NORTHERN WILD SHEEP AND GOAT COUNCIL

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The Northern Wild Sheep and Goat Council is a nonprofit professional organization developed in 1978 from the Parent organization – The Northern Wild Sheep Council.

GUIDELINES OF THE NORTHERN WILD SHEEP AND GOAT COUNCIL

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

This purpose will be achieved by:

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

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

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

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

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

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

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

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

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

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

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

FORWARD

Papers in these Proceedings were presented during the Thirteenth Biennial Symposium of the Northern Wild Sheep and Goat Council held April 23 to April 27, 2002 at Rapid City, South Dakota.

The manuscripts published herein were reviewed by the session moderator. Some papers were submitted to other peer biologists/researchers for review if moderators were involved in those papers. This ensured that all manuscripts received independent review prior to publication. Reviews were returned to the authors and final papers were forwarded to the editor for incorporation. Final content was left to the authors and therefore, readers are responsible for the critical evaluation of information contained within.

Table of Contents

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DISEASE AND PARASITES

Emily Jenkins - Moderator

Parasites In Dall's Sheep: What We Can Learn From Historical And Contemporary Collections (Or: Putting Together The Pieces!)

SUSAN J. KUTZ, Department of Veterinary Microbiology, Western College of Veterinary Medicine, 52 Campus Drive, Saskatoon, SK, S7N 5B4 Canada
ALASDAIR M. VEITCH, Department of Resources, Wildlife, and Economic Development (DRWED), Box 130, Norman Wells, NT, X0E 0V0 Canada
NORMAN SIMMONS, Box 248, Pincher Creek, AB, T0K 1W0 Canada
ERIC HOBERG, Parasite Biology, Epidemiology and Systematics Laboratory, 10300 Baltimore Avenue, Beltsville, MD, 20715 U.S.A.
BRETT ELKIN, DRWED, #600 5102 50th Ave., Yellowknife, NT, X0E 0V0 Canada
EMILY J. JENKINS, Department of Veterinary Microbiology, Western College of Veterinary Medicine, 52 Campus Drive, Saskatoon, SK, S7N 5B4 Canada
LYDDEN POLLEY, Department of Veterinary Microbiology, Western College of Veterinary Medicine, 52 Campus Drive, Saskatoon, SK, S7N 5B4 Canada

Abstract: In 1997 we began investigating parasites of Dall's sheep in the Mackenzie Mountains in Canada's Northwest Territories (NWT). During the course of this work we found little in the published literature about parasites in this or other thinhorn species. We did find, however, two in-depth, but unpublished, studies on gastrointestinal parasites of Dall's sheep in the NWT and Alaska done between 1964 and 1973. In the Mackenzie Mountains, NWT, Norm Simmons, Anne Currier and colleagues (Canadian Wildlife Service) collected 24 and 81 sheep in February of 1971 and 1972, respectively. Post mortem examinations, including parasitology, were performed, but detailed examination of the parasites and analyses of the data were not completed. The parasites from these sheep were preserved and deposited as an orphaned collection (the Simmons Collection) at the Canadian Museum of Nature in Ottawa. In November 2000, we resumed the examination of these specimens. In Alaska, a total of 79 Dall's sheep collected from various locations between 1964 and 1973 were examined for gastrointestinal parasites by Carol Neilsen and Kenneth Neiland. The results were reported in an Alaska Department of Fish and Game progress report, 1974. These two studies are unparalleled historical baselines, providing valuable information on the gastrointestinal parasite fauna in Dall's sheep 30 years ago. Together with current research on Dall's sheep in the Mackenzie Mountains, including seasonal collections of fecal samples and periodic whole sheep necropsies, they serve as the basis for understanding the biology and effects of gastrointestinal parasites in wild Dall's sheep. The value of these historical collections and the ongoing research are discussed within the context of monitoring disease in wildlife populations and the possible influence of climate change on host-parasite systems.

Distribution And Abundance Of Terrestrial Gastropod Intermediate Hosts Of Lungworms On Isolated, Semi-Arid Bighorn Sheep Ranges.

JARED D. ROGERSON, Department of Biology, University of Nebraska-Omaha, 6001 Dodge, Omaha, NE, 68182 U.S.A.
W. SUE FAIRBANKS, Department of Biology, University of Nebraska-Omaha, 6001 Dodge, Omaha, NE, 68182 U.S.A.

Abstract: Recent bighorn sheep (*Ovis canadensis*) introductions in northwestern Utah may serve as models to explore the ecology of parasite-host relationships existing under isolated circumstances. Isolation may alter typical movement patterns of bighorn sheep and increase exposure to lungworms (*Protostrongylus stilesi* and *P. rushi*) through a build-up of fecal material. However, dry environments may hinder parasite transmission through limitations placed on terrestrial gastropods, the intermediate hosts. Bighorn sheep habitat use and gastropod distribution and abundance are compared to evaluate potential for lungworm transmission in isolated, semi-arid conditions. Gastropods were collected weekly on Antelope Island and Newfoundland Mountains during May-August 2001 among four major habitat types (grass, rock, spring, and scrub). Three sampling techniques were used. Gastropods were collected from within the families Pupillidae, Succineidae, Thysanophoridae, and Vallonidae. Experimental infections in the laboratory are being conducted to determine host suitability. In the field, gastropods were most abundant near springs, followed by rock, grass, and scrub habitat types. However, on Newfoundland Mountains, gastropods were not collected in grass or scrub. Habitat use by bighorn sheep was determined through visual observations of radio-marked individuals. On Antelope Island, bighorn sheep were observed most in grass, followed by rocks, scrub and springs. Current lungworm loads in the bighorn sheep populations were assessed by collecting fresh feces and extracting larvae to estimate mean lungworm larvae per gram of feces (LPG). LPG values for Antelope Island bighorn sheep are moderate to high suggesting that lungworms may be an important factor to the health of this population. Springs are probably the most important areas of lungworm transmission. A second field season will be conducted May-August 2002.

Investigating And Interpreting Population Health In Dall's Sheep In The Mackenzie Mountains, Northwest Territories, Canada

EMILY J. JENKINS, Department of Veterinary Microbiology, Western College of Veterinary Medicine, 52 Campus Drive, Saskatoon, SK, S7N 5B4 Canada
ALASDAIR M. VEITCH, Department of Resources, Wildlife, and Economic Development, Box 130, Norman Wells, NT, X0E 0V0 Canada
BRETT T. ELKIN, Department of Resources, Wildlife, and Economic Development, #600 5102 50th Ave., Yellowknife, NT, X1A 3S8 Canada
SUSAN J. KUTZ, Department of Veterinary Microbiology, Western College of Veterinary Medicine, 52 Campus Drive, Saskatoon, SK, S7N 5B4 Canada
MANUEL CHIRINO-TREJO, Department of Veterinary Microbiology, Western College of Veterinary Medicine, 52 Campus Drive, Saskatoon, SK, S7N 5B4 Canada
LYDDEN POLLEY, Department of Veterinary Microbiology, Western College of Veterinary Medicine, 52 Campus Drive, Saskatoon, SK, S7N 5B4 Canada

Abstract: Monitoring infectious agents in both diseased and healthy animals in a wildlife population allows us to identify and differentiate significant pathogens and bacteria, viruses, and parasites that are normally present in the population. Since 1999, from the Mackenzie Mountains, we have examined carcasses of 9 Dall's sheep found dead and 5 healthy sheep, and samples from 2 sick sheep and 29 hunter-killed sheep. Pneumonia was present in all 11 Dall's sheep found dead or observed to be sick. In 10 cases, bacteria including *Arcanobacterium pyogenes*, *Mannheimia haemolytica*, and *Pasteurella multocida* were cultured from the lungs. These bacteria were not recovered from the lungs of healthy animals, although *Arcanobacterium pyogenes* was present in the tonsils of 2 of 12 healthy animals. Of four healthy sheep that were tested, all had very low (essentially negative) serum titers for leukotoxin, A1, A2, and T10 serotypes of *Mannheimia/Pasteurella*. Bovine respiratory viruses (bovine respiratory syncytial virus, infectious bovine rhinotracheitis virus, parainfluenza-3 virus) were not detected on immunohistochemistry of lungs of 5 sick/dead sheep, nor was bovine viral diarrhea virus detected in 2 sick/dead sheep. These viruses and ovine progressive pneumonia virus were not detected on serological testing of 11 healthy sheep. Histologically, inflammation surrounded the eggs and larvae of protostrongylid parasites in the lungs of both healthy and sick animals; in one case, this proved fatal in the absence of any bacterial involvement. Ninety percent of the sick/dead sheep and 72% of the healthy animals were infected with the lungworm *Protostrongylus stilesi*, and 70% of the sick/dead and 97% of the healthy sheep were infected with the muscleworm *Parelaphostrongylus odocoilei*. Fecal shedding of eggs of gastrointestinal parasites was higher in the sick/dead animals (n=9) than in the healthy ones (n=30). In eggs per gram of feces for sick/dead vs healthy sheep: *Marshallagia* spp. 39 vs 4; *Nematodirus* spp. 7 vs 2; *Trichuris* spp. 2 vs 1; *Eimeria* spp. 72 vs 57; and trichostrongyles 18 vs 0.92. Similarly, fecal shedding (larvae or eggs per gram of feces) of *Protostrongylus* spp. larvae (521 vs 129), *Marshallagia* spp. (4 vs 2.6), and *Nematodirus* spp. (4 vs 1.8) was greater in sheep in poor (n=5) versus good (n=20) body condition. The microbiological fauna (bacteria, viruses, and parasites) and health of Dall's sheep in the Mackenzie Mountains can be compared to the past (e.g. the Simmons collection of parasites from these sheep in 1971-72) and to other wild sheep populations, particularly bighorn sheep affected by pneumonia.

Contact Zones Between Expanding Muskox Populations And Dall's Sheep – An Emerging Disease Issue

SUSAN J. KUTZ, Department of Veterinary Microbiology, Western College of Veterinary Medicine, 52 Campus Drive, Saskatoon, SK, S7N 5B4 Canada
ALASDAIR M. VEITCH, Department of Resources, Wildlife, and Economic Development, (DRWED) Box 130, Norman Wells, NT, X0E 0V0 Canada
JOHN NAGY, DRWED, Bag Service #1, Inuvik, NT, X0E 0T0 Canada
BRETT ELKIN, DRWED, #600 5102 50th Ave., Yellowknife, NT, X0E 0V0 Canada
ERIC HOBERG, Parasite Biology, Epidemiology and Systematics Laboratory, 10300 Baltimore Avenue, Beltsville, MD, 20715 U.S.A.
EMILY J. JENKINS Department of Veterinary Microbiology, Western College of Veterinary Medicine, 52 Campus Drive, Saskatoon, SK, S7N 5B4 Canada
LYDDEN POLLEY Department of Veterinary Microbiology, Western College of Veterinary Medicine, 52 Campus Drive, Saskatoon, SK, S7N 5B4 Canada

Abstract: Emerging diseases often result from changes in the ecology of a host, pathogen, or both. In wildlife, these are frequently anthropogenic in origin - e.g., host and/or pathogen translocation, habitat alteration, contact with domestic species, or climate change. In northern Canada, however, we may soon observe disease emergence resulting from natural movements of native and introduced wildlife populations. During the last 20yr mainland muskox populations have expanded their range into regions they have not occupied in recent history. We anticipate that continued expansion in the next few years will result in contact between: a) an introduced muskox population west of the Mackenzie River, and a native one east of the river; and b) the native muskoxen and Dall's sheep populations in the Mackenzie and Richardson Mountains. Native muskoxen, introduced muskoxen, and Dall's sheep each have their own characteristic parasite faunas. Some of their parasite species are transmitted between hosts, e.g., range overlap between the introduced muskoxen and Dall's sheep recently resulted in emergence of the sheep lungworm, *Protostrongylus stilesi,* in muskoxen. *Umingmakstrongylus pallikuukensis,* a common lungworm of native muskoxen, is currently absent from introduced muskoxen and Dall's sheep. We predict that, with contact, it will establish in introduced muskoxen and possibly in Dall's sheep. Other gastrointestinal and tissue parasites are also likely to be transmitted among the different host populations. Introduction of 'new' and resultant disruption of 'normal' parasite faunas in these host species may have detrimental effects. To evaluate the risk of disease emergence following contact among these host populations we are using field and laboratory studies. From historical parasite collections and ongoing post mortems we are identifying the parasite fauna and assessing the effects on hosts. Monthly or bimonthly fecal examinations are defining seasonal patterns of parasite shedding and providing insight into the epidemiology of various parasites. Future research includes experimental infections of thinhorn sheep to determine susceptibility to *U. pallikuukensis* and to *Teladorsagia boreoarcticus,* an abomasal parasite of muskoxen. Results from these studies will be used to assess the risk of parasite transmission between hosts, to predict the consequences of such an introduction, and to provide the basis for management decisions regarding preventing contact between the different host populations.

