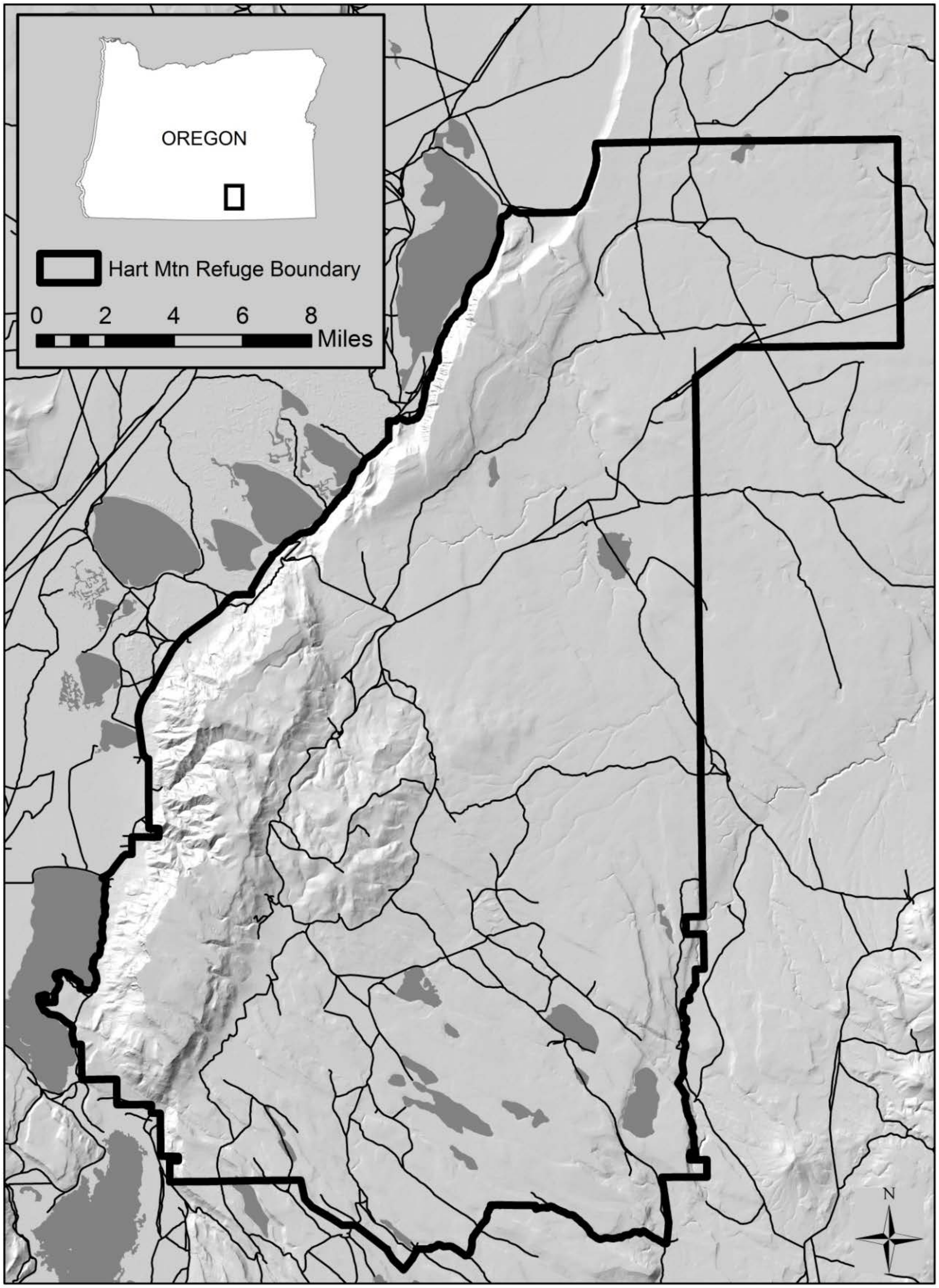

Figure 1. Hart Mountain National Antelope Refuge, Oregon, December 2004.

of the northern Great Basin including low sagebrush (*Artemisia arbuscula*) on Hart Mountain and Poker Jim Ridge, mountain big sagebrush (*A. tridentata vaseyana*) above 1,700 m, and Wyoming big sagebrush (*A. t. wyomingensis*) below 1,700 m. Isolated aspen (*Populus tremuloides*), mountain mahogany (*Cercocarpus ledifolius*) and ponderosa pine (*Pinus ponderosa*) stands occur on Hart Mountain. Western Juniper (*Juniperus occidentalis*) were encroaching on the west slope of Hart Mountain and east slope of Poker Jim Ridge (Miller et al., 2007). The Hart Mountain National Antelope Refuge Coordinated Management Plan (USFWS 1993) provides detailed habitat descriptions.

METHODS

Bighorn were captured using a net gun fired from a MD 500D helicopter. Following capture, individuals were manually restrained, processed at the capture location and released, or transported to an operations base for processing and released. Captures were distributed throughout the sheep range and rams were captured from all age classes. Captured sheep were fitted with a VHF radio collar (Advanced Telemetry Systems®) with a 6 hour mortality switch. Two large All-Flex ear tags were placed at the 3 and 9 o'clock positions on each collar for individual animal identification. Signal checks were done at least once per week and more often as time allowed.

When a mortality signal was heard the collar and carcass were located as soon as possible to determine cause of death. Upon location of the carcass a visual inspection of the remains was recorded and pictures were taken. Mortalities occurring within 14 days of capture were attributed to capture related injuries and these individuals were excluded from analyses. Cause of death was determined based on evidence at the location. Characteristics of the carcass and kill site used to attribute cause of death to cougar or probable cougar included cougar tracks or scat at site, evidence of caching, presence of claw marks in the hide, hemorrhage in throat area, signs of entrails or rumen content being removed from the subsequent feeding site, and evidence of ribs being removed from one side of the carcass.

Biological samples including blood, feces, and pharyngeal swabs were taken from each bighorn to monitor herd health. Analysis of samples was consistent with the testing protocol suggested by the Western Wildlife Health Committee (WWHC, Foster 2005). In addition to WWHC suggested bacterial and viral analysis from serum, blood chemistry values were compared to normal values (Whittaker et al. 2001) as an index of overall herd health. Fecal samples were analyzed for the presence of common bighorn parasites using flotation and the Baermann technique (Forrester and Lankester 1997) to estimate larval levels of *Protostrongylus*. Pharyngeal swabs were analyzed for presence of *Pasturella* and *Mannhaemia* bacteria.

Herd composition surveys were conducted annually in March and July from 2004 through 2008. The sheep range was flown using a Bell Helicopter (B-3 or L-3) and all bighorns were classified as ewes, lambs or rams. Rams were further classified by horn characteristics to Class I through IV (Geist 1971). All marked individuals were identified and noted during surveys. Detection rates calculated as the ratio of marked animals observed during surveys relative to the known number of marked animals alive in the study area. We used the Kaplan–Meier product limit estimator (Kaplan and Meier 1958, White and Garrott 1990) to estimate survival probabilities ($S_{(t)}$). Annual mortality rates were calculated as 1-$S_{(t)}$. We used logistic regression to determine if sex, age class, or capture location predicted adult survival where the binary response variable was alive or dead (White and Garrott 1990).

RESULTS

Between January 2004 and December 2006, 49 bighorn sheep (12 rams and 37 ewes) were radio-collared (Table 1). Two rams died due to capture and 3 radio collars failed; thus analyses were based on 44 individuals. Comparison of blood chemistry, parasitology, and bacteriology with historic and normal values showed no indication of herd health issues which could result in a population decline for the HMNAR bighorn population (Table 2, Table 3). PI3 values were within the reference range for active or recent infections, but no indication of disease was noted during the study.

Table1. Bighorn sheep marked on Hart Mountain National Antelope Refuge, Oregon. January 2004 – December 2007.

	Males		Females	
Capture Date	N	Age Range (Yr)	N	Age Range (Yr)
Jan. ‘04	12	1–7	28	1–8
Nov.’04			5	2–4+
Dec ‘05			4	Adult

Table 2. Blood chemistry, complete blood counts and trace mineral values from California bighorn caught at Hart Mountain National Antelope Refuge, Oregon, December 2004.

Parameter (units)	n	$\bar{x}$	Median	Range	Normal Range[a]
Thyroxine (nmol/L)	40	93	89	72-140	NR
Triiodothyronine (nmol/L)	40	2.3	2.2	1.3 - 3.4	NR
Selinium (ng/ml)	40	73	70	31 - 124	NR
Vitamin E (ug/ml)	41	2.01	1.98	0.51 - 4.81	NR
Sodium (Meq/L)	38	154	154	149 -162	146 – 164
Potassium (Meq/L)	38	4.9	4.8	3.6 - 7.1	4.0 – 7.2
Chloride (Meq/L	38	105	105	100 - 111	88 – 105
Glucose (MG/DL)	38	134	131	88 - 174	89 – 199
BUN (MG/DL)	38	9	9	5 - 19	7 – 28
Creatinine (MG/DL)	38	2	2	1.6 - 2.5	1.5 – 2.8
Uric Acid (MG/DL)	38	0.4	0.3	0.2 - 1.8	0.1 – 0.6
T. Protein (G/DL)	38	6.7	6.5	5.7 - 8.7	5.8 – 8.3
Albumin (G/DL)	38	3.6	3.7	2.6 - 4.2	3.0 – 4.9
T. Bilirubin (MG/DL)	38	0.1	0.1	0.1 - .02	0 – 0.4
GGTP (U/L)	37	64	59	35 - 112	23 – 123
Alk. Phos. (U/L)	38	206	181	83 - 388	82 – 1,050
ALT (U/L)	38	32	34	11 - 50	23 – 60
AST (U/L)	38	230	214	164 - 484	117 – 545
LDH (U/L)	37	651	656	557 - 798	535 – 1,160
Calcium (MG/DL)	38	10.3	10.3	9.6 - 11.1	8.9 – 12.4
I. Phos.(MG/DL)	37	6.6	6.7	4.7 - 8.5	4.0 – 9.6
Cholesterol (MG/DL)	38	58	56	47 - 77	42 – 71
RBC (M/uL)	36	11.6	11.6	8.5 - 13.5	NR
WBC (K/ul)	36	39	37	22 - 60	NR
HGB (G/DL)	36	18.3	18.4	14 - 21.5	NR
HCT %	36	52	53	42 - 62	NR
MCV fl	36	41	41	38 - 45	NR
Platlet (K/uL)	36	748	706	322 - 1,000	NR
SEG %	36	39	33	6 - 69	NR
Lymph %	36	61	65	25 - 94	NR

[a] Normal chemistry values from Whittaker et al. 2001; NR = Not reported.

Table 3. Serum Titer analysis for selected bacteria or virus from 41 California bighorn on Hart Mt. National Antelope Refuge, Oregon, 2004.

Disease Organisim	# Positive	% positive
Leptospira brat.	9	21
Leptospira can.	0	0
Leptospira gripp.	2	4
Leptospira hardj.	2	4
Leptospira icter.	0	0
Leptospira pom.	0	0
Blue Tongue	5	12
BRSV	0	0
BVD	0	0
EHD	5	12
IBR	0	0
PI-3	20	49

Leptospira spp positive at 1:100 (n=11) or 1:200 (n=2)

PI-3 positive range = 1:8 to 1:256

No marked individuals left the HMNAR bighorn sheep range. We were unable to determine the fate of one animal. All available habitat surrounding HMNAR was stocked with bighorn sheep prior to this study and none of these herds exhibited unexpected population growth prior to or during the study period. There are no data to indicate the population decline on Hart resulted from bighorn moving out of the known herd range.

Nineteen bighorns died. Cougar predation or probable cougar predation accounted for 63.2% of the mortalities (Table 4). Two young rams died of injuries likely sustained as a result of head butting during the rut. Individuals dying of undetermined causes were not located quickly enough to confirm cause of death. Mortalities occurred throughout the year with no indication cougar predation was more prevalent in any particular season (Table 5).

Annual adult survival, averaged 0.832 and 0.897 for adult males and adult females, respectively (Table 6). Annual survival varied more for males (0.636 – 1.00) than for females (0.880 – 0.930), and male survival was slightly less than females in all years except 2005. Neither age class or capture location adequately predicted survival ($P > 0.05$) and gender influenced survival only during 2004 ($\chi^2 = 5.35$, $P = 0.0207$).

Table 4. Mortality cause for radio-collared bighorn sheep on Hart Mt. National Antelope Refuge, Oregon, 2004–2007.

Cause of Death	N	%
Capture Myopathy	2	10.5
Predation [a]	12	63.2
Injury	2	10.5
Hunting	1	5.3
Unknown	2	10.5
Total	19	

[a] All due to cougar or probable cougar predation

Table 5. Season of cougar caused mortality for radio marked bighorn sheep on Hart Mountain National Antelope Refuge, Oregon.

Year	Season	# Cougar Mortality
2004	Winter	2
	Spring	
	Summer	1
	Fall	3
2005	Winter	
	Spring	1
	Summer	2
	Fall	
2006	Winter	2
	Spring	1
	Summer	
	Fall	1
2007	Winter	1
	Spring	2
	Summer	
	Fall	1
Combined	Winter	5
	Spring	4
	Summer	3
	Fall	5

Seven classification surveys were conducted between 2004 and 2007 (Table 7). Three included only one observer, while

Table 6. Annual survival probabilities for radio-collared bighorn sheep on Hart Mountain National Antelope Refuge, Oregon, 2004 – 2007.

	Male			Female		
Year	L 95%	Rate	U 95%	L 95%	Rate	U 95%
2004	0.352	0.636	0.921	0.767	0.887	1.000
2005	.	1.000	.	0.778	0.893	1.000
2006	0.598	0.857	1.000	0.836	0.930	1.000
2007	0.535	0.833	1.000	0.753	0.880	1.000
Mean Survival		0.832			0.897	
Mean Mortality (1-St)		0.168			0.103	

Table 7. Detection rates of radio marked bighorn sheep on Hart Mountain National Antelope Refuge, Oregon.

Survey Date	# Observers	Marked Bighorns Observed	Marked Bighorns Available	Detection Rate (%)
3/25/04	1	22	36	61.11
7/27/04	2	31	36	86.11
3/30/05	1	21	38	55.26
7/15/05	2	28	34	82.35
7/16/06	2	24	31	77.42
3/19/07	1	21	28	75.00
7/10/07	2	18	26	69.23

Mean detection rate 1 observer = 64%
Mean detection rate 2 observers = 79%

4 included two observers. Detection rate of marked bighorns observed during surveys ranged from 55%–86%. Not surprisingly surveys using 2 observers ($\bar{x}$ = 79% of available marks detected) resulted in a higher proportion of marked bighorns seen than a single observer ($\bar{x}$ = 64% of available marks detected). The overall average detection rate for marked animals was 73%.

Population modeling has been used to estimate bighorn herd size in Oregon since 1985. The HMNAR bighorn population is tracked using POP II® (Fossil Creek Software, Fort Collins, Colorado, USA) as the modeling platform using classification surveys and harvest data collected annually as inputs. Survival parameters used in the model have been estimated from other Oregon bighorn sheep studies (ODFW unpublished data). Prior to this project, the HMNAR model used annual natural mortality estimates of 7% for adult ewes and 9% for adult rams. A revised population model was developed using average annual mortality estimates (1- $S_{(t)}$) based on radio-collared animals in this study (10.3% for adult ewes, 16.8% for adult rams). All variables in the two models other than natural mortality were the same. Population estimates from the revised model suggests the population is declining and is consistent with data from classification surveys (Table 8).

DISCUSSION

From 1988 to 1996, between 5–11% of the modeled bighorn population and 7 – 23% of the bighorns counted during surveys were removed for relocation to other areas. Most of the animals removed were females and this likely had a regulatory affect on the population. Since 1996, only16 adult ewes

Table 8. Population models using historic natural mortality versus 2004-2007 values measured for bighorn sheep on Hart Mountain National Antelope Refuge, Oregon, 1990 – 2006.

		Historic Mortality Model[a]		Observed Mortality Model[b]		
Year	Bighorns Observed	Population Size	Density (bighorn/km^2)[c]	Population Size	Density (bighorn/km^2)[c]	Lambs/ 100 Ewes
1990	209	448	2.4			45
1991	282	450	2.4			26
1992	395	469	2.5			37
1993	224	449	2.4			34
1994	304	459	2.5			38
1995	165	367	2.0			28
1996	189	355	1.9			29
1997	166	328	1.8			21
1998	236	391	2.1	360	1.9	53
1999	256	420	2.3	346	1.9	55
2000	136	485	2.6	377	2.0	61
2001	187	494	2.7	324	1.7	45
2002	206	531	2.9	317	1.7	35
2003	174	604	3.3	322	1.7	47
2004	192	644	3.5	295	1.6	45
2005		672	3.6	283	1.5	40
2006	141	718	3.9	276	1.5	38

[a] 7% for adult ewes and 9% for adult rams

[b] 10.3% for adult ewes and 16.8% for adult rams

[c] Hart sheep range = 185.2 km^2

have been removed. The lower female removal rate after 1996, and its associated regulatory affect, allowed a substantial population increase in the modeled population (Table 8). However, observed counts were not consistent with modeled results when using the pre-study mortality estimates (Table 8). Population estimates from the revised model using mortality estimates measured in this study agree with the declining trend in number of bighorns observed during aerial surveys. In 1990-1991, Payer (1992) investigated the distribution and survival of 20 Class III and IV bighorn rams on HMNAR. During his study he had 4 mortalities, all due to hunter harvest. Based on Payer (1992), the observed population decline beginning in 1996, and our research, it appears cougar predation on HMNAR bighorns has been sufficient enough to affect population growth.