Viability Of Airborne *Pasteurella* Spp.

DAVID M. DIXON, P.O. Box 189, Greenleaf, Idaho 83626
KAREN M. RUDOLPH, Idaho Department of Fish and Game, Wildlife Health Laboratory, 16569 S. 10th Avenue, Caldwell, Idaho 83607
MARK L. KINSEL, Agricultural Information Management, Inc., 741 Naneum Road, Ellensburg, Washington 98926
LISA M. COWAN, 22884 Rodeo Ct., Bend, Oregon 97701
DAVID L. HUNTER, Turner Enterprises, 1123 Research Dr., Bozeman, Montana 59718
ALTON C. S. WARD, University of Idaho, Caine Veterinary Teaching Center, 1020 E. Homedale Road, Caldwell, Idaho 83607

Abstract: Pasteurella spp. are commensal organisms in bighorn sheep that have been frequently associated with pneumonia die-offs. The method of transmission in bighorn sheep generally has been assumed to be by direct (nose-to-nose) contact. An observational study was conducted to determine the effects of two wind tunnel distances (short and long), two bacterial doses (high and low), and two seasons (summer and winter) on the airborne bacterial viability of three strains of *Pasteurella* bacteria. One strain from each of the species *P. haemolytica, P. trehalosi* and *P. multocida* was nebulized into a wind tunnel. Selective media plates were suspended at the tunnel exit to collect viable organisms. The experiments were done in triplicate. The final multiple linear regression model suggests that the *P. multocida* strain was significantly more likely to survive aerosol transmission than either the *P. haemolytica or P. trehalosi* strain (P = 0.0043). A majority of the variation (74%) in airborne viability could be explained by the *P. multocida* strain alone. Although not statistically significant at the P = 0.05 level, there was evidence that the number of viable colonies recovered was higher in summer conditions (P = 0.1396), and temperature dependent (P = 0.1036). At an initial high bacterial dose (1 x 10^6 cfu), the predicted number of *P. multocida* bacteria remaining viable over short (6.1 m) and long (18.3 m) distances during summer was n = 2820 (0.28 %) and n = 1620 (0.16 %), respectively, and during winter was n = 1800 (0.18%) and n = 600 (0.06%), respectively. At the initial high bacterial dose for the *P. haemolytica* strain, the predicted number of bacteria remaining viable over short and long distances during summer was n = 2370 (0.24%) and n = 1170 (0.12%), respectively, and during winter was n = 1350 (0.14%) and n = 150 (0.02%), respectively. Results for the *P. trehalosi* strain did not differ significantly from the results for the *P. haemolytica* strain. These findings suggest a potential exists for *Pasteurella* spp. to be transmitted between animals without direct contact.

Key Words: bighorn sheep, *Pasteurella* spp., aerosol transmission, wind tunnel, *Pasteurella* viability

Pasteurella-related pneumonia epizootics continue to be a major factor in the decline of bighorn sheep populations (Onderka and Wishart 1984, Spraker et al. 1984, Coggins 1988, Cassirer et al. 1996). The predominant mechanism for transmission of *Pasteurella* spp. among ungulates is generally assumed to be by direct (nose-to-nose) contact (Carter and De Alwis 1980, Chanter and Rutter 1980, Frank 1980, Gilmour and Gilmour 1980). Other mechanisms for transmission of *Pasteurella* spp. have been identified including exposure to contaminated water for waterfowl (Rhoades and Rimler 1980), and aerosol transmission in livestock (Gilmour and Gilmour 1980, Dinter and Muller 1984) and rabbits (Manning et al.

1980). Possible similar mechanisms of transmission have not been ruled out in bighorn sheep.

In 1995-96, a die-off of major proportions appears to have systematically worked its way through bighorn sheep herds residing on either side of the Snake River near and in the Hells Canyon National Recreation Area, ID, OR and WA. Initially, 72 Rocky Mountain bighorn sheep were captured from the Black Butte, WA herd and transported to captivity for further study at the Idaho Department of Fish and Game, Wildlife Health Laboratory (WHL) (Cassirer et al. 1996). Despite carefully implemented controls at the WHL to prevent human foments between the visiting Black Butte herd and resident WHL bighorn sheep, within three weeks, resident bighorn sheep began showing signs of respiratory disease. Extremely windy weather conditions with a prevailing wind direction in favor of aerosol transmission from the Black Butte herd to the resident captive herd were noted. The epidemiology of this epizootic (on the range and in captivity), and others, has raised the question of whether aerosol transmission may play a role in some bighorn sheep die-offs. The following are findings of an observational study at the WHL using a wind tunnel system to study the effects of wind tunnel distance, bacterial dose, and season on the potential for airborne transmission of three selected strains of *Pasteurella* bacteria.

MATERIALS AND METHODS

Wind Tunnel Design.

The wind tunnel was constructed of one or three 6.1 m lengths of PVC pipe, each with a 30.2 cm diameter. A 120 V squirrel cage fan was secured completely over the entrance of the pipe, to generate a fixed wind speed of approx. 11.3 m/s, as measured by a Turbo Meter Wind Speed Indicator. A glass nebulizer was suspended at the tunnel entrance, centered on top at a distance of 25 cm from the wind source. A 1/3 hp, 115 V electric air pump (General Electric) was connected to the nebulizer with 0.63 cm diameter surgical tubing and run at 8 psi. At the tunnel exit, a 10 cm selective media plate (CBAA, Ward et al. 1986) was centered and suspended to collect viable *Pasteurella* spp.

Wind Tunnel Experiment.

Humidity and temperature were recorded before each trial using a Weksler sling psychrometer. A series of two experiments were run each day, in triplicate. At the beginning of each experiment day, a control run was carried out by suspending a selective CBAA media plate at the exit end of the tunnel and running the fan for five min before removal. Next, a fresh CBAA plate was placed at the exit end of the tunnel, and pipetting 3 ml bacterial broth into a marked, weighed nebulizer set at the entrance end. The fan and air pump were run for five minutes; the pump was shut off while the fan was run an additional minute. The CBAA plate was exchanged for a fresh control CBAA plate, the fan run for an additional five min, and the nebulizer removed for a post-trial weight to determine the volume of inoculum vaporized. All CBAA plates were placed in a 35 C incubator with 10% added CO_2 immediately after the experiment was completed, and examined at 24 hr and 48 hr for viable *Pasteurella* colonies. Representative colonies were selected and identified using the essential tests of Jaworski et al. (1998).

Wind tunnel distances of 6.1 m and 18.3 m were used for summer trials, and a single distance of 18.3 m was used for winter trials. Three trials were run using a dilute bacterial dose based on colony forming units (cfu) (1×10^4cfu), followed by three trials at a more concentrated bacterial dose (1×10^6 cfu) on a given day at the WHL. Initial bacterial doses were chosen based on previous publications (Gilmour et al 1975; Gilmour et al. 1984). The day following a wind tunnel trial, the tunnel was sampled with a sterile swab around the entrance and exit, and the swabs were cultured on a 5% Columbia blood agar plate (CBA) media and CBAA media to determine the number of viable *Pasteurella* spp., as described above.

Bacteriology

The three *Pasteurella* strains chosen for this study were a *P. haemolytica*, biovariant 1 strain (CVTC #94-1427), a *P. trehalosi*, biovariant 2 strain (CVTC #89-269-L), and a *P. multocida multocida* A strain (CVTC #96-162). Each strain was isolated in pure culture from lung samples from three Rocky Mountain bighorn sheep carcasses (*Ovis canadensis canadensis*) submitted during the seven year period from 1989-1996 to the University of Idaho, Caine Veterinary Teaching Center (CVTC) for *Pasteurella* culture.

Bacterial cultures for each aerosol trial were prepared by inoculating brain heart infusion (BHI) broth with one of the three *Pasteurella* spp. strains and incubated overnight at 35 C in an incubator with 10% added CO_2. The next morning the percent transmittance (%T) for each inoculate was determined at a wavelength of 610 nm and adjusted to 75 %T, to approximate 1×10^8 colony forming units (cfu) per ml (Blau et al. 1987). Ten-fold serial dilutions (10^8-10^2) were plated on CBAA media plates. The following day, *Pasteurella* colonies on each dilution series plate were counted to determine bacterial concentration (cfu/ml), and the identities of representative colonies from the dilution series were confirmed using the essential tests of Jaworski et al. (1998).

Statistics

Data analysis was initially conducted using a Student's T test, followed by re-evaluation using a multiple linear regression model. The reference group for this analysis was the percent of viable *P. haemolytica* recovered from an initial 1×10^4 (cfu) dose at a distance of 6.1 m during winter at 0° C and 0% humidity. Significance for tests was determined using a P value of $P < 0.05$. Statistics were performed using Statview.

RESULTS

Summer temperatures ranged from 22–32 C, with humidity at 50-55% for trials at 6.1 m distance and 28-34% for trials at 18.3 m distance. Winter temperatures ranged from –1.0 – 4.5 C, with humidity at 55-82%. Control media plates used before and after each experimental trial were always culture negative for *Pasteurella* spp. Biochemical identification for each strain of *Pasteurella* spp. recovered on media plates during each trial resulted in a monoculture of the identical *Pasteurella* strain used (data not shown).

The two sample T Test for initial dose and distance resulted in a trend toward a higher initial dose for the long distance experiments ($P < 0.12$) (Table. 1). To avoid the potential of confounding of this reaction, a multiple linear regression model was generated with an interaction term (FarInit) of distance (Far) and initial dose (Initial) (Table 2).

Table 1. Two-sample T Tests for initial dose vs distance

Distance	Mean dose
6.1 m	1×10^6
18.3 m	5.5×10^6

$P < 0.12$

Table 2. Linear regression model of % viable bacteria recovered

Predictor variables	Coefficient	95% CI	P value
Constant	0.135	-0.037, 0.307	0.1320
P. multocida	0.045	0.016, 0.074	0.0043
P. trehalosi	-0.002	-0.029, 0.026	-0.9003
Summer	0.102	-0.033, 0.235	0.1396
Humidity 10	0.007	-0.011, 0.024	0.4770
Temperature 10	-0.018	-0.038, -0.003	-0.1036
Initial	-3.48×10^{8}	-0.000, 0.000	0.0000
Far	-0.119	0.166, -0.072	0.0000
FarInit	3.49×10^{8}	-0.000, 0.000	0.0000

Definitions of Independent Variables for the Regression Model:

P. multocida = A variable coded 1 if the organism was *P. multocida* and 0 if it was not

P. trehalosi = A variable coded 1 if the organism was *P. trehalosi* and 0 if it was not

Summer = A variable coded 1 if the current season was summer and 0 if it was winter

Humidity10 = A variable representing the effect of a 10% change in humidity

Temperature10 = A variable representing the effect of a 10 C change in temperature

Initial = The initial dose of the bacteria of interest in colony forming units

Far = A variable coded 1 if the distance was 18.3 m and 0 if it was 6.1 m

Results from the multiple linear regression model showed that the *P. multocida* strain used in this experiment was significantly more likely to survive aerosol transmission than the *P. haemolytica* or *P. trehalosi* strains (P = 0.0043). There were non-significant trends for season (summer) (P = 0.1396) and increasing temperatures (P = 0.1036) for the viability of airborne *Pasteurella* strains used in this study.

The square of the correlation coefficient for the final regression model, R^2, was approximately 0.76, indicating that 76% of the variation in airborne viability could be explained by the variables in this model, with approximately 74% explained by the *P. multocida* strain alone.