From 1996 through the start of our research only 16 bighorn were captured for relocation and sampled for herd health monitoring. This capture occurred in 2001. Because the herd was not sampled between 1996 and 2001 we have no evidence of a disease event or other health issue affecting population growth. Because the observed population decline was chronic rather than acute, it is reasonable to assume that a pasturellosis pneumonia event did not occur on HMNAR. This assumption is supported by a lack of reports for coughing bighorn on HMNAR from resident refuge staff or refuge visitors, and there has been no observed decline in lamb recruitment as typically follows an acute respiratory disease outbreak in bighorn sheep.

We recognize that pathological evidence is quickly lost from an aging carcass and therefore the absence of disease caused mortality may be a result of the time it took to locate carcasses after first hearing a mortality signal. However, evidence at carcasses indicative of cougar predation, coupled with no indication of illness in live sheep observed while monitoring radio marked individuals leads us to believe that disease was not a substantial mortality factor.

Historic data suggest habitats on HMNAR can sustain a population of approximately 400 bighorns, or a density of 2.15 bighorn/km^2 (5.6 bighorn/mi^2). Trend in number of bighorns observed during annual classification surveys and modeled population estimates indicate the population is well below this desired population size. We suggest that controlling cougars on bighorn sheep ranges would likely benefit bighorn sheep populations on HMNAR.

Our data suggest that we did not mark enough rams. Future investigations should mark sex and age classes at the ratio they occur in the population. This is a reasonable suggestion for rams due to the ability to determine relative age prior to capture. Adult ewes are difficult to age prior to capture and it may not be possible to select specific age classes without capturing and rel1easing unwanted individuals.

Although we did not find a difference in mortality based on ram age, circumstantially it appears that older age class rams were more susceptible to cougar predation than other segments of the population. Because older rams are solitary or occur in very small groups, and for most of the year were bedded down for a majority of the day, cougars may be able to select for this group. Future projects should select adequate sample sizes of older age class rams to investigate this observation further.

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Responses of Bighorn Sheep and Mule Deer to Fire and Rain in the San Gabriel Mountains, California

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***Abstract**:* We used retrospective analyses to evaluate relationships between fire history, precipitation, and productivity in bighorn sheep (*Ovis canadensis nelsoni*) and mule deer (*Odocoileus hemionus californicus*) in southern California's San Gabriel Mountains. The number of bighorn sheep increased 5 times faster after fires on chaparral-covered ranges than the number of sheep on unburned chaparral ranges. When individual time periods were considered during 1976-2006, bighorn sheep population estimates were positively associated (P <0.01) with the amount to winter-spring range burned during all years except 1989-1995. As vegetation matured and habitat suitability declined, the density of female sheep increased, and recruitment declined. Mule deer recruitment rates were positively associated (P <0.1) with the amount of winter-spring range burned during 1976-1989, but not in later years. During 1985-2004, there was a linear relationship (r^2 = 0.58, P = 0.004) between mule deer recruitment rates and precipitation during pregnancy, whereas bighorn sheep recruitment rates were not associated (P > 0.05) with precipitation during pregnancy. During years with less than normal precipitation (1989-1990 and 1999-2004) mule deer recruitment rates were approximately 50% less than recruitment rates during all years with at least normal precipitation, which was also reflected in lower mule deer abundance. We hypothesize that a lack of wildfires combined with drought reduced mule deer availability, and mountain lion (*Felis concolor*) predation was responsible for the population decline in bighorn sheep during 1989-1995.

KEY WORDS: bighorn sheep, California, chaparral, fire, mountain lion, mule deer, *Odocoileus hemionus*, *Ovis canadensis*, precipitation, predation, *Puma concolor*.

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INTRODUCTION

Bighorn sheep (*Ovis canadensis nelsoni*) and mule deer (*Odocoileus hemionus californicus*) are sympatric in the eastern half of southern California's San Gabriel Mountains, occupying chaparral for at least 4 months during winter and spring each year (Cronemiller and Bartholomew 1950, Weaver et al. 1972, Holl and Bleich 1983). Chaparral is a fire-adapted community characterized by periodic large and intense crown fires that reduce shrub canopy cover and produce an ephemeral (Biswell et al. 1952, Hanes 1971, Keeley and Davis 2007) and highly nutritious forage crop (Biswell et al. 1952, Taber and Dasmann 1958). In response to wildfires in chaparral, black-tailed deer (*O. h. columbianus*) move into recently burned areas to consume higher quality forage, which results in improved fawn production and survival (Taber and Dasmann 1957, 1958). High densities of black-tailed deer remain in burned areas for 4-5 years post-fire (Taber and Dasmann 1957, 1958) before declining.

Bighorn sheep in the San Gabriel Mountains are attracted to recently burned areas (Holl et al. 2004), presumably in search of increased forage quality (Biswell et al. 1952, Hobbs and Spowart 1984). Their distribution is positively associated with those burned areas for ≤15 years after fires and negatively associated with those areas >15 years after fires (Bleich et al. 2008), likely because changes in shrub cover affects their field of vision that is necessary for predator detection (Risenhoover and Bailey 1980). Although the positive effects of wildfire on habitat suitability and resulting influences on demographic parameters of bighorn sheep habitat have been inferred by several authors (Stelfox 1976, Wakelyn 1987, Etchberger et al. 1989, Holl et al. 2004), there are no quantitative descriptions of the relationships between fire history and bighorn sheep demographics (Cain et al. 2005).

The decline in the area burned by wildfires in the San Gabriel Mountains during 1980-1995 (Bleich et al. 2008) appeared to correspond to the decline in population estimates (±SE) for bighorn sheep from 740±49 to 130 individuals (Holl and Bleich 2009) and a similar decline in mule deer during that same period (Holl et al. 2004). During 1997-2003 wildfires burned 70,100 ha in the San Gabriel Mountains and the bighorn sheep population increased to 292±69 by 2006 (Holl and Bleich 2009); however, the abundance of mule deer did not appear to increase immediately, as indicated by the reported buck harvest (California Department of Fish and Game [CDFG] files).

In xeric southwestern mountain ranges precipitation influences nutrient availability (McKinney et al. 2006) and recruitment of young in bighorn sheep (Leslie and Douglas 1979, Wehausen et al. 1987, Douglas 2001, McKinney et al. 2006) and mule deer (Marshall et al. 2002, Lawrence et al. 2004, Bender et al. 2007). Moreover, lower than normal precipitation was associated with mule deer population declines in the southwest during 1985-1990 (Kucera 1988, Sweitzer et al. 1997, Logan and Sweanor 2001, Kamler 2002). The San Gabriel Mountains are, however, a mesic range with predictably greater annual precipitation (89±6.3 cm, Mt. Wilson, CA) than desert mountain ranges (10.8±0.86 cm, Barstow, CA) occupied by bighorn sheep and mule deer.

Early winter precipitation contributed to variation in lamb recruitment rates during 1976-1984 (Holl and Bleich 1983, Holl et al. 2004, Holl and Bleich 2009) when female bighorn sheep densities were high (Holl et al. 2004). Available data for mule deer indicate precipitation on the central coast of California, a mesic area west of the San Gabriel Mountains, was positively correlated with the reported buck harvest (Longhurst et al. 1976); however, nothing is known about the effects of precipitation on mule deer in this mountain range.

Habitat management for both species in these mountains has been limited to wildfires. Prescribed burning is an effective management technique that mimics the results of a wildfire and will improve mule deer habitat in chaparral (Biswell et al. 1952, Taber and Dasmann 1957, 1958) and it is the only technique available to improve bighorn sheep habitat in this mountain range because excessively steep slopes preclude the use of mechanical equipment. Both species receive additional management consideration by the Forest Service and CDFG because bighorn sheep qualify as a distinct vertebrate population segment (Holl 2002) and they are listed as a regionally sensitive species by the Forest Service and as a fully protected species by the State of California (CDFG Code section 4700), and mule deer are an important game species in this mountain range. Therefore, understanding the relationships between fire, precipitation, and demographic responses is fundamental to implementing effective management strategies for both species.