DISCUSSION

This observational study demonstrated that small numbers, colony forming units (cfu), of selected strains of *Pasteurella* bacteria, particularly the *P. multocida* strain, remained viable after traveling distances of up to 18.3 m through a wind tunnel, at a fixed wind speed of 11.3 m/s both in summer and winter climates in Caldwell, Idaho. Analysis of the dataset using two-sample T tests indicated a potential for confounding from a possible relationship between initial dose and distance. To avoid such a case, further analysis was conducted using a multiple linear regression model to partition out the initial dose and distance factors. The model can be used to predict the number of viable bacteria recovered from the windtunnel study (Figure 1, Table 3). For example, from an initial dose of 1×10^6 cfu of the *P. multocida* strain, 2.8×10^3 (0 – 6160) (0.28 %) are predicted to survive aerosol transmission of 6.1 m in the summer, while from an initial dose of 1×10^6 cfu of the *P. haemolytica* strain, 1.5×10^1 (0, 2340) (0.02 %) are predicted to

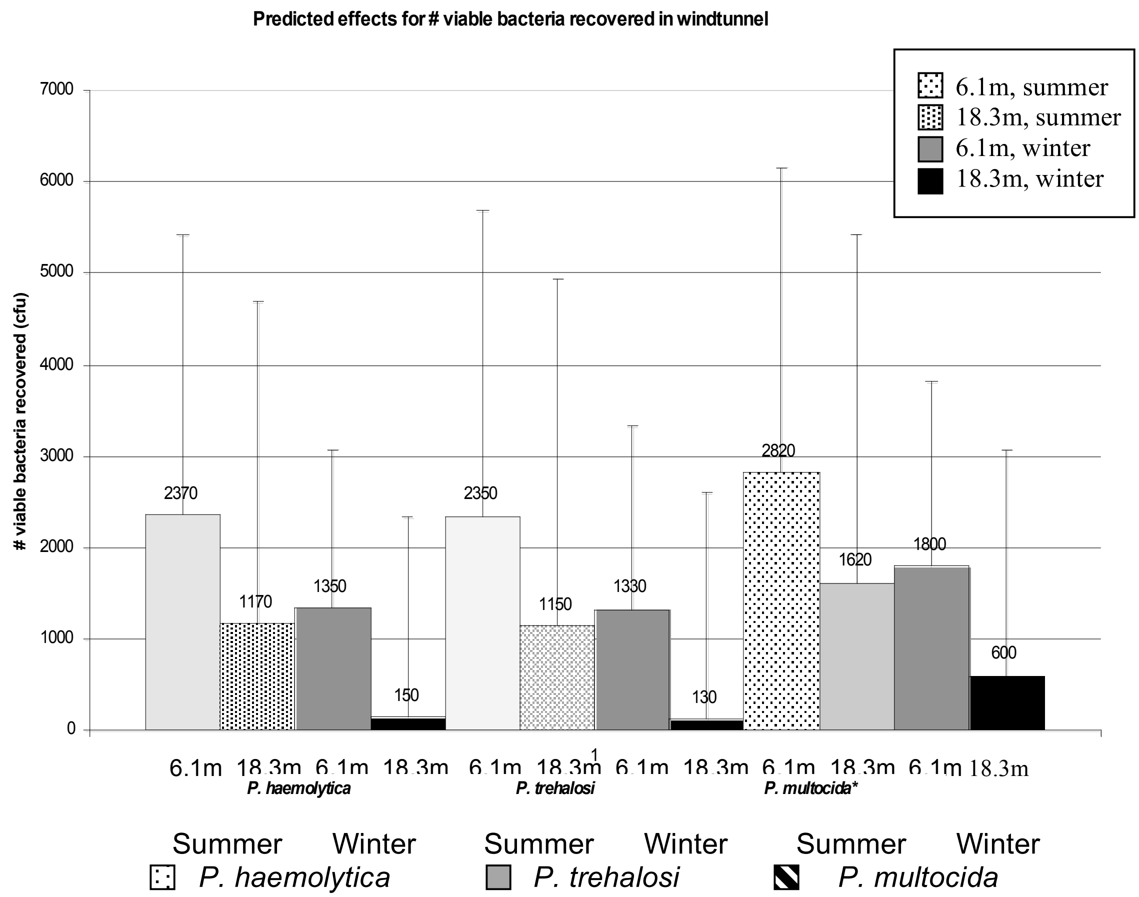

Figure 1. Graph of predicted effects for number of viable bacteria recovered from the wind tunnel at an initial high dose (1 x 10^6 cfu). *indicates statistical significance (P = .0043) for the *Pasteurella* strain *P. multocida*.

survive aerosol transmission of 18.3 m in the winter.

Of great interest is the finding that the square of the correlation coefficient, R2, indicated that three quarters of the variation in airborne viability could be explained by the strain of *Pasteurella* spp alone. This provides preliminary evidence for the importance of Pasteurella strain to the success of airborne transmission, and much less so on other factors such as season, temperature and humidity.

The biological relevance of these results to bighorn sheep management may be gained from consideration of two previously published papers (Gilmour et al. 1975; Gilmour et al. 1984). In these two studies, Caesarean-derived, colostrum-deprived, specific pathogen free domestic lambs at 8 wk of age were used in experimental infection studies with an aerosol of *P. haemolytica*. In the first study (Gilmour et al. 1975), it was determined that experimental aerosol administration of a *P. haemolytica* strain at a dose of 1 x $10^{4.8}$ cfu resulted in pneumonia 7 days later in 4/9 experimental (non-vaccinated) lambs, indistinguishable from that described in the natural disease. In this study, an infectious dose of 1 x $10^{4.8}$ cfu resulted in

Table 3. Predicted effects for viable bacteria recovered at high dose (1 x 10^6cfu)

Bacterial strain	Season	Distance	Number viable bacteria recovered	% viable bacteria recovered	95% CI
P. haemolytica	Summer	6.1 m	2370	0.24%	0-5420
P. haemolytica	Summer	18.3 m	1170	0.12%	0-4690
P. haemolytica	Winter	6.1 m	1350	0.14%	0-3070
P. haemolytica	Winter	18.3 m	150	0.02%	0-2340
P. trehalosi	Summer	6.1 m	2350	0.24%	0-5680
P. trehalosi	Summer	18.3 m	1150	0.12%	0-4950
P. trehalosi	Winter	6.1 m	1330	0.13%	0-3330
P. trehalosi	Winter	18.3 m	130	0.01%	0-2600
P. multocida	Summer	6.1 m	2820	0.28%	0-6160
P. multocida	Summer	18.3 m	1620	0.16%	0-5430
P. multocida	Winter	6.1 m	1800	0.18%	0-3810
P. multocida	Winter	18.3 m	600	0.06%	0-3080

lamb mortality of 4/9 lambs on day 7 post-infection.

In the second aerosol study (Gilmour et al. 1984), it was determined that in lambs first infected with parainfluenza 3 (PI-3) virus, then 7 days later exposed to aerosols of a *P. haemolytica* strain at an initial dose as low as 5.5 x 10^2 cfu, 6/7 lambs developed pneumonia as determined by necropsy seven days post *P. haemolytica* infection. Under the conditions of the study, a PI-3 viral infection significantly reduced the infectious dose necessary for lethality in domestic sheep lambs. This study and others reviewed in Brogden et al. (1998) demonstrates the importance of predisposing factors, such as the PI-3 virus, to the health of sheep.

The resulting predicted number of viable *Pasteurella* organisms in our study was two to four fold less than that described in the Gilmour et al. (1975) study, and likely would not be considered a risk as an infectious dose. However, such a dose as identified in our study may result in colonization and growth of airborne *Pasteurella* spp. in the oro-pharyngeal passages of bighorn sheep, with a potential of developing into pneumonia. We propose that such a dose as identified in this study may serve as a clinically active dose. Further, results from the Gilmour et al (1984) paper clearly suggest that doses on the order identified in this study can result in immediate death, if exposure occurs concurrently with other risk factors such as viral infections.

Results from this observational study, especially when taken together with previous studies discussed above, lead us to suggest that further directed studies are warranted.

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Molecular Identification Of Pasteurella-Related Outbreaks In Bighorn Sheep Using Pulse Field Gel Electrophoresis

TRICIA HOSCH-HEBDON [1,2], [1] Idaho Department of Health and Welfare, Idaho State Health Laboratory, 2220 Old Penitentiary Road, Boise, ID 83712 U.S.A.
[2] Idaho Fish and Game, Wildlife Health Laboratory, 16569 S. 10th, Caldwell, ID 83705 U.S.A.

Abstract: Bacterial pneumonia-related outbreaks remain a major mortality factor in free ranging bighorn sheep. Current phenotypic (e.g. serotyping, biotyping) analysis of bighorn sheep bacterial pathogens makes it difficult determine lateral transmission of disease between vectors, individual sheep and even whole populations. Pulse Field Gel Electrophoresis (PFGE), a molecular based subtyping method, is a sensitive and whole genome technique that can detect clonal relationships and determine lateral disease transmission of pathogenic microorganisms. The concept of a clonal relationship between bacterial isolates from a common-source outbreak is important in the epidemiology of infectious diseases and many bacterial outbreaks result from exposure to a common source pathogen. In general, these infectious microorganisms are clonal; that is, they are the progeny of a single cell and thus are genetically identical or nearly so. PFGE is commonly utilized by Federal and State Health agencies to detect outbreaks and conduct epidemiological investigations. It is currently the accepted method for the determination of foodborne disease transmission and outbreak detection throughout the United States and Canada. PFGE was used to determine the clonal relatedness of *Pasteurella multocida* and *Mannheimia haemolytica* isolates that were obtained from healthy free-ranging bighorn sheep, deceased animals from the 1995-1996 Hells Canyon die-off and sick animals that were taken to Idaho Fish and Game's Wildlife Health Laboratory. Identical PFGE restriction products were obtained for *Pasteurella multocida* isolates from 95-96 Hells Canyon die-off but restriction products from free-ranging bighorn sheep and captive sheep from the Wildlife Health Lab differed from the main die-off by a minimum of two mutational events. This suggests that lateral transmission of bacterial isolates occurred during the die-off, but that recolonization or mutation by Pasteurella multocida isolates occurred in the free-ranging and captive colonies following the main die-off. In addition, Mannheimia haemolytica isolates obtained from a domestic goat and free-ranging bighorn sheep were also found to be identical and support the theory that domestic livestock can infect free ranging wild sheep populations. The direct application of PFGE subtyping in wildlife disease investigation could potentially lead to early detection, tracking and understanding of the spread of pneumonic outbreaks in free-ranging bighorn sheep populations, as well as identifying the source of infection in such outbreaks and the incidence of sporadic disease within these populations.

Genetic Resistance To Disease In Wild Sheep

KAREN M. RUDOLPH, Idaho Department of Fish and Game, Wildlife Health Lab, 16569 S. 10th Ave., Caldwell, ID 83607 U.S.A.
TRICIA HOSCH-HEBDON, Idaho Department of Health and Welfare, Idaho State Health Laboratory, 2220 Old Penitentiary Road, Boise, ID 83712 U.S.A.
DALE E. TOWEILL, Idaho Department of Fish and Game, 600 S. Walnut, PO Box 25, Boise, ID 83712 U.S.A.

Abstract: Genetic resistance is an inherent ability of a previously unexposed animal to resist infection when exposed to pathogens. Because such resistance is genetically coded, it is transmitted from parent to offspring. Studies of genetic resistance to disease have been done on species including mice, man, elk and bison. In all studies an important molecular component of genetic resistance has been identified as an `Nramp' (Natural resistance-associated macrophage protein) gene. We examined DNA extracted from tissue and blood samples from 295 Rocky Mountain, 46 California, and 82 desert bighorn sheep and 12 Stone's sheep to characterize the presence, prevalence, and function of the Nramp gene. In bighorn sheep, the Nramp gene occurs in three forms, or alleles (Nramp allele 1, 2, and 3). Preliminary data suggest that one form, Nramp allele 1, protects from intracellular pathogens such as *Brucella abortus* and possibly *Mannheimia* spp. and *Pasteurella* spp. We determined the Nramp genotype of 425 bighorn sheep samples, and calculated the frequency of each Nramp genotype based on bighorn sheep subspecies. Nramp allele 1 was identified in 26% of 82 desert bighorn sheep (*Ovis canadensis nelsoni*), in 1% of 295 Rocky Mountain bighorn sheep (*O. c. canadensis*), and was not found in 46 sampled California bighorn sheep (*O. c. californiana*) or the 12 sampled Stone's sheep (*O. dalli stonei*).

GENETICS

Alasdair Veitch - Moderator

Mountain Goat Horns Of The Kootenay Region Of British Columbia

DUNCAN GILCHRIST, POB 696, Corvallis, MT. 59828, 406 961-4314.

Abstract: The Wildlife Branch of the province of British Columbia was kind enough to supply me with a computerized list of horn measurements for all mountain goats taken in the Kootenay Region for the years 1976 through 1985. By entering part of the data (1984 and 1985) in my computer I was able to verify information that would be of interest to the hunter. At a later time, I added 1989 and 1990, so as to see if there were any great changes in the age or horn size of harvested mountain goats due to management or weather.
Questions that were examined include: Percent Of Mountain Goat Horns Over Listed Age, Percentage of Horns Over Given Length, Average Horn Length By Age And Sex, Average Age and Length of Longest Horn By Year and Sex, and The Question of Broken Horns.
My son Stuart, who was a high school student at the time, designed the computer program so that these questions could be examined.