Based on our observations in the San Gabriel Mountains during 1976-2006 we conducted this retrospective analysis to evaluate 4 hypotheses:1) wildfires on chaparral ranges increased lamb recruitment in bighorn sheep, similar to that described for black-tailed deer in chaparral (Taber and Dasmann (1957, 1958); 2) as a result of improved recruitment sheep populations on burned ranges increased faster than populations on unburned ranges; and 3) wildfire history was associated with the abundance of bighorn sheep and mule deer. We also hypothesized that (4) precipitation was associated with recruitment in mule deer, which affected their abundance.

STUDY AREA

The San Gabriel Mountains, located in Los Angeles and San Bernardino counties, California (34°19'N; 117°45'W), are part of the Transverse Range. The San Gabriel are essentially isolated from the adjacent Santa Monica and San Bernardino ranges (Epps 2007) by 10 million people along the southern boundary, eight lane freeways along the eastern and western flanks of the range, and the Antelope Valley to the north, which provides little suitable habitat for either species. Over 95% of the mountain range is administered by the Angeles and San Bernardino National forests.

Elevations range from 200-3,300 m; below 1,850 m the climate is Mediterranean, characterized by hot, dry summers and cool, moist winters, where 95% of the precipitation occurs between October 1 and May 1 (Bailey 1966). Cooler temperatures and snow are common above 1,850 m. Springs, which provide surface water, are not uncommon on the steep slopes and permanent streams occur in the bottoms of the larger canyons.

Chaparral, the dominant vegetation below 1,850 m, is adapted to the summer droughts, by becoming dormant during summer. As moisture levels decline in shrubs, the vegetation becomes more susceptible to fire (Hanes 1971, Keeley and Davis 2007). The fire regime is characterized by 30-70 year fire-return intervals and high intensity crown fires (Stephenson and Calcarone 1999, Keeley and Fotheringham 2001, Minnich 2001) that are frequently driven by strong winds during the fall (Keeley and Fotheringham 2001, 2003, Minnich 2001).

Post-fire succession in chaparral has been described in detail elsewhere (Biswell et al. 1952, Hanes 1971, Keeley and Davis 2007). After most fires, fall and winter rains germinate the abundant seeds of annual grasses and herbaceous plants; however, this ephemeral flora is essentially gone by the 3rd year post-fire because of increased crown cover of shrubs, such as chamise (*Adenostoma fasciculatum*), California lilac (*Ceanothus* spp.), manzanita (*Arctostaphylos* spp.), scrub oak (*Quercus dumosa*), and mountain mahogany (*Cercocarpus betuloides*) that sprout from root burls, seeds, or both. Growth is rapid the first season, often exceeding 50 cm in height; as canopy cover increases, it often forms impenetrable stands.

Bighorn sheep are distributed among 4 subgroups (Figure 1), of which 3 each use a single winter-spring range (Cattle Canyon, East Fork San Gabriel River, and San Gabriel Wilderness) and 1 subgroup (Cucamonga) uses 5 winter-spring ranges (Middle and South Forks Lytle Creek, Deer Canyon, Cucamonga Canyon, and Barrett-Cascade Canyons). Additional descriptions of these populations are provided by Weaver et al. (1972), Holl and Bleich (1983), and Holl et al. (2004). Mule deer occur

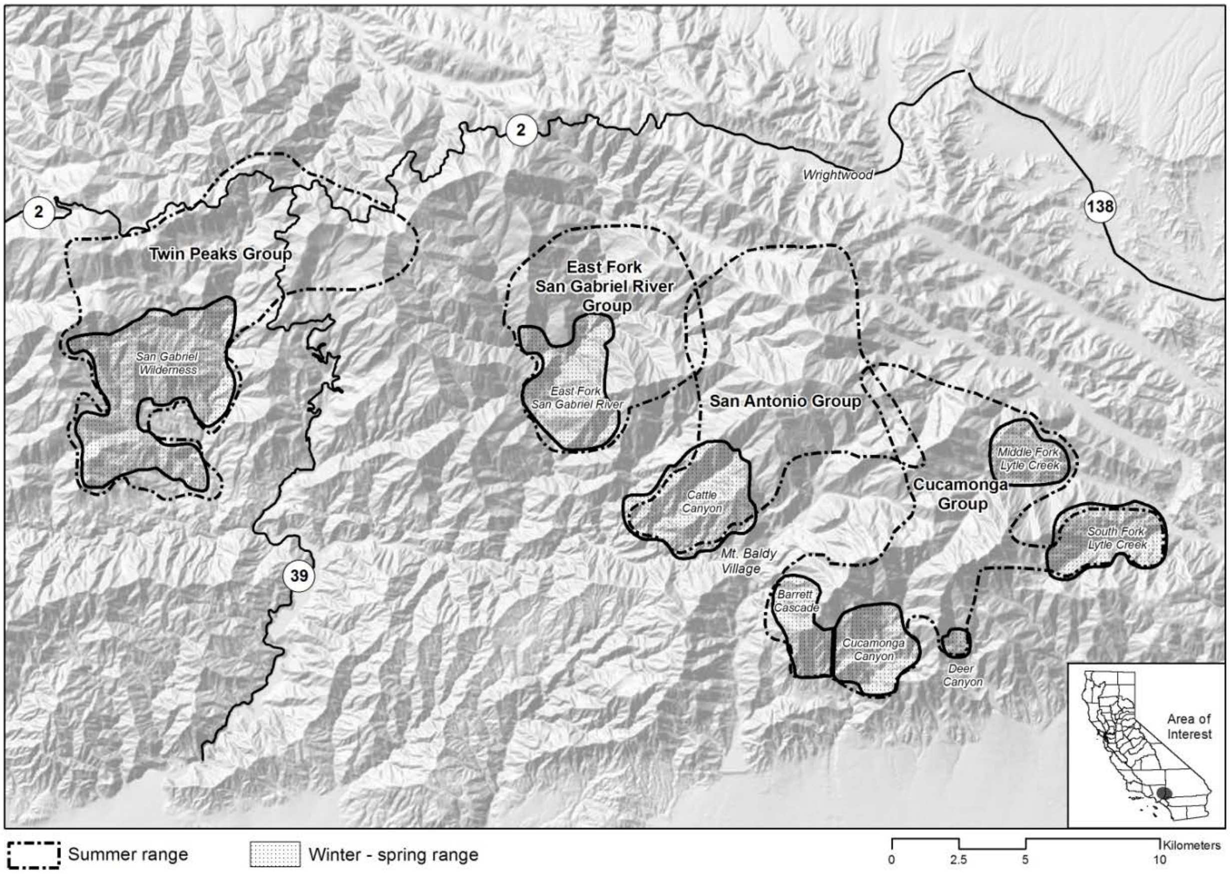

Figure 1. Distribution of bighorn sheep seasonal ranges in the San Gabriel Mountains, California.

throughout the mountain range (Cronemiller and Bartholomew 1950). Both species include resident animals that remain on chaparral ranges year around and migratory animals that migrate above 1,850 m elevation during summer, presumably in search of more nutritious forage (Hebert 1973, Festa-Bianchet 1988). The mountain range also supports a full complement of predators capable of killing bighorn sheep or mule deer, including mountain lions (*Puma concolor*), bobcats (*Lynx rufus*), coyotes (*Canis latrans*) and black bears (*Ursus americanus*); no livestock allotments are permitted on national forest land and no incidents of disease that could have affected population levels of bighorn sheep (Holl et al. 2004) or mule deer (CDFG files) have been reported.

METHODS

We used data from population surveys of bighorn sheep and mule deer, Forest Service fire history reports, and precipitation records from Mt. Wilson, Los Angeles, County, CA collected during 1976-2006. None of these data sets were initially designed to satisfy an experimental design targeted to address our 4 hypotheses; therefore, we used the serendipitous wildfires to compare the response of bighorn sheep between burned and unburned areas and to evaluate chronological responses to fire and precipitation.

Demographic Data for Bighorn Sheep and Mule Deer

We used demographic data from annual March helicopter surveys of bighorn sheep in the San Gabriel Mountains, conducted since 1976 (Holl et al. 2004, Bleich et al. 2008, Holl and Bleich 2009), to estimate age and sex composition and recruitment rates of bighorn sheep. Similarly, we used data on sex and age ratios obtained during helicopter surveys of mule deer by CDFG personnel during November 1985-2004.

We used the annual reported buck harvest for Los Angeles County, adjusted to include only animals removed from the national forest (79-88% of the total harvest), as an index to estimate changes in mule deer abundance during 1976-2006; hunter tag returns are used by at least 40% of state agencies to track deer population trends (Rupp et al. 2000) and there was a significant correlation between the reported buck harvest and the number of mule deer observed per hour of helicopter survey time in this mountain range during 1985-1998 (Holl et al. 2004), indicating tag returns provided a valid index of abundance. During the surveys all animals that were observed moved in response to the helicopter and no bias in visibility as a result of animal movement or plant succession was detected (Holl et al. 2004, Bleich et al. 2008).

Comparison of Bighorn Sheep Recruitment and Growth Rates between Burned and Unburned Ranges

We calculated 95% confidence limits for recruitment rates following Riney (1956) and compared bighorn sheep recruitment rates from individual winter-spring ranges that burned in 1975, 1997, and 2003 with recruitment rates on unburned ranges during those same periods using Fisher's exact test. We limited these comparisons to 1.5-3.5 years post-fire because the nutritional benefits in chaparral and montane shrublands only lasts 2-3 years (Taber and Dasman 1958, Hobbs and Spowart 1984). All fires occurred during fall, and we did not consider recruitment rates obtained the first March post-fire because those fires would not have affected nutritional status of young, which were 6-8 months-of-age and weaned when the fires occurred.

We compared the exponential rates of increase for bighorn sheep occupying burned and unburned ranges during 1996-2006, the only period we identified where the abundance of bighorn sheep on multiple burned and unburned ranges could be evaluated simultaneously. The total number of animals counted during the annual surveys was used to calculate the rates of increase (Caughley 1977). Burned ranges were the East Fork of the San Gabriel River, which burned in 1997 and the Cucamonga subunit that burned in 2003. We used 1996 for the initial year in the Cucamonga subunit because some of the winter-spring ranges were not surveyed between 1999 and 2002 and, therefore, could not contribute to the analysis. Unburned ranges were Cattle Canyon and the San Gabriel Wilderness winter-spring ranges which had not burned since at least 1975.

Responses of Bighorn Sheep and Mule deer to Changes in Habitat Suitability Resulting from Wildfires

We used Forest Service fire history data to determine the area burned annually on bighorn sheep winter-spring ranges (Figure 1) and the entire mountain range was used for mule deer. Within those areas the amount of suitable habitat resulting from fire (HSF) was recalculated annually as the area burned ≤15 years ago for bighorn sheep and ≤5 years ago for mule deer. We used 15 years for bighorn sheep because they are positively associated with burned areas for 15 years post-fire (Bleich et al. 2008) and we used 5 years for mule deer because Taber and Dasmann (1957) concluded deer densities in chaparral habitat returned to pre-burn levels approximately 4-5 years post-fire. As a result, the HSF includes a spatial and temporal component.

We used correlation analysis to determine the relationships between bighorn sheep HSF and population estimates (Holl and Bleich 2009) during 1976-2006; we repeated the analysis for 3 shorter periods: 1976-1989, and 1989-1995, periods where sheep declined at different rates (Holl et al. 2004, Holl and Bleich 2009); and 1995-2006, when the sheep population increased. We used linear regression to evaluate the influence of density on lamb recruitment, with adult female density as the independent variable. The number of females was determined using the observed age and sex ratios obtained during the surveys and the reconstructed population estimates (Holl and Bleich 2009). This analysis did not include 1976-1984, when recruitment was associated with early winter precipitation and low temperatures and precipitation during the spring birthing season (Holl et al. 2004). We also used correlation to determine the relationship between mule deer HSF and the reported buck harvest during 1976-2006. We repeated that analysis during 2 shorter periods, 1976-1989 and 1989-2006. The reported buck harvest was also staggered 3 years to represent fawn production 3 years earlier to determine if changes in mule deer HSF were associated with earlier fawn recruitment.

Response of Recruitment to Precipitation

We used precipitation as an index of annual nutrient availability in forage (McKinney et al. 2006). We used correlation and regression analyses to test for a relationship between nutrient availability during pregnancy (total precipitation October-March) and observed fawn and lamb recruitment rates during 1985-2004.

Acceptance of Statistical Tests

All statistical tests were considered to be significant when $\alpha \leq 0.05$, except for the relationship between reported buck harvest and mule deer HSF, when $\alpha = 0.1$ was accepted because an index of abundance was used and that index was staggered to represent events that occurred 3 years earlier.

RESULTS

Comparison of Bighorn Sheep Recruitment and Exponential Growth Rates between Burned and Unburned Ranges

Recruitment Rates.—Following the 1975 fire, recruitment rates of bighorn sheep at 1.5 years were lower on the burned range in Cattle Canyon (13±10) than the unburned ranges (37±11) ($P = 0.009$; Table 1) and at 2.5 years, recruitment rates were higher on the burned range (37±23) than the unburned ranges (10±6) ($P = 0.003$); there was no difference ($P = 0.99$) 3.5 years post-fire. No data on recruitment rates were available from the East Fork San Gabriel River immediately following the 1997 fire; however, there was no difference in recruitment rates ($P = 0.28$) between burned and unburned ranges 3.5 years post-fire. Although recruitment rates appeared higher on the Cucamonga subunit than on the unburned ranges at 1.5 years post-fire (76±81 *vs*. 33±24) and at 2.5 years (28±16 *vs*. 22±16), they were not statistically different ($P = 0.17$). There was no difference ($P = 0.82$) at 3.5 years post-fire (Table 1).

Exponential Rates of Increase.—From 1996-2006, the exponential rate of increase for bighorn sheep was 0.103 on the East Fork San Gabriel River winter-spring range following the 1997 fire and it was 0.133 in the Cucamonga subgroup (burned in 2003) during 1998-2006. Given these rates, the East Fork San Gabriel River population would double every 6.6 years and the Cucamonga subgroup would double

Table 1. Recruitment rates (LL:100EE) ± 95% confidence limits in burned and unburned winter-spring ranges following 3 fires in the San Gabriel Mountains, California.

Years Post-Fire	1975 Cattle Canyon	1975 Unburned Ranges	1997 East Fork San Gabriel	1997 Unburned Ranges	2003 Cucamonga Subgroup	2003 Unburned Ranges
1.5	13±10*	37±11*			76±81	28±16
2.5	37±23*	10±6*			33±24	22±16
3.5	36±20	36±10	14±21	43±34	62±32	68±49

* significant differences ($P < 0.05$) between burned and unburned ranges for each fire.

every 5.2 years. On the 2 unburned ranges, the exponential rate of increase was 0.022 and the population would be expected to double about every 32 years.

Responses of Bighorn Sheep and Mule Deer to Changes in Habitat Suitability Resulting from Wildfires

Bighorn Sheep.—During 1976-2006 HSF for bighorn sheep winter-spring ranges varied from 2,093 ha in 1976 to 2,837 ha in 1980, declined to 670 ha in 1994, and increased to 3,392 ha in 2003 (Figure 2). The HSF increased as a result of large wildfires in 1975, 1980, 1997, and 2003. Although small wildfires in 1983 and 1984 burned portions (115 ha) of 2 winter-spring ranges, it did not result in a net increase in available habitat because larger quantities of habitat on other winter-spring ranges were simultaneously maturing and becoming less suitable for bighorn sheep. There was a significant correlation ($r_{29} = 0.414$, $P < 0.05$) between the HSF and population estimates during 1976-2006 (Figure 2).

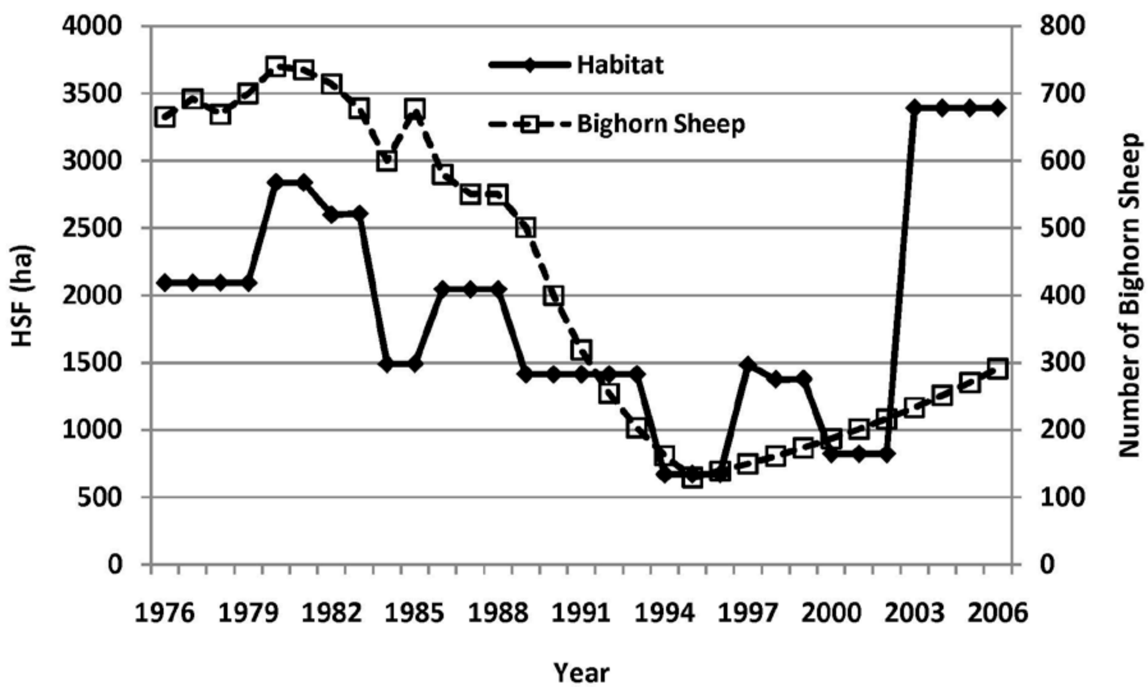

Figure 2. Changes in bighorn sheep population estimates and habitat suitability resulting from fire (HSF) during 1976-2006 in the San Gabriel Mountains, California.