As an outdoor communicator, a past Alaska outfitter and a serious mountain goat hunter, I had several theories on mountain goat horns and their growth. These ideas were based on some 14 years of extensive mountain goat hunting on both the Kenai Peninsula and along the Lynn Canal between Juneau and Haines, Alaska. In addition, commonly I would spend 100 hours a year, or more, observing mountain goats from my Super Cub (PA-18). This was at a time when the Alaska Department of Fish and Game virtually ignored the species. I could not find any biologist in any state or province who could answer any of my questions. My questions included:

1- By aging many horns it appeared that mountain goats live longer than Dall sheep.

2- For any given age, there was little difference in horn length for billies or nannies. I also thought that horn lengths over 10 inches were more common with nannies.

3- After examining many mountain goat horns I concluded that most billies mature with 9 3/8 inches of horn length and lengths over that are uncommon.

4- There appeared to be little horn growth after age four. I felt that no matter how old that a goat lives he or she would not likely grow more than a half inch of additional horn length.

5- I pondered the percentage of mountain goat horns that are broken significantly**.**

Ray Demarchi from the British Columbia Wildlife Branch in Cranbrook said they did not have the answers but that they could supply me with raw data if I wanted to analyze it. I worked with Bill Warkentin, a technician from the branch, who supplied the data.

Table 1. Sample Size - Kootenay Region - British Columbia

	1984- 85	*1989- 90*
Males	255	500
Females	249	295
	504	795

The Wildlife Branch of the province of British Columbia was kind enough to supply me with a computerized list of horn measurements of all mountain goats taken in the Kootenay Region during the years 1976 through 1985. By entering part of the data (1984 and 1985) in my computer I was able to verify information that would be of interest to the hunter. At a later time, I added 1989 and 1990 so as to see if there were any changes due to management or weather.

To answer question 1 from Table 2 it can be readily seen that mountain goats do not appear to live longer than Dall sheep, In the period 1989- 90, there were definitely more older age class (71/2 years or older) mountain goats of both sexes than there was in 1984- 85. I suspect that this increase in older mountain goats may have been the result of conservative management (harvest) practices. Bill Warkentin (personal communication) said that management goals at the time were to harvest no more than 5% of the known population.

Table 2. Percent Of Mountain Goats Over Listed Age

	% Males		%Females	
Age*	1984- 85	1989- 90	1984- 85	1989- 90
1.5	100.00	100.00	100.00	100.00
2.5	97.25	95.60	94.38	93.90
3.5	88.63	87.00	88.76	83.05
4.5	74.12	73.80	68.67	66.10
5.5	55.29	61.20	49.00	49.49
6.5	38.82	47.80	30.92	33.90
7.5	23.14	37.20	17.67	22.37
8.5	15.69	25.60	9.64	16.27
9.5	9.02	15.04	4.82	10.85
10.5	5.49	8.40	3.21	5.76
11.5	3.53	4.00	1.61	4.07
12.5	0.78	3.06	1.61	3.39
13.5	0.39	1.02	0.40	1.69
14.5	0.39	0.20	0.40	1.02
15.5	0.00	0.20	0.00	0.34

* Age was determined from horn annuli

To answer questions 2 and 3 one can find from Table 3 that my ideas might have been valid along the coasts of Alaska but not in the Kootenay Region of British Columbia. By examining Table 3 one can quickly see that the horns from nannies are definitely shorter than those from billies. The author has frequently stated that the magic length for billy horns is 9 3/8 inches with lengths over that being fairly rare. This conclusion is based on goats observed living as a guide and serious mountain goat hunter for 14 years along the coast of Alaska. At least in Southeast British Columbia it would appear that approximately a third have lengths greater

Table 3. Percentage of Horns Over Given Length

	% Males		% Females	
Length (ins.)	1984- 85	1989- 90	1984- 85	1989- 90
5.00	100.00	99.60	99.19	97.63
6.00	98.65	97.60	96.79	95.93
7.00	96.77	94.80	93.98	90.85
8.00	88.14	83.60	72.79	66.44
8.50	74.66	69.00	49.80	44.07
9.00	53.10	47.20	26.91	21.02
9.25	41.78	34.80	16.87	11.86
9.50	25.07	20.80	9.64	5.08
9.75	15.90	12.00	4.82	2.71
10.00	7.82	6.60	2.41	1.36
10.25	3.50	3.00	1.61	0.34
10.50	1.62	1.00	0.80	0.34
10.75	0.81	0.00	0.00	0.34
11.00	0.27	0.00	0.00	0.00
12.00	0.27	0.00	0.00	0.00

than 9 3/8 inches. Note that about 7% have horn lengths exceeding 10.0 inches.

The longest horn noted was 12.0472 inches, with a 5.7 inch base, from a 6 ½ year old billy, which was harvested in October 1984 from Unit 35B. I have heard that after being officially scored this trophy still had a length of 11 7/8 inches. The records also noted a 13/0 inch nanny from the East Kootenays that was only 4.5 years old. To answer question 4 a person needs to examine Table 4. It should be noted that billy goats on the average only grow 0.6 inches of horn after age 4 ½. After age 8 ½ there was no indicated growth. Horn growth after age 4 ½ appears similar for both sexes. This corresponds with mountain goat horns that I have personally examined.

To answer question 5 breaking a horn has always been the bane of the alpine hunter. I have always been amazed at how few mountain goats break their horns after being shot and plunging from their rocky homes. In all my years of hunting the species in Alaska, I only saw one break off a significant length of horn but others have had chunks torn away by hitting rocks, with the length remaining close to intact. I scored on a Montana goat and was surprised when finding one horn was missing nearly an inch from a fresh break. It had only rolled a short distance down a relatively gentle slope.

With the mountain goat horn data available to me from the Kootenays, I decided to try to answer question 5 on the frequency of horn breakage. By inspecting the measurements of 1,299 horns, I found that 10.4% had 1/2 inch or more of horn length difference.

MANAGEMENT IMPLICATIONS

From table 5, if we discount the years

Table 4 Average Horn Length By Age and Sex

Age In Years	Males Average Length Inches 1984- 85	Males Average Length Inches 1989- 90	Females Average Length Inches 1984- 85	Females Average Length Inches 1989- 90
1.5	6.46	6.53	6.27	5. 97
2.5	7.80	8.05	7.91	7.52
3.5	8.79	8.46	8.10	8.29
4.5	8.94	8.76	8.58	8.33
5.5	9.07	8.98	8.74	8.41
6.5	9.32	9.04	8.75	8.63
7.5	9.40	9.18	8.93	8.68
8.5	9.55	9.15	8.86	8.84
9.5	9.61	9.34	9.48	8.84
10.5	9.66	8.97	9.26	8.87
11.5	9.54	8.91	7.28 *2	9.53
12.5	8.61*1	9.33	8.75	9.25
13.5	No Data	9.24	No Data	10.04
14.5	9.33	No Data	8.70	8.96
15.5	No Data	9.65	No Data	7.76*2

*1 This age class only represented by four individuals; two of which appeared to have broken horns.

*2 As was the case with males the sample size of older females was very small so an individual with a broken horn can greatly influence the data.

Table 5 Average Age and Length Of Longest Horn By Year and Sex

Year	Males Ave. Age	Males Ave. Length	Females Ave. Age	Females Average Length
1976*	6.6	9.2	3.5	8.3
1977*	6.6	8.9	6.3	8.7
1978	5.5	8.6	4.5	8.5
1979	5.5	8.5	4.3	8.1
1980	5.1	8.8	4.7	8.4
1981	5.1	8.3	4.2	8.3
1982	5.8	8.6	5.3	8.3
1983	5.6	8.8	5.1	8.3
1984	5.8	8.8	5.0	8.3
1985	5.7	8.9	5.2	8.4
1989	5.5	8.7	4.9	8.7
1990	5.8	8.8	4.9	8.3

* Sample size for 1976 and 1977 was very small and probably meaningless.

1976 and 1977, because of the small sample size, we can find that the mountain goat herds of the Kootenays were holding up well to the level of harvest at the time. The average size of horn and average age of harvested animal was nearly static.

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There was no outside funding for this project. The project was carried on to satisfy my own curiosity and to be able to pass on what was learned to others that are interested in mountain goats

LITERATURE CITED

None.

Genetic Paternity And Horn Size In Bighorn Sheep: Evolutionary And Management Implications

DAVE COLTMAN, University of Sheffield, Sheffield, S10 2TN, England
MARCO FESTA-BIANCHET, University of Sherbrooke, Sherbrooke, Québec, J1K 2R1, Canada
JON JORGENSON, Alberta Department of Environmental Protection, Canmore, Alberta, T1W 1P1, Canada
CURT STROBECK, University of Alberta, Edmonton, Alberta, T6R 2E1, Canada.

Abstract: We used molecular genetic paternity analysis to determine the parentage of 83 bighorn sheep (*Ovis canadensis*) lambs born between 1995 and 2000 at Ram Mountain, Alberta, Canada. We could assign the paternity of 64 lambs at a high level of statistical confidence (95%). Within each season, the most successful ram sired an average of 35.5% of the lambs with assigned paternity, and a single ram sired 26.1% of all lambs over the 6 mating seasons. Although a few large horned, mature (age 8+) rams had very high reproductive success, younger rams sired approximately 50% of the lambs. Mixed effects models indicated that mating success increases as a non-linear function of age, with horn length increasingly positively correlated with mating success in older rams. These results suggest that young or small rams achieve mating success through alternative mating tactics that are less dependant on body and weapon size, such as coursing and blocking. Sexual selection is therefore likely to have age-dependent effects on traits such as agility, body and horn size. Preliminary analyses of the pedigree indicate that horn length is highly heritable in this population ($h^2 = 0.70$). Because large horned rams do not achieve most of their mating success until after they have reached legal status, less restrictive trophy management regimes are likely to deplete genetic variation for large horns by removing genetically superior rams from the gene pool before they have a chance to pass on their genes for large horns. Smaller horns and increased precocial maturity are the likely evolutionary responses in populations with a history of intense trophy harvesting.

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Quantification Of A Known Population Bottleneck In Rocky Mountain Bighorn Sheep In Custer State Park, South Dakota

ELISE J. GOLDSTEIN, Department of Wildlife Sciences, University of Washington, Seattle, WA 98195 U.S.A.
GORDON LUIKART, Laboratoire de Biologie des Populations d'Altitude, CNRS UMR 5553, Universite Joseph Fourier, F-38041 Grenoble Cedex 09, France
GARY C. BRUNDIGE, Custer State Park, HC 83 Box 70, Custer, SD 57730 U.S.A.

Abstract: A population bottleneck occurred when 22 Rocky Mountain bighorn sheep (*Ovis canadensis canadensis*) were transplanted from Whiskey Basin, WY (WB) to Custer State Park, SD (CSP) to start a new herd. To quantify the bottleneck that occurred, data from five microsatellite loci from 32 CSP bighorn were compared with previously published data from WB bighorn. There was a reduction in heterozygosity from WB bighorn to CSP bighorn (P=0.039). CSP had fewer alleles per loci than WB bighorn (P=0.019). CSP bighorn had a heterozygote excess based on the number of alleles in the CSP population (P=0.016) and therefore were not at mutation-drift equilibrium. A mode shift was also observed when comparing allele frequency classes of the non-bottlenecked WB population with the bottlenecked CSP population, but heterozygosity still remains higher than in most Rocky Mountain herds.

POPULATION MONITORING

Dale Toweill - Moderator

A Review And Comparison Of Management Concerns, Objectives And Strategies For Two Native Montana Bighorn Sheep Populations

KURT ALT, Montana Fish, Wildlife and Parks, 1400 South 19th, Bozeman, MT, 59718 U.S.A.
QUENTIN KUJALA, Montana Fish, Wildlife and Parks, Box 291, Fairfield, MT, 59436 U.S.A.

Native bighorn sheep populations occur across a diversity of environmental conditions in Montana. Not least among these are structural habitat, prevailing weather systems, predator complexes and human social dimensions. Population dynamics also vary and include periods of decline associated, exclusively or otherwise, with chronic poor lamb survival and/or acute all age die-offs. Many biotic and abiotic components, potentially affecting sheep populations or offering some indication of general health, are only partially identified, measured and understood via herd health assessments. These factors and others, as they are tied to specific areas and corresponding sheep populations, interact to generate similar and unique management concerns, uncertainties, objectives and strategies. A brief review focusing on native bighorn sheep in the Spanish Peaks of southwest Montana and the Sun River drainage of west central Montana offers specific opportunity to compare and contrast management interpretations, needs and responses to our oftentimes incomplete understanding of any number of environmental or herd health conditions.

Bighorn Sheep Survival In Badlands National Park 1997-2000: Can Routine Sampling Help Predict Survival?