When individual time periods were considered, the relationships between the HSF and population estimates improved during 1976-1989 (r_{12} = 0.654, P < 0.01), when the largest population estimate (740±49) was obtained, and during 1995-2006 (r_{10} = 0.823, P < 0.01), as the population increased from 130 in 1995 to 292±69 in 2006 (Fig. 2). There was no correlation between the HSF and bighorn sheep population estimates during 1989-1995 (r_5 = 0.69, P > 0.05) when the HSF remained unchanged from 1989-1993 and the bighorn sheep population declined from 501±30 to 203 animals (Figure 2); during 1994-1995 both the HSF and the sheep population estimates declined, culminating in 130 bighorn sheep. Thus, 80% of the population decline during 1989-1995 occurred when there was no change in the HSF, suggesting other factors were affecting the number of sheep.

During 1976-1979 mean densities were 16.6 ewes/km^2 HSF; densities increased to a peak of 21.3 ewes/km^2 in 1984, and then declined to 15.6 ewe/ km^2 and 5.0 ewe/ km^2 in 1986 and 1997, respectively, following wildfires; densities then increased to 17.9 females/ km^2 in 2002. In response to the 2003 wildfire, mean densities declined to 10.7 /km^2 during 2004-2006. During 1984-2006 there was a linear and negative relationship (slope = -1.21; r^2 = 0.47, P < 0.05) between lamb recruitment rates and ewe density (Figure 3).

Mule Deer.—The mule deer HSF was more variable during 1976-2006 (Figure 4) than the bighorn sheep HSF (Figure 2). The HSF increased in response to wildfires in 1975, 1979, 1988, 1997, and 2003 (Figure 4) and oscillated during 1985-2002. There was no relationship (r_{29} = 0.04, P >0.1) between the HSF and reported buck harvest (Figure 4) during 1976-2006.

When shorter time periods were used and the reported harvest was staggered 3 years there was a relationship (r_{15} = 0.51, P< 0.1) between the HSF during 1973-1986 and the reported buck harvest during 1976-1989, indicating fawn recruitment was associated with changes in the HSF. That relationship did not occur (r_{16} = 0.158, P >0.1) during 1989-2006, indicating other factors may have been associated with fawn recruitment.

Response of Recruitment to Precipitation

There was a linear relationship (y = 10.3 + 0.34x, r^2 = 0.58, P = 0.004) between precipitation during pregnancy and fawn recruitment during 1985-2004, while there was no relationship between precipitation and lamb recruitment during the same years (r_{16} = 0.323, P > 0.05) (Figure 5). Fawn recruitment rates were approximately 50% lower during periods of less than normal precipitation in 1990 (23) and 1999-2004 (20±4.4) when compared to the mean recruitment rate (47±3.4) during years of at least normal precipitation.

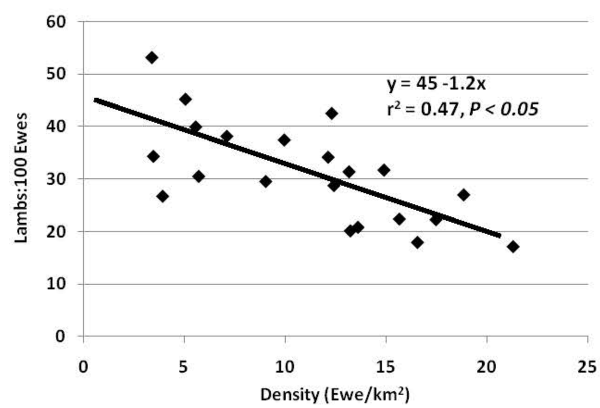

Figure 3. Relationship between ewe density and recruitment during 1984-2006 in the San Gabriel Mountains, California.

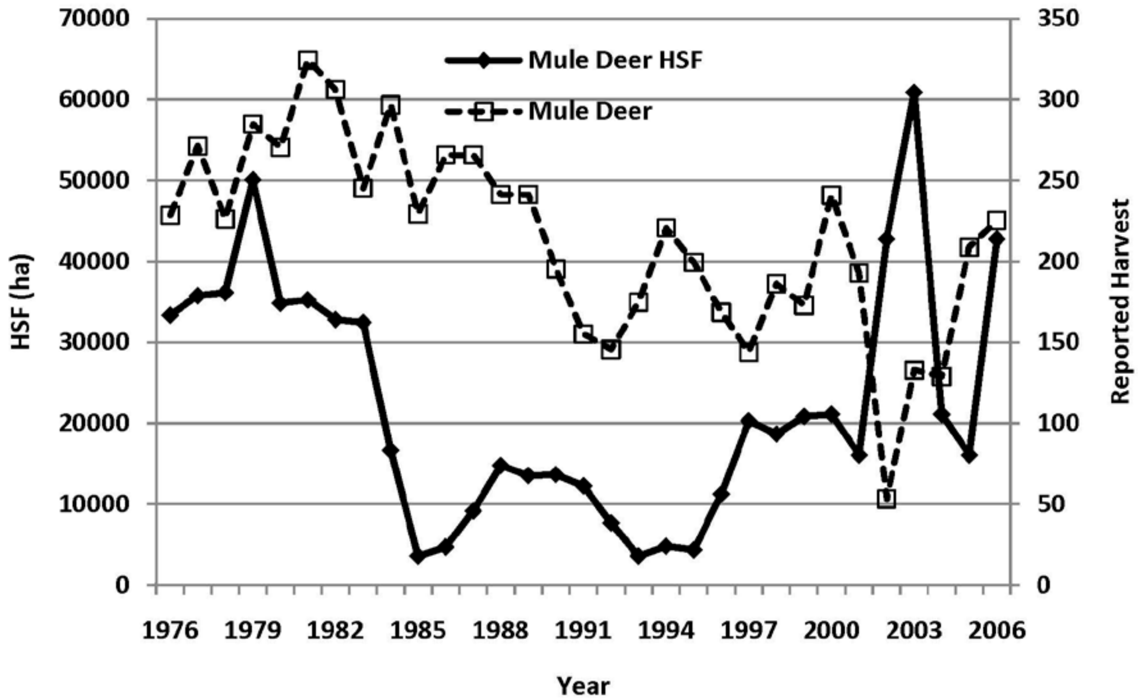

Figure 4. Relationship between mule deer abundance during 1976-1989 and habitat suitability resulting from fire 3 years earlier in the San Gabriel Mountains, California.

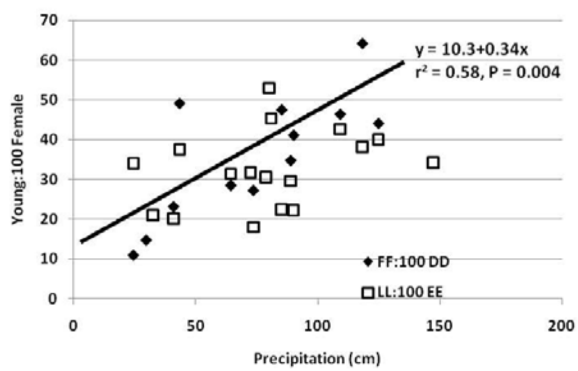

Figure 5. Relationship between precipitation during pregnancy and recruitment rates in mule deer and bighorn sheep during 1985-2004 in the San Gabriel Mountains, California.