MICHELLE A. BOURASSA, Department of Statistics, PO Box 3332, University of Wyoming, Laramie, WY 82071-3332 U.S.A.
SNEHALATA V. HUZURBAZAR, Department of Statistics, PO Box 3332, University of Wyoming, Laramie, WY 82071-3332 U.S.A.

Between fall 1996 and spring 1999, a total of 32 sheep were captured, radio-collared, and monitored at Badlands National Park (BADL). Routine sampling at the time of all captures included the collection of blood and fecal samples, and tonsillar and nasal swabs. Complete blood counts, serum chemistry panels, trace element screens, and serologic testing for diseases were completed along with isolation of bacteria and parasites of importance in bighorn sheep. Fifteen individuals subsequently died within two years of capture, thirteen within the first year. Although nothing noteworthy was identified in the sampling test results at the time, could any of these results considered together help predict the observed survival? In order to answer this question, the test and screen results will be used as covariates along with other individual factors in an Anderson and Gill modified Cox proportional hazards regression model and applied to the survival data. Although the sample size is limited and the number of covariates potentially large, it is hoped that the analysis will be able to identify factors available through routine sampling that influence survival of bighorn sheep at BADL. The identification of these factors may allow wildlife biologists and resource managers to make more proactive management decisions regarding bighorn sheep populations in the face of potential epizootic outbreaks of disease.

Population Density And Mortality Of Adult Bighorn Sheep In Hells Canyon

E. FRANCES CASSIRER, Idaho Department of Fish and Game, 1540 Warner Ave., Lewiston, ID 83501
WENDY M. LAMMERS, Idaho Department of Fish and Game, 1540 Warner Ave., Lewiston, ID 83501
A. R. E. SINCLAIR, Centre for Biodiversity, Dept. of Zoology, University of British Columbia, Vancouver, BC V6T 1Z4.

Abstract: Disease-related mortality is a limiting factor for bighorn sheep populations throughout much of the U.S. and Canada. Factors contributing to this mortality are poorly understood, but critical to implementing appropriate management. We tested the hypothesis that population density was a causal factor in precipitating disease outbreaks in bighorn sheep. We monitored movements and survival of radio-marked ewes and rams at least biweekly in 4-9 herds in Hells Canyon over the period 1997 - 2001. During this period, annual adult survival rates varied from 40 to 100%. Disease (primarily pneumonia) was the cause of 36% of ewe mortality and 42% of ram mortality. Most disease-related adult mortality occurred November – January and did not occur in all herds. Population growth was depressed in herds that experienced disease-related adult mortality, and disease-related mortality occurred in both large (>100 animals) and small herds (< 40 animals). In this study, we selected 4 herds (2 with disease-related mortality and 2 without) for investigation of population density using home range area and overlap and interaction indices. Population density was not greater among herds, years, or seasons where disease-related mortality occurred. Population density was not related to differences in population size. Home range overlap was greater in herds with disease-related mortality, but was not greater during or prior to disease outbreaks. The most ewe and ram overlap and interaction occurred during breeding when the most disease-related mortalities occurred. Our preliminary analysis does not support the hypothesis that high population density triggered these disease outbreaks.

Epizootics historically decimated bighorn sheep populations throughout the western United States and disease continues to complicate management of existing populations. In Hells Canyon, restoration of an extirpated bighorn sheep population has been underway for 30 years. Population growth has been erratic, but overall, as observed in many other restored bighorn populations (Singer et al. 2000), growth has been lower than what would be expected for an animal released into vacant or sparsely occupied habitat. Disease, particularly pneumonia, has been a recurrent factor in the dynamics of the population.

There are numerous, not necessarily mutually exclusive theories as to causes of disease outbreaks in bighorn sheep. These include the introduction of pathogens from domestic sheep (Foreyt 1988), poor nutrition (Jones and Worley 1994), low genetic variability (Skiba and Schmidt 1982), weather (Douglas and Leslie 1986), stress (Belden et al. 1994), and high population density (Aune et al. 1998). In this study we explore the role that population density may play in initiating disease outbreaks in bighorn sheep populations. Our predictions are that disease-related mortality will occur when sheep are concentrated in smaller areas, and that disease outbreaks will occur when bighorns associate and interact more frequently.

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STUDY AREA

The Hells Canyon study area encompassed 2,273,194 ha along the Snake, Salmon, and Grande Ronde Rivers in Idaho, Oregon, and Washington. Elevations range from 243 m in canyon bottoms to above 2743 m in the Seven Devils, ID and Wallowa Mountains, OR. Climate is generally continental and dry with light precipitation (25 cm to 127 cm), low relative humidity, and wide ranges in temperature (-2 degrees C to above 40 degrees C) (Johnson and Simon 1987). Columbia River basalts are the dominant geologic formation. Plant associations include primarily perennial bunchgrass, with deciduous riparian stringers and shrub-fields. Douglas-fir (*Pseudotsuga menziesii*) and ponderosa pine (*Pinus ponderosa*) stands occur on northerly aspects.

Over fifty percent of the area is publicly owned and managed by various federal and state agencies. Habitat improvements have included vacation of most domestic sheep allotments, development of water sources, pasture cultivation, noxious weed control, and prescribed fire.

At least 6 epizootics have occurred since bighorns were first reintroduced into Hells Canyon in 1971. The most recent dieoff occurred in 1995-1996, when about one third of the population died with most deaths concentrated in herds in Oregon and Washington (Cassirer et al. 1996). There are currently about 800 bighorns in 15 herds (Figure 1).

METHODS

Between 1997 and 2001, 167 sheep were radiocollared and monitored in 9 study herds (approx. 600 sheep) through out the project area (Figure 1). Resident bighorns were captured by helicopter net-gun in March 1997 and/or in January 2000 or in a corral trap in winter 1999 - 2000. Transplanted bighorns in the Asotin, Big Canyon, and Muir Creek herds were captured by drop net in Spences Bridge, British Columbia (BC) or on the Cadomin coal mine near Hinton, Alberta (AB) and relocated to Hells Canyon in December 1997 (BC) or February 1999 (AB). All sheep handled were radiocollared except for 4 lambs transplanted from BC. Only data collected one year or more post-release from transplanted sheep were included in analyses.

Pharyngeal bacterial swabs were collected from all sheep, cultured, and all Pasteurella and Mannheimia isolates biotyped at the University of Idaho Caine Veterinary Teaching Center using standard techniques (Ward et al. 1999). Fecal samples were screened for intestinal parasites via sugar flotation (Foreyt 1994) and abundance of lungworm larvae was estimated using a modified Baermann

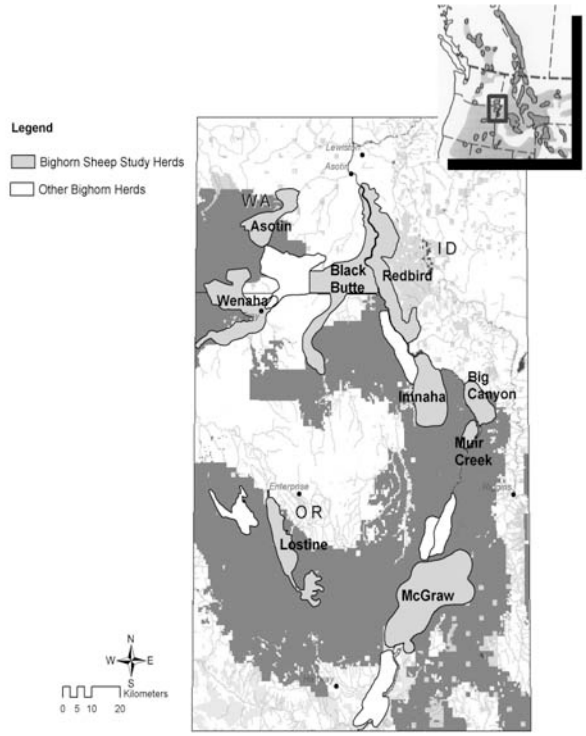

Figure 1. Hells Canyon Study Area and bighorn sheep herds.

technique (Beane and Hobbs 1983) at the Washington Animal Disease and Diagnostic Laboratory (WADDL). Ears and ear swabs were visually inspected for *Psoroptes* spp. Serologic tests were conducted at the State of Idaho Department of Agriculture laboratory for antibodies to bluetongue virus, epizootic hemorrhagic disease virus, bovine respiratory syncytial virus, parainfluenza-3 virus, infectious bovine rhinotracheitis virus, bovine viral diarrhea virus, *Brucella ovis*, serovars of *Leptospira interrogans*, and *Anaplasma* spp.

All resident sheep were judged healthy when handled in 1997 and all transplanted sheep were certified healthy by a provincial veterinarian. One ewe captured in the Wenaha herd in 2000 was diagnosed with chronic pneumonia and 2 ewes captured in the Black Butte herd in 2000 were diagnosed with mastitis. The Wenaha ewe and one of the Black Butte ewes subsequently died during this study. Low to moderate levels of *Psoroptes* infection were found in all resident herds except the Lostine herd and in none of the transplanted sheep.

We located all radio-collared sheep from the ground or from a fixed-wing aircraft at least bi-weekly, and often several times per week during the spring and summer. Over 95% of locations were visual. Sheep were located systematically to the greatest extent possible in order to obtain equal numbers of locations of individuals.
Radiocollars were equipped with a 4-hour delay mortality switch. When the mortality sensor was activated, we conducted a site investigation and collected the sheep where possible for evaluation at the Washington Animal Disease and Diagnostic Laboratory (WADDL) at the Washington State University Veterinary School in Pullman, WA. Where this was not possible, we conducted a field necropsy and collected tissue for gross and histological investigation at WADDL. Survival rates of radiocollared sheep were calculated using staggered entry Kaplan-Meier analysis (Kaplan and Meier 1958, Pollock et al. 1989).

We selected 4 herds for population density analysis. Two herds (Big Canyon and Wenaha) experienced disease-related mortality and the other two (Asotin and Redbird) did not (Figure 2). Population sizes were estimated from March helicopter counts combined with information from ground counts. Evaluation of visibility of radio-collared sheep indicated that 88% of ewes and 67% of rams were observed in helicopter counts (Hells Canyon Initiative, unpubl. data).

We used Animal Movements v. 1.1 extension for ArcView 3.1 (Hooge et al.

1999) to calculate pooled 100% and 85% minimum convex polygon (MCP, Mohr 1947) seasonal herd ranges for ewes and for rams. We used locations of both marked and unmarked sheep in home range analysis. Outliers eliminated in the 85% MCP analysis were calculated from the harmonic mean range center. We estimated population density by dividing the seasonal MCP area by the total number of sheep counted in the herd during the year analyzed.

We used Ranges V software (Kenward and Hodder 1996) to calculate home range overlap and a dynamic interaction index. The interaction or "cohesion" index measured the tendency for pairs of animals to be near each other at a given point in time. Even though home ranges overlap, animals may seldom encounter each other if they rarely visit the same place at the same time. The interaction index compared the geometric mean of actual distances between pairs of animals located on the same day to the geometric mean of $n \times n$ possible locations if animal 2 could be at any of its n used positions when animal 1 was at each of its used positions (Kenward et al. 1993). The relationship between the observed and expected distances (Jacobs 1974) for each pair of animals was analyzed with a sign test. The index equaled 0 if observed and expected distances were equal (animals distributed at random), increased towards 1 if the observed distance was small relative to the expected distance (animals tended to be together), and decreased towards –1 if the observed difference was larger relative to the expected, indicating the animals avoided one another.

SAS v. 8.02 (2001) was used to calculate general linear model statistics on 85% MCP home range data and interaction indices. We used the herd as the sample unit in calculating means and in statistical analyses.

RESULTS

The Big Canyon herd was started in December 1997 with the release of 16 sheep from Spences Bridge, British Columbia. The herd was supplemented in February 1999 with 4 ewes and 3 rams from Cadomin, Alberta. The population grew 15%, from 26 to 30 animals between 1999 and 2000 (total population of 37 including 7 transplanted animals) followed by a 19% decline from 37 to 30 sheep in 2001. The average population size 1998 - 2001 was 31 animals. The Asotin herd was started in 1991 with the release of 6 sheep from Hall Mountain, WA, supplemented in 1994 with another 9 sheep from Hall Mountain, and again in December 1997 with 10 sheep from Spences Bridge, British Columbia. The population increased from 24 to 32 at annual rate of 16% between 1999 and 2001 (average population 29). All but two of the sheep transplanted from Canada to these herds were radiocollared and used in this study following their first year in Hells Canyon.

The Redbird herd was started in 1984 with the release of 17 sheep transplanted from Whiskey Basin, Wyoming. The population increased at annual rate of 11% during the study from 85 to 120 sheep (average 91 animals). The Wenaha herd was started in 1983 with the release of 30 sheep from Hall Mountain, Washington and Lostine, Oregon, and supplemented in 1984 with 28 bighorns from the Salmon River, Idaho, and in 1986 with 14 sheep from Hall Mountain. The population was stable during the study (average 64 animals).

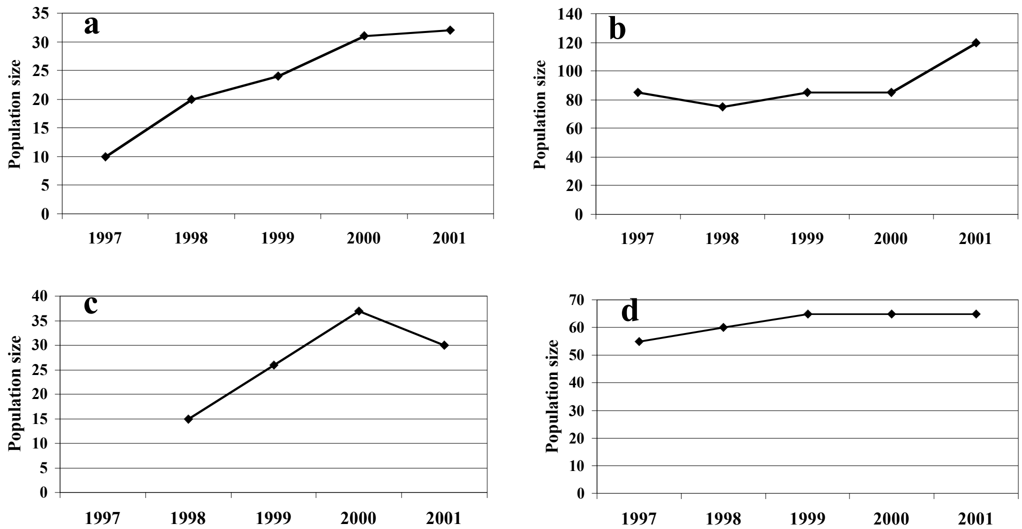

Figure 2. Bighorn sheep population dynamics 1997 – 2001 in 4 herds used in density analyses. Two herds experienced disease-related adult mortality and 2 did not. (a) Asotin, no disease; (b) Redbird, no disease; (c) Big Canyon, disease; (d) Wenaha, disease.

Survival

Thirty-six radio-collared ewes and 12 radio-collared rams died 1997 – 2001. Annual ewe survival averaged 91% and annual ram survival averaged 86%. Causes of ewe mortality were disease (36%), predation (25%), fall or injury (11%), and unknown (28%) (Figure 3). Causes of ram mortality were disease (41.5%), predation (16.5%), fall (16.5%), human-caused (16.5%), and unknown (8%) (Figure 4). Diseases included bronchopneumonia (n = 15) and hypothermia due to severe scabies (*Psoroptes ovis*) infection (n = 3). Predation was by cougars (*Felis concolor*). Injuries included trauma due to falling (5) and infection from foot laceration (1). Human-caused mortalities included tribal harvest (1) and motor vehicle collision (1). The unknown category included animals that were too scavenged to determine a cause of death, and intact animals where a cause of death could not be determined at the diagnostic laboratory.

Over ¾ (77%) of mortalities occurred during the 8-month period between October and May. From October – January, 72% of mortalities were due to disease and 6% to predation (Figure 5). During February – May, 42% of mortalities were due to cougar predation and 16% were due to disease. Based on these patterns we used 3 seasons: summer (Jun – Sept); winter (Oct – Jan); and spring (Feb – May) for survival and population density analyses.

Of the five study years, most disease-related mortality took place in winter 2000 – 2001 and this mortality occurred in 5 of the 9 herds (Table 1). These herds were distributed throughout the study area (Figure 1). In 3 herds, only ewes were diagnosed with disease-related mortality but the sample size of radiocollared rams was small. In one of these herds (Big Canyon), although no radiocollared rams died, an uncollared ram was diagnosed with pneumonia prior to the onset of mortality in the radiocollared ewes. In 1

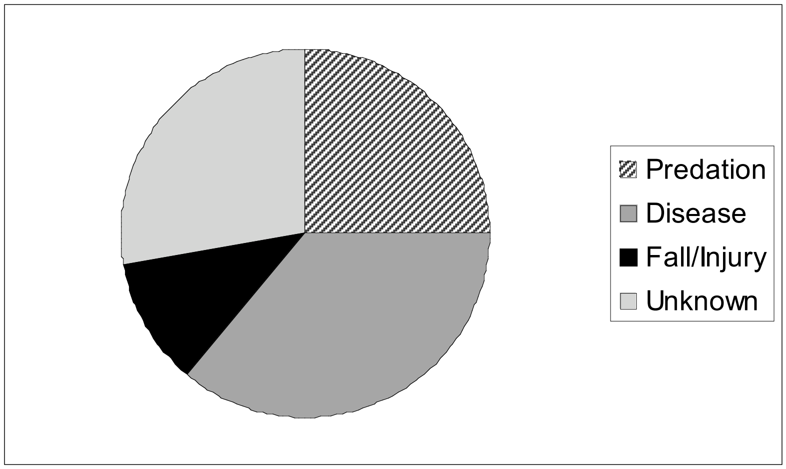

Figure 3. Causes of ewe mortality, 1997 – 2001 (n = 36).

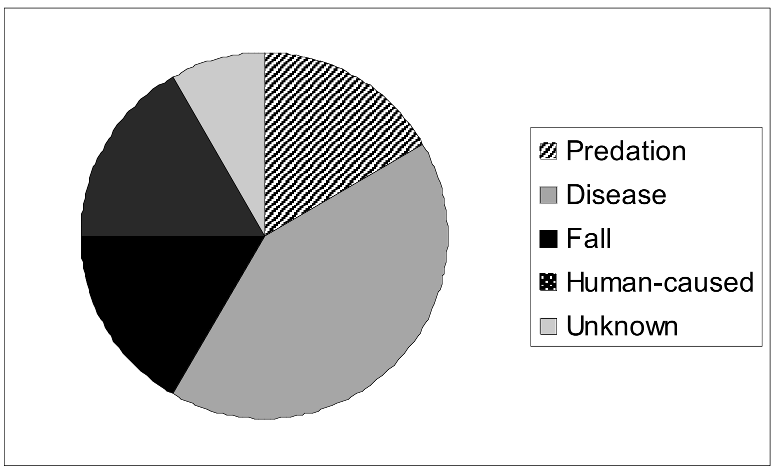

Figure 4. Causes of ram mortality, 1997 – 2001 (n = 12).

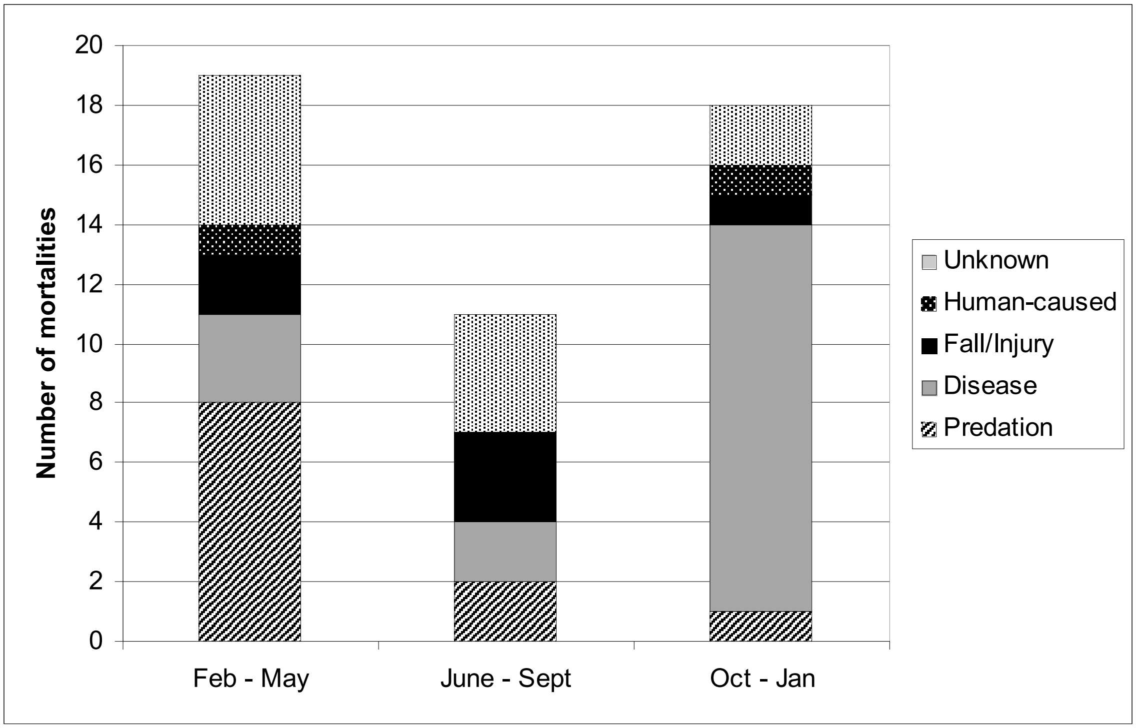

Figure 5. Seasonal occurrence of adult bighorn mortality, 1997 – 2001.

herd (Wenaha) disease-related mortality was only observed in rams although one ewe was diagnosed with pneumonia at capture.

Population density

The seasonal 100% minimum convex polygon area (%MCP) used by radiocollared sheep was highly variable among herds. The smallest average ewe range (15 sq km) occurred in spring in the Asotin herd (average 7 radio-collared ewes, 84 locations per spring) whereas the Redbird ewes (average 12 radio-collared ewes, 157 locations per winter) used a 285 sq km winter range. Average density (total population size/ewe 100% MCP) was highest in the Asotin and Big Canyon herds during all seasons (1.25 – 3.69 sheep/sq km), and lowest in the Redbird and Wenaha herd during all seasons (0.39 – 0.65 sheep/sq km/sheep, Figure 6). Population densities were not higher in herds, years, or in seasons with disease-related mortality (p = 0.68).

Ram 100% MCP range areas averaged 1.5x larger than ewe range areas in the 2 herds with no disease-related mortality (Asotin and Redbird) and 2.1x larger in the 2 herds with disease-related mortality (Big Canyon and Wenaha respectively) however density was not significantly different in herds, years, or in seasons with disease-related mortality (p = 0.39).

Within herds, over 90% of radio-collared ewes had overlapping 100% MCP home ranges in all seasons (spring 91%, summer 95%, winter 93%) and there were no differences in overlap among years or by disease status (p = 0.77). The greatest frequency of radio-collared rams with home range overlap was in spring (89%) and summer (83%) and the lowest was in winter (72%) but this seasonal difference was not statistically significant (p = 0.206). The percent of ewes and rams

Table 1. Female and male seasonal survival rates in 5 herds experiencing disease-related mortality 1997 – 2001[1].

Herd	Sex[2]	1999			2000			2001		
		SP[3]	SU	WI	SP	SU	WI	SP	SU	WI
Big Canyon	Female	1	0.94	1	1	0.8	0.75	1	1	1
Muir Creek	Female	0.95	1	0.94	1	1	0.71	1	1	1
Muir Creek	Male	1	1	1	1	1	0.5	1	1	1
Imnaha	Female	ND[4]	ND	ND	0.93	0.92	0.91	1	1	1
McGraw	Female	1	1	1	0.78	0.86	1	1	1	1
Wenaha	Male	1	1	1	1	1	0.67	1	1	1

[1] No disease-related adult mortality observed in 1997 and 1998.
[2] No disease-related mortality observed in sexes not represented in table.
[3] SP = Feb – May; SU = Jun – Sep; WI = Oct – Jan.
[4] No data.