DISCUSSION

Comparison of Bighorn Sheep Recruitment and Growth Rates between Burned and Unburned Ranges

Recruitment Rates.—Improved nutrition has been associated with increased recruitment in bighorn sheep (Seip and Bunnell 1985, Blanchard et al. 2003, McKinney et al. 2006), and forage quality in chaparral improves for 2-3 years after fires (Biswell et al. 1952). Although we expected recruitment would be consistently higher on burned ranges for at least 2 years following fires, we detected that pattern only during the second year after the 1975 fire (Table 1). Small samples sizes ($n < 20$ females) in the East Fork of the San Gabriel River in 2001, Cucamonga Canyon in 2005, and on unburned ranges in 2007 may not have yielded representative estimates of recruitment rates; however, sample sizes were substantially larger ($n > 30$ females) for all other ranges and years, and likely had little influence on our ability to detect differences. Alternatively, intra-annual differences in the distribution of bighorn sheep may have had an important, but undetected, affect.

Earlier investigators (Weaver et al. 1972, Holl and Bleich 1983) noted that both resident and migratory bighorn sheep occurred in the San Gabriel Mountains. Resident animals generally remain below 2,000 m elevation, while all migratory animals occupy summer ranges above 2,000 m. Vegetation associations change substantially above 1,850 m, and sheep that migrate to higher elevations can take advantage of differences in plant phenology and, presumably, more nutritional forage than animals remaining on lower elevation ranges (Hebert 1973, Wehausen 1983, Festa-Bianchet 1988). Our ability to detect differences in recruitment rates was confounded by sympatry between resident and migratory animals, which were indistinguishable during the annual aerial surveys on winter-spring ranges.

Exponential Rates of Increase.—Exponential rates of increase on burned ranges indicated bighorn sheep subgroups doubled every 5-6 years when compared with 32 years on unburned ranges, and the very low rate of increase on unburned ranges indicated that the majority of the population increase after 1997 was attributable to additional sheep on burned ranges. It is very unlikely that additional bighorn sheep on burned ranges was the result of immigration because bighorn sheep have high fidelity to seasonal ranges (Geist 1971), there are large patches of unsuitable and unoccupied habitat between winter-spring ranges (Holl and Bleich 1983), and available evidence indicates the San Gabriel Mountains are effectively isolated from other mountain ranges inhabited by bighorn sheep (Bleich et al. 1996, Epps et al. 2007). Short pulses of improved forage quality and recruitment on burned ranges would however, increase the number of animals and contribute to the higher rates of increase on those ranges.

Responses of Bighorn Sheep and Mule Deer to Changes in Habitat Suitability Resulting from Wildfires

Bighorn Sheep.—Wildfire changes the suitability and availability of bighorn sheep habitat (Stelfox 1976, Riggs and Peek 1980, Wakelyn 1987, Etchberger et al. 1989, Cain et al. 2005, Bleich et al. 2008) by reducing the canopy cover of shrubs and trees, which improves access and the field of vision of bighorn sheep (Risenhoover and Bailey 1980, Holl and Bleich 1983) which is required for the detection of predators. The HSF for winter-spring ranges used by bighorn sheep in the San Gabriel Mountains expanded and contracted during 1976-2006 as a result of wildfires and the HSF was positively associated with population changes in bighorn sheep during that period (Figure 2). When individual time periods were considered, the relationship between the HSF and bighorn sheep abundance improved during 1976-1989 and during 1995-2006; however, there was no relationship between HSF and abundance during 1989-1995.

During 1976-1989 the HSF initially improved as a result of wildfires in 1975 and 1980 and the largest population estimate, 749±49, was recorded in 1980 (Figure 2). After 1980 the HSF started to decline as a result of increased shrub growth and canopy cover in previously burned areas, and this corresponded with a decline in the abundance of bighorn sheep. During 1976-1982 adult survival was high, recruitment rates were influenced by precipitation and cold temperatures during the birthing season, and the exponential rate of increase (0.015) indicated the population was stable (Holl et al. 2004, Holl and Bleich 2009). Although small wildfires burned on winter-spring ranges after 1983 the HSF declined 46% during 1983-1989 (Figure 2), fewer sheep were observed in previously burned areas during the annual surveys (Holl et al. 2004), and the population estimates declined 23% during that period (Figure 2).

Between 1989 and 1995, there was no relationship between the HSF and bighorn sheep population estimates because the HSF remained unchanged during the first 4 years of that period while 80% of the sheep population decline during 1989-1995 occurred (Figure 2), indicating another factor was associated with the population decline.

The rate of the population decline during 1989-1995 was 4 times the rate of the decline during 1982-1989 (Holl et al. 2004, Holl and Bleich 2009), and it was characterized by the loss of adult sheep (Holl et al. 2004), which is uncommon (Gaillard et al. 2000, Harris et al. 2008); however, disease or large predators may account for much of the variation in adult survival (Gaillard et al. 2000). There is no evidence that disease influenced population changes in bighorn sheep in the San Gabriel Mountains (Holl et al. 2004). Based on the known demographic changes in the San Gabriel Mountains and observed declines in bighorn sheep resulting from mountain lion predation in nearby mountain ranges during a similar time period (Wehausen 1996, Hayes et al. 2000, Schaefer et al. 2000), it previously had been hypothesized that the bighorn sheep population decline during 1989-1995 was associated with mountain lion predation (Holl et al. 2004, Holl and Bleich 2009).

By 1995 the HSF and bighorn sheep population reached their lowest values (Figure 2). All previously burned areas had recovered and dense shrub cover would have substantially reduced the visual field of sheep and their ability to detect predators or move into adjacent habitat. Wakelyn (1987) and Etchberger et al. (1989) reported bighorn sheep abandoned seasonal ranges in the absence of fire in other mountain ranges. Yet, during the annual surveys in 1995 and 1996, sheep were observed on every winter-spring range except Cucamonga Canyon. Similarly, during 1976-1983 an estimated 290 bighorn sheep inhabited the Iron Mountain and Twin Peaks subgroups (Holl and Bleich 1983) even though those 2 areas had not burned in more than 25 years. Thus, the lack of fires in the San Gabriel Mountains did not result in complete abandonment of all seasonal ranges. In the absence of fire, escape terrain (Holl 1982) remains suitable habitat providing a refuge in the San Gabriel Mountains, likely because the steep, rocky substrate limits the density of shrubs and does not eliminate the ability of bighorn sheep to detect predators. As a result, the majority of the population changes associated with fire-related habitat changes likely occurred because fire had a disproportionately greater effect on the suitability and availability of chaparral habitat adjacent to escape terrain. Wildfires in 1997 and 2003 increased the HSF, which was associated with an increase in the number of bighorn sheep during 1998-2006 (Figure 2; Holl and Bleich 2009).

The reduction in shrub canopy cover that resulted from the wildfires in 1975, 1980, 1986, 1997, and 2003 increased the field of vision of bighorn sheep and improved access into recently burned areas (Stelfox 1976, Smith et al. 1989, Holl et al. 2004, DeCesare and Pletscher 2006), which reduced sheep densities, presumably as they searched for higher quality forage (Biswell et al. 1952, Hobbs and Spowart 1984). Browse species compose approximately 60% of the annual diet of bighorn sheep in the San Gabriel Mountains (Perry et al. 1987); therefore, seedlings and basal sprouts from root burls, combined with increased availability of grasses and forbs that followed fires, likely resulted in a short-term improvement in the quality of their diets (Biswell et al. 1952, Taber and Dasmann 1958, Hobbs and Spowart 1984) and should have improved lamb recruitment. Although this was not detected when recruitment on burned and unburned ranges was compared (Table 1), the number of bighorn sheep on burned ranges increased about 5 times faster than on unburned ranges.

During 1984-2006 there was a negative relationship between the density of adult females and recruitment rates (Figure 3). Density estimates are also ratios and are subject to the same concerns identified for age ratios (Caughley 1974, McCullough 1994, Harris et al. 2008), where changes in either the numerator (number of females) or denominator (area of habitat) can affect the ratio.

The highest density of ewes occurred in 1984. That peak resulted from a decline in the HSF during 1983-1984, rather than an increase in the number of ewes (Figure 2). Ewe densities generally declined during 1984-1997 as the number of ewes and the HSF declined (Figure 2), the latter a result of increased shrub cover. As ewe survivorship improved after 1995, density increased and recruitment rates declined until the 2003 fire increased the HSF, and thereby allowed sheep to redistribute themselves, reduce densities, and increase recruitment.

Mule Deer— Population estimates of mule deer were not available, but the reported buck harvest was correlated with the results of helicopter surveys and provides a reasonable index of changes in abundance in this mountain range (Holl et al. 2004). Annual changes in the HSF were not associated with the reported buck harvest, indicating habitat changes did not affect hunter success and minimized another potential source of bias that could have affected our analyses.

Black-tailed deer that occupy chaparral-dominated habitat increase production and survival of young for approximately 3 years post-fire (Taber and Dasmann 1957). During 1976-1989 the reported buck harvest was positively associated with the HSF 3 years earlier, indicating the HSF was associated with fawn recruitment 3 years earlier. Thus, the population increase during 1976-1981, as indicated by the reported buck harvest for those years, resulted from an increase in fawn recruitment that was initiated by earlier in the HSF (Figure 4).