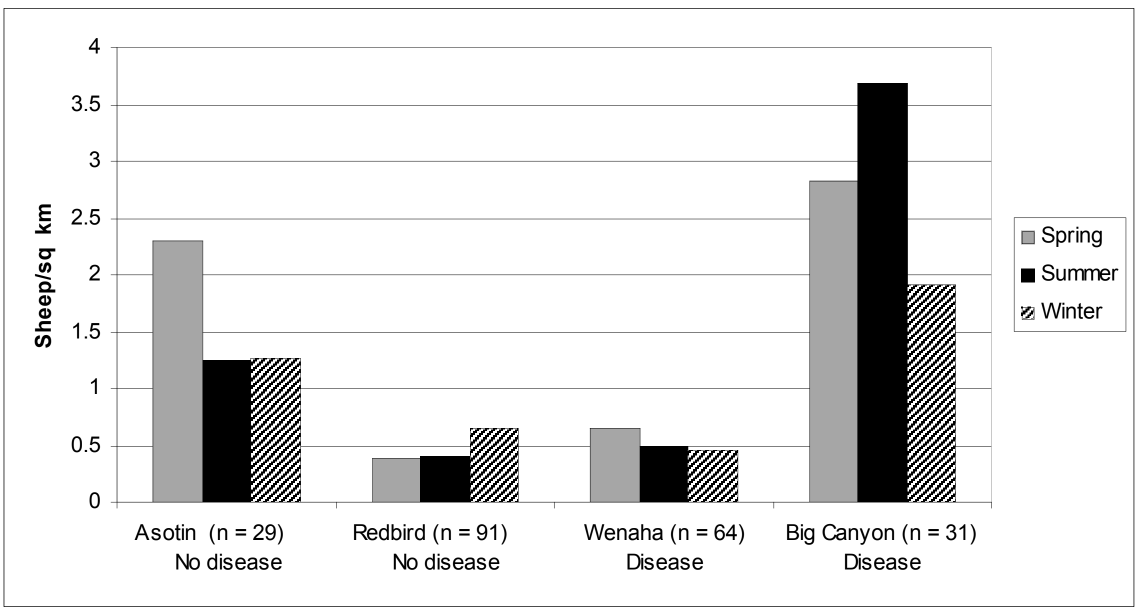

Figure 6. Average seasonal bighorn density in herds with and without disease-related mortality (100% MCP).

with overlapping home ranges was highest in spring (88%) and winter (81%) and lowest in summer (72%) ($p = 0.05$). Herds with disease-related mortality had more ram home range overlap and more ewes and rams with overlapping home ranges ($p = 0.001$) but within herds that experienced home range overlap, there were no differences among years or seasons ($p > 0.2$). Home range overlap was not greater during the winter of 2000-2001 when disease-related mortality occurred

Interactions

Animals with overlapping home ranges tended to use those overlap areas at the same time and presumably were interacting. Female-female interaction indices were higher than male-male interaction indices ($p < 0.02$) and higher than female-male interactions in all seasons except winter (Figure 7). There were no significant seasonal differences in female-female or male-male ($p > 0.5$) interaction indices. There was no difference in female-female or female-male interaction indices between herds with and without disease-related mortality (Figure 8, $p > 0.5$). Male-male interactions were higher in the herds with disease-related mortality than in the Redbird herd. Male-male interactions were not calculated in the Asotin herd because only one ram was radio-collared.

DISCUSSION

Overall, average annual adult bighorn survival rates in all Hells Canyon study herds 1997 - 2001 (ewes 0.91; rams 0.86) were similar to those of prime-age animals in stable to expanding populations in Montana, Wyoming, Colorado, and Alberta (summarized in McCarty and Miller 1998, p. 3: 95% CI ewes 0.92 – 0.95; rams 0.83 – 0.90). However, annual adult survival was significantly lower than average in years and in herds experiencing disease-related mortality (ewes average 0.67; rams 0.59). Disease (mainly pneumonia) was the most common cause of mortality, and occurred in 5 of 9 herds, primarily from September 2000 to January 2001. Seasonal patterns of mortality were similar to those observed by Enk et al. (2001). They observed little adult mortality occurred in summer, fall mortality due to disease, and spring mortality due to predation.

Herds that experienced disease-related mortality remained stable or declined, while those without disease-related mortality increased over the study period. Disease related adult mortality apparently depressed growth of even relatively small populations (30 – 40 sheep).

Minimum convex polygon analysis is sensitive to sample size, and MCP's based on small numbers of locations tend to underestimate home range area (Seaman et al. 1999, Garton et al. 2001). Sample sizes of radio-marked animals and numbers of locations differed among herds and among seasons. Also, since bighorns are sexually segregated in spring and summer, using ewe/lamb and ram numbers as a population estimate during those seasons would give more accurate population density estimates. However based on preliminary analysis of both 100% and 85% MCP, population density was not greater in herds, years, or seasons with disease-related mortality. Small herds tended to be at equal or even higher population densities than large herds, presumably due to the gregarious nature of bighorns. The relationship between population size and density has implications for disease transmission. If density remains constant as numbers of hosts change, the probability that a susceptible host (sheep) will become infected is independent of population size, and there is no "threshold" number of sheep required for initiation of epizootics (MacCallum et al. 2001, Swinton et al. 2002).

Females had the greatest amount of home range overlap, and the highest interaction indices in all seasons. However, disease-related mortality occurred primarily during the breeding and winter seasons when home range overlap between ewes and rams was highest and when ewe:ram interactions were most likely. Ewe and ram home range overlap was greater in herds with disease-related mortality, but within herds with disease-related mortality there was no difference

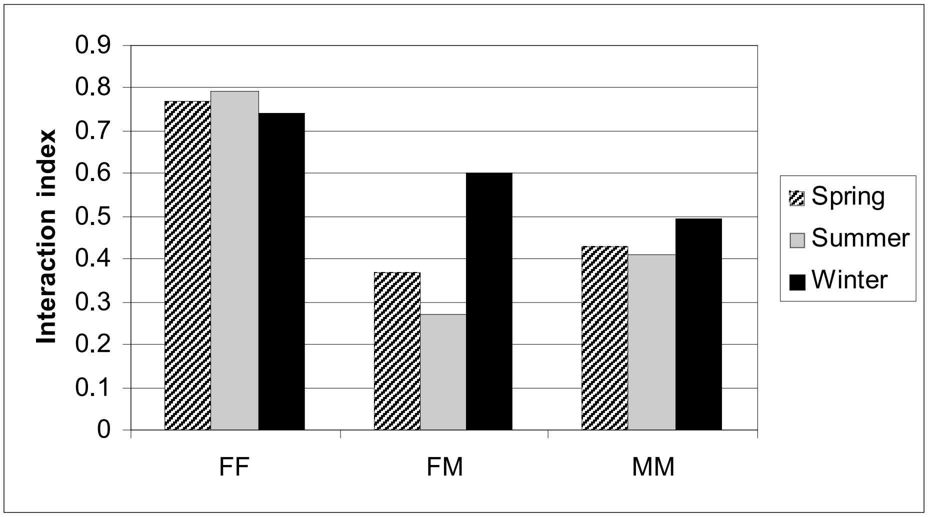

Figure 7. Seasonal interaction indices for females (F) and males (M).

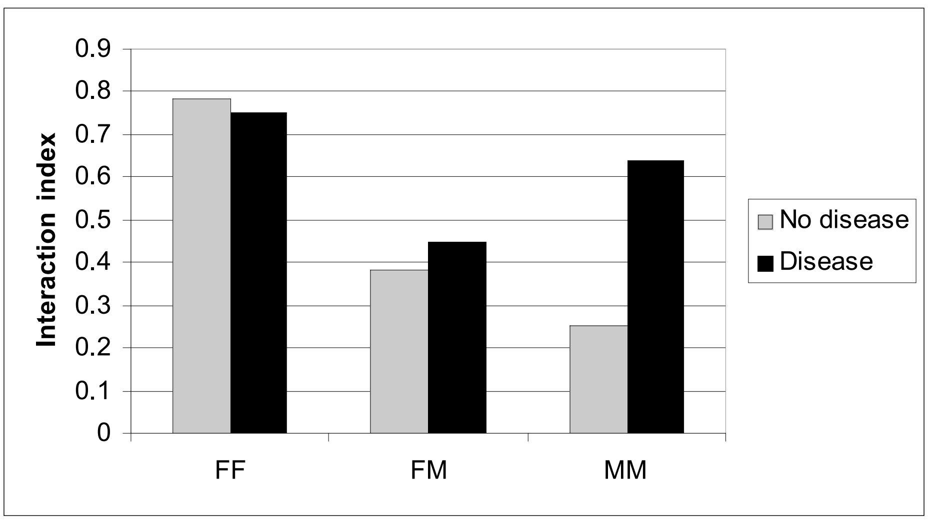

Figure 8. Female-female (FF), female-male (FM), and male-male (MM)[1] interaction indices in herds with and without disease-related mortality.

[1]MM interaction indices could only be calculated for 3 herds (2 with disease-related mortality and 1 without) due to limited number of radio-collared rams.

in home range overlap during years or seasons with disease outbreaks and those when no outbreaks occurred.

Disease-related mortality appeared to be synchronized among subpopulations and pathogens may have been transmitted among herds. No movement of ewes among herds was documented. Ram movement was documented between the Big Canyon, Imnaha, and Muir Creek herds all of which experienced disease-related mortality. However, no movements of sheep have been documented between the Wenaha or McGraw herds and any of the other study herds with disease-related mortality.

CONCLUSIONS

Disease-related adult mortality can play a role in the population dynamics of even small bighorn herds. Our preliminary analysis does not support the hypothesis that commensal pathogens carried by bighorns became virulent during periods of high population density. The hypothesis that disease-related mortality was initiated by the introduction of novel pathogens to the population, possibly by rams during the breeding season deserves further evaluation.

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Age- And Sex-Specific Local Survival In Unhunted Mountain Goats.

MARCO FESTA-BIANCHET, Département de biologie, Université de Sherbrooke, Sherbrooke, Québec, J1K 2R1, Canada
STEVE D. CÔTÉ, Département de biologie, Université Laval, Ste-Foy, Québec, G1K 7P4, Canada

Abstract: We examined the survival of marked yearling and adult mountain goats of both sexes at Caw Ridge, Alberta, from 1989 to 2001. We monitored 94 females and 78 males. Resighting rate was 100%, because no marked goat not seen one year was ever resighted in the study area. Survival to 2 years was 72% for yearling males and 84% for yearling females. Age-specific adult survival patterns varied substantially according to sex. Many males died or emigrated as 2- and 3-year-olds: only 39% of yearling males were still present as 4-year-olds. Survival of males aged 4 - 7 years was about 95%, similar to that of females of the same age, except for an unexplained drop to 75% survival for 5-year-old males. From 8 years of age onward, males experienced very high mortality. Age-specific survival rates suggest that less than 10% of yearling males would survive to 10 years of age on Caw Ridge. Over half of the yearling females would survive to 10 years. The local survival of 2-year-old females was 89.5%, but at least 2 emigrated. Survival of females aged 2 to 7 years averaged 94%, but declined to 75% for females aged 10-15 years. The oldest goats monitored were a 15-year-old male and three 16-year-old females. Our results provide evidence of survival senescence in both sexes, and suggest that in unhunted populations adult sex ratio is heavily biased towards females because of the high rate of disappearance of young males, and possibly the rapid senescence of older males. If local survival in our study population is typical of mountain goats, harvesting programs that target males should envisage a yearly harvest of 1% of the estimated population.

Validation Of A Helicopter Sightability Model For Bighorn Sheep

ELROY TAYLOR, U. S. Geological Survey, Forest and Rangeland Ecosystem Science Center, Snake River Field Station, 970 Lusk Street, Boise, Idaho 83706 U.S.A.
DALE E. TOWEILL, Idaho Department of Fish and Game, P.O. Box 25, Boise, Idaho 83707 U.S.A.
WALTER A. VAN DYKE, Oregon Department of Fish and Wildlife, 3814 Clark Blvd, Ontario, Oregon 97914 U.S.A.

Abstract: We surveyed the bighorn sheep population at Leslie Gulch, Oregon (W117^{o} 16', N43^{o} 20') to obtain an estimate of population size and to begin validation of the Idaho sightability model developed by Bodie et al. (1995) and subsequently employed by the Idaho Department of Fish and Game, 1996-2000. There were approximately 150 bighorn sheep including 33 radiocollared ewes in the surveyed herd. This herd had not been surveyed using the techniques described by Bodie et al. (1995). The survey area was partitioned into sampling units prior to the survey, and each unit was stratified as having a "high-" or "low-" probability of bighorn sheep occurrence in an effort to partition sample variability (Bodie et al 1995). We surveyed all sampling units in strata with high-probability of bighorn sheep occurrence, and 10 of 38 units in strata with "low" probability of occurrence. We relocated radiocollared bighorns from a fixed-wing aircraft before and after the helicopter survey. Radio-equipped bighorn sheep located before the survey moved 1.2 $\pm$ 0.85 km prior to being observed from the helicopter. However, probability of locating radio-equipped bighorns was 66%, consistent with the Idaho model (Bodie et al. 1995) despite differences in bighorn sheep habitat components and arrangement. The Idaho model, developed in canyon-and-range habitats, appears robust relative to the steep hills and rocky faces of the Leslie Gulch study area. Distance traveled by many of the radio-equipped bighorn ewes prior to being located by helicopter-based observers is of continuing concern, because bighorns may avoid being included in helicopter surveys.