Between 1981 and 1989, the reported buck harvest indicated the deer population declined by approximately 26% (Figure 4). That population decline corresponded with a reduction in the amount of habitat that had burned and lower recruitment 3 years earlier, which is consistent with the decline in the number of black-tailed deer that occurred as chaparral matured (Taber and Dasmann 1957, 1958). Following 1989, the reported buck harvest and aerial survey data (CDFG files) indicated a sharp decline in the deer population. During1990-1992, the reported buck harvest declined 40% from 1989 levels. Harvest data indicated that mule deer increased during 1993-2000 and then oscillated, but those changes were not related to habitat changes (Figure 4). Thus, factors other than habitat changes resulting from wildfires likely affected the mule deer population after 1989 (Figure 4).

Effects of Precipitation

During 1976-2004, fawn recruitment was directly affected by nutrient availability, as indexed by precipitation (Figure 5), and the lowest fawn recruitment rates occurred during 1989-1990 and 1999-2004, periods of lower than normal precipitation and when the HSF was not associated with the abundance of mule deer.

Mule deer commonly produce multiparous births (Anderson 1981), and nutrition affects ovulation and fetal rates, and fetal growth rates, in mule and white-tailed deer (*O. virginianus*). Females on lower nutritional planes produce fewer and smaller young (Taber and Dasmann 1957, 1958; Verme 1963, 1969). More recently, fawn production and survival on arid southwest ranges has been linked to precipitation and forage production (Kucera 1988, Lawrence et al. 2004, Bender et al. 2007) and population declines in southeastern California (Pierce et al. 2000). Similar observations of the effects of drought on mule deer recruitment and abundance were also reported from Arizona (Kamler et al. 2002), New Mexico (Logan and Sweanor 2001), and Nevada (Sweitzer et al. 1997). Thus, a regional drought appears to have been associated with the decline or constrained growth in mule deer populations across the southwest during the 1990s.

There was no apparent relationship between lamb recruitment and precipitation (Figure 5). Browse species comprise most of the annual diets of mule deer and bighorn sheep in the San Gabriel Mountains (Cronemiller and Bartholomew 1950, Perry et al. 1987), and the timing of changes in the nutritional value of the annual diet of black-tailed deer in chaparral (Taber and Dasmann 1958) is identical to that for bighorn sheep in the San Gabriel Mountains (Perry et al. 1987). Young of both species are born April through June, with the majority in May (Cronemiller and Bartholomew 1950, Holl and Bleich 1983). Thus, differences in foraging strategies or the timing of births do not explain observed differences in responses to decreased levels of precipitation and nutrient availability.

Bighorn sheep produce a single young (Geist 1971) and the birth weight of that young is small in relation to maternal weight when compared to white-tailed or black-tailed deer (Robbins and Robbins 1979). Producing a single offspring that is small would be advantageous during periods of reduced nutrient availability; conversely, a smaller individual would have a larger surface area:volume ratio, which would be disadvantageous if it was cold and wet during the birthing period (Holl et al. 2004). Although lack of precipitation in desert ranges affects nutrient availability and lamb recruitment (Leslie and Douglas 1979, Wehausen et al. 1987, Douglas 2001, McKinney et al. 2006), the San Gabriel Mountains are mesic and produce more biomass than those desert ranges; as a result, recruitment in bighorn sheep was less apt to be affected by changes in precipitation (an index to nutrient availability) than in arid desert ranges.

CONCLUSIONS

Wildfires on chaparral winter-spring ranges in the San Gabriel Mountains improved habitat suitability, resulting in reduced ewe densities that were associated with increased recruitment rates and bighorn sheep populations on burned ranges increased faster than populations on unburned ranges. Wildfire history was associated with the abundance of bighorn sheep during all years except 1989-1995, and with the abundance of mule deer during 1976-1989. Precipitation during pregnancy was associated with recruitment in mule deer, and drought years reduced recruitment and mule deer abundance during the 1990s, similar to what was observed in other mule deer populations in the southwest during that period.

In their review of temporal variation in the dynamics of ungulates Gaillard et al. (2000) identified 4 sources of temporal variation that influenced demographic responses in large herbivores: predictable seasonal environmental variation, unpredictable weather fluctuations, density-dependent responses, and changes in the behavior or abundance of predators. California's very predictable Mediterranean climate results in a similar annual cycle in forage quality in chaparral. In northern California, the crude protein content in chaparral browse consumed by black-tailed deer peaked in April, then declined to its lowest quantity in September and gradually increased during winter fall and winter (Taber and Dasmann 1958). This is identical to the annual cycle of crude protein content in the diet of bighorn sheep in the San Gabriel Mountains (Perry et al. 1987). The predictability of the annual forage quality cycle corresponds to the timing and duration of the birthing season for mule deer and bighorn sheep (mid-April to early-June), which has little annual variability.

Unpredictable amounts of spring precipitation influence critical fuel moisture levels in late summer (Dennison et al. 2008) and warm fall winds influence wildfire behavior which directly affects habitat suitability and demographic responses of mule deer and bighorn sheep. Changes in habitat suitability resulting from wildfires may have the greatest influence on inter-year variability in mule deer and bighorn sheep in the San Gabriel Mountains. Unpredictable droughts influence recruitment and abundance of mule deer; however, variability in precipitation appears to have little influence on bighorn sheep, except when they are at high densities and precipitation and cold temperatures occur during the birthing season.

Predators, particularly mountain lions, increase demographic variability in mule deer and bighorn sheep. Variability in survivorship associated with predators is high in mule deer because they are the primary prey of mountain lions (Ballard et al. 2001). The available information indicates predation has had little influence on the abundance bighorn sheep in the San Gabriel Mountains (Robinson and Cronemiller 1954, Weaver et al. 1972, Holl and Bleich 1983, Holl et al. 2004) and predation may only have a substantial effect on the number of bighorn sheep after the mule deer population has declined (Sweitzer et al. 1997, Logan and Sweanor 2001, Holl et al. 2004). The population decline in bighorn sheep during 1989-1995 that was hypothesized to have resulted from mountain lion predation (Holl et al. 2004) was preceded by the decline in mule deer that was associated with the rare alignment of few wildfires that reduced habitat suitability and a drought that reduced fawn recruitment.

MANAGEMENT IMPLICATIONS

For the past 50 years the management of large mammals in the San Gabriel Mountains has been limited to suppressing all wildfires in a fire-adapted ecosystem, a limited harvest of mule deer, and removal of 66 bighorn sheep for translocation. The decline of bighorn sheep during 1989-1995 led to their re-listing as a Forest Service Sensitive Species and the preparation of a restoration plan (US Forest Service et al. 2004).

Habitat changes resulting from fires clearly affect the distribution, productivity, and abundance of mule deer and bighorn sheep. Modeling has demonstrated that fire can significantly increase bighorn sheep habitat in the San Gabriel Mountains (Bleich et al. 2008) and our analysis demonstrated a similar relationship exists for mule deer. Bighorn sheep can be removed from the Sensitive Species list after demonstrating that a larger population can be sustained (US Forest Service et al. 2004). Although prescribed burns to improve habitat suitability and increase the number of bighorn sheep were identified in the restoration plan (US Forest Service et al. 2004), no prescribed burns have been implemented because the current local paradigm does not recognize prescribed fire as an effective tool to manipulate a fire-adapted ecosystem. Local perceptions and policies that constrain the use of prescribed burning or the use of natural fire to improve habitat suitability for mule deer and bighorn sheep will have to be modified before the restoration goal can be achieved.

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Correction to Bleich 2006. Mountain Sheep in California: Perspectives on the Past, and Prospects for the Future

An article published in the 2006 Proceedings of the 15th Biennial Symposium of the Northern Wild Sheep and Goat Council contained an error. Please amend: ***Bleich, V. C. 2006. Mountain sheep in California: perspectives on the past, and prospects for the future***. ***Biennial Symposium of the Northern Wild Sheep and Goat Council 15:1–13*** as indicated below. The text on page 2, right column, very near the top should be corrected by deleting strikethrough text and adding underlined text as follows:

> "Indeed, ~~Francisco Garces~~ <u>Frey Pedro Font</u>, who chronicled the <u>Anza</u> expeditions ~~of Father Anza~~ as ~~he~~ they traveled north and west from what is now Arizona toward the Pacific coast of California, described dead and dying ~~mountain sheep~~ <u>cattle</u> in the Santa Rosa Mountains of southern California as early as ~~1776~~ 1775 (Bolton 1930)."

The author sincerely regrets the error.