Key words: Aerial survey, bighorn sheep, helicopter, Idaho, *Ovis canadensis*, population estimates, sightability, visibility bias.

The Idaho sightability model (Bodie et al. 1995) was developed to estimate the number of California bighorn sheep in the canyonlands of southwestern Idaho. This sightability model assigns a statistical probability of observation to bighorn sheep based on activity and habitat. Model assumptions are: (1) the population is demographically closed during the survey, (2) no animals are counted more than once, (3) survey techniques and weather conditions are the same as those used to develop the model, and (4) bighorn sheep behavior is the same as the behavior of bighorns used to develop the model (Bodie et al. 1995). Concerns about the validity of model assumptions (particularly assumption 4) have increased in recent years, at least in part due to declines in bighorn sheep population estimates despite a lack of other data to indicate reasons for a general population decline. Some biologists suspect that bighorn sheep are learning to avoid being counted during helicopter surveys.

Bodie et al. (1995) pointed out that the Idaho sightability model was not validated by surveying bighorn populations of known size in comparable habitats. We used the Idaho model to estimate bighorn sheep numbers in the Lower Owyhee River population wherein approximately

25% of the sheep were radiocollared. This bighorn sheep population had a long history of being exposed to helicopters. Recent helicopter activities included net-gun captures and annual counts. In January, 15 ewes were captured in the Santa Rosa Mountains of Nevada then collared and released at Leslie Gulch. In addition, 18 ewes in the resident Leslie Gulch population were captured and collared. All were captured with helicopter net-gun procedures following Oregon Department of Fish and Wildlife (ODFW) animal handling and welfare protocols. Helicopter counts had been conducted at Leslie Gulch annually since 1981; the most recent count before the July survey was in March. The annual helicopter counts were part of a general big game survey and did not follow the Idaho sightability technique methods.

STUDY AREA

The 2,518 ha Leslie Gulch study area, in Malheur County, Oregon (Fig. 1), extended north from Mahogany Mountain to Sheephead Basin, and east from Owyhee Reservoir to Grassy Ridge. It constituted the entire range of Oregon's Lower Owyhee River herd of bighorn sheep (see map *in* Toweill and Geist 1999). This herd of California bighorn sheep was re-established in previously occupied habitat via transplants beginning in 1965. The Lower Owyhee River bighorn sheep population was believed demographically closed and relatively stable.

The area is within the Shrub-Steppe Province and Desert Shrub Zone (Frenkel 1976). Vegetation was similar to vegetation in southwestern Idaho. Dominant vegetation included bluebunch wheatgrass (*Pseudoroegneria spicata*), sagebrush (*Artemisia tridentata wyomingensis* and *A. t. tridentata*) and western juniper (*Juniperus occidentalis*).

Elevation ranged from 814 m at Owyhee Reservoir to 1,710 m near Mahogany Mountain. Topography consisted of steep hills with rocky outcrops, different from the rocky canyons and wide plateaus where the Idaho model was developed (Bodie et al. 1995). The patchy rough terrain in Oregon contrasts with continuous canyons in Idaho. Both areas had abundant caves and crevices.

Geology of the Leslie Gulch area is dissected late Miocene tuffs overlain by 2 layers of consolidated volcanic rhyolitic ash deposited during eruptions of the Mahogany Mountain and 3 Fingers calderas about 15.5 million years ago (Baldwin 1964). Much of the volcanic material fell as fine ash intermingled with rock fragments, forming layers as much as 1,000 feet thick. The present steep slopes, cliffs and honeycombed rock towers have resulted from subsequent erosion and chemical weathering. Less-resistant ash has weathered away leaving numerous caves, rock overhangs and crevices that provide excellent shelter for bighorn sheep attempting to hide from aerial disturbance.

The climate of the study area includes hot summers and cold winters in an arid regime (Lahey 1976). Mean maximum temperature in July was 32 ^{o}C; maximum summer temperatures averaged 40 ^{o}C (Lahey 1976). Extreme summer temperatures may reach 49 ^{o}C within canyonlands near Owyhee reservoir. Winter temperatures typically range from -18 to 4 ^{o}C. Precipitation during summer (July-August) averages about 2.5 cm; winter precipitation (December-February) averages 10 cm (Lahey 1976). Total annual precipitation rarely exceeds 20-25 cm.

METHODS

We divided the study area into 54 counting blocks of 40.0 $\pm$ 21.4 ha each. Boundaries followed draws, flats, roads, or the reservoir edge, places bighorn sheep were less likely to cross undetected. We pre-assigned each block to either high-probability or low-probability of bighorn occurrence, based on habitat and knowledge of prior distribution, following the approach used by Bodie et al. (1995). Most of the radiocollared sheep were known to have been in high-probability counting blocks within 7 days prior to the survey (Walt VanDyke, unpublished data). We surveyed all 16 high-probability blocks and 10 of 38 (26%) low-probability blocks. We used a table of random numbers to select low-probability blocks for sampling. We digitized block boundaries using ArcView (ESRI, Redlands, California) and compared the resulting map with the location of each bighorn sheep seen during the survey.

We located all radiocollared bighorn sheep on July 3, before the helicopter survey on July 5 and 6. We used a scanning receiver (Telonics, Mesa, Arizona) in a Cessna 182 airplane fitted with external antennas and flown approximately 300 m Above Ground Level (AGL). We determined sheep locations by signal strength and recorded locations on the aircraft GPS unit. We also used the same technique to record sheep locations on July 6, after the helicopter survey. We used a paired t-test to compare distances moved by radiocollared bighorns before and after the helicopter survey. In addition, strategically placed volunteers collected sheep behavior data before and during the helicopter survey. We selected observer locations and travel routes to minimize the potential for them to disturb bighorn sheep. Volunteers recorded bighorn sheep responses to the (apparent) helicopter disturbance and mapped bighorn sheep movements.

We used a Bell 206 Jet Ranger helicopter, flown with doors off for increased visibility. Flights began at about 0700 hrs MDT on July 5 and 6, 2001. Two experienced observers (primary observer in the left front; secondary observer in the right rear seat) counted and classified bighorn sheep. Data recorded during each flight included: date, temperature, percent cloud cover, wind (speed and direction), precipitation, and names of the primary and secondary observers. Data we collected for each group of bighorn sheep included: time of initial sighting, total number of ewes (classed as adult or yearling), lambs, and rams (classified by horn length into 4 categories), activity (moving or not), habitat, relative helicopter position, and GPS location. Habitat categories were riparian, cliff, talus, terraces, dissected cliff, flats or open slopes, and caves. Helicopter position was recorded as above, below or level with observed sheep. We recorded data for sheep seen outside designated counting blocks when it appeared that we chased them from a designated counting block.

Van Dyke was the primary observer on all flights because he was most familiar with the study area; secondary observers (all experienced in classifying bighorn sheep from a helicopter) varied by flight. We documented the initial location of each bighorn sheep by recording the GPS coordinates from helicopter navigation instruments. We analyzed location data in ArcView.

In an effort to evaluate observer performance, a third experienced observer equipped with a scanning receiver accompanied all flights. We used the scanning receiver to identify radiocollared animals near the helicopter whether observed or not. We used a hand-held GPS receiver (Garmin 12 XL, Garmin International Inc., Olathe, Kansas) to record the locations of any bighorn sheep missed by the survey crew. The third observer did not communicate his observations with other crewmembers during survey flights.

To minimize the risk of bighorn sheep moving between blocks before being counted, we began the survey in each block at its highest point (e.g., ridgelines). Subsequent passes were at progressively lower elevations. Although a modification of the procedure described by Bodie et al. (1995), we adopted this protocol because data (Bodie et al. 1995, table 1) revealed that bighorn sheep were more visible to observers when the helicopter was above (visibility 0.62) or at the same elevation as bighorn sheep (visibility 0.86). Beginning at elevations below sheep would have resulted in reduced visibility (0.44) and increased likelihood of animals crossing delineated boundaries undetected. No visibility factors in the model were altered by this search pattern change. Survey flights were flown as parallel transects in a systematic pattern at approximately 40 km/h, 50 m above ground level on 100 m contours. When sheep were observed, the helicopter was maneuvered until all sheep were counted and classified to sex, age, and horn class.

RESULTS

We confirmed that bighorn ewes move about considerably during helicopter surveys. We located all 33 radiocollared bighorn ewes before the helicopter flight: 24 (73%) were in designated counting blocks, 4 (12%) were in the survey area but not in a designated counting block, and 5 (15%) were outside the survey area. We failed to predict where the radiocollared ewes would be before the helicopter flight even though we had recent records of their locations. Radiocollared ewes were present in 31% (5/16) of the designated high-probability counting blocks prior to the survey. Surprisingly, radiocollared ewes were equally likely (30%) to occur in low-probability counting blocks (3/10). During the helicopter survey, collared ewes were only seen in high-probability blocks but uncollared sheep were counted in both high- and low-probability counting blocks.

We counted 91 bighorn sheep during the survey (Table 1), including 19 of 29 radio-equipped ewes present in the survey area, as determined by the third observer with a scanning receiver. Fourteen of the 19 (74%) radioed ewes were in counted blocks, but only 1 of the 14 animals was in the same block it occupied prior to the helicopter flights. None of the 9 radiocollared bighorns that were outside of designated counting blocks before the survey was observed during the survey, and of the 10 bighorn ewes present in

Table 1. Number of bighorn sheep counted from the helicopter in selected blocks, Leslie Gulch Oregon, July 2001.

Stratum	Units sampled	Number of each class counted					
		Total	Ewes	Rams	Lambs	Slegal*	Legal
High	16	79	35	32	12	21	11
Low	10	12	3	6	3	6	0
Total	26	91	38	38	15	25	11

* Slegal = sublegal (in Idaho) rams with horns of less than 3/4 curl

counting blocks but not detected during the survey, 4 (44%) had moved outside the study area when relocated immediately after the completion of the survey.

Linear distance moved might be related to a bighorn sheep's ability to avoid the helicopter. Bighorn sheep found in the survey area before the helicopter survey but for which radio signals were not heard during the survey (n = 4) moved an average of 3.0 ± 3.14 km between the first location (3 July) and last location (6 July). Bighorn sheep found in the area before the survey and also seen from the helicopter (n = 19), moved less than half the distance (1.41 ± 0.95 km) of the 4 ewes that were originally within the survey area but not observed from the helicopter.

Radio-equipped bighorn sheep (n = 19) moved an average of 1.2 ± 0.85 km between fixed-wing and helicopter survey locations, and an average of 1.3 ± 0.95 km after being counted from the helicopter. There was no difference between distances moved by bighorn sheep before and after being counted from the helicopter (paired t = -0.048, n = 19, P = 0.962). Directions traveled during these movements varied. Some radio-equipped bighorn sheep returned toward their original locations after the helicopter passed, while others continued to move away from their original location. One ewe traveled 2.7 km before being observed from the helicopter and 2.9 km afterward, but was last found only 0.3 km from her original location. Another ewe traveled 0.5 km before being observed from the helicopter, 2.9 km afterward, and was finally located 3.5 km from her original location.

The primary observers missed 15 bighorns that were seen by the third observer. All undetected animals were moving when first observed but were away from typical escape terrain. Ten of these sheep were first observed in open shrub/grass habitat and 5 (one group) were in talus near the bottom of a small canyon. Most (9) were lower than the helicopter; 5 were higher, and 1 was about level with the helicopter. All missed sheep would have been readily detectable if observers had looked in their direction.

We saw a slight but significantly greater proportion of radiocollared ewes (66%) than the detection probability (57%; SE 0.03) estimated for bighorn ewes by Bodie et al. (1995). Using the Idaho model, we estimated the population of bighorn sheep in the Leslie Gulch survey area at 172 ± 68 animals (Table 2). Recent helicopter surveys (Van Dyke, file data) had produced population estimates of 175 (1999), 150 (2000) and 160 (March 2001).

Initiation of helicopter flights resulted in a general melee of bighorn sheep movements, as indicated by movement of radiocollared animals between and away from designated counting blocks and supported by observations of ground-based observers (n = 20 observer days). Not only did bighorn sheep flee as the

Table 2. Total number of sheep estimated to have been present in Leslie Gulch, Oregon in July 2001. Helicopter counts were adjusted for sightability and sampling.

Number of Units			Variance				Bound
Stratum	Popn*	Sample	Estimate	Sampling	Sightability	Model	90%
High	16	16	112	0	308	12	29
Low	38	10	60	1308	72	2	61
Total	54	26	172	1308	380	14	68

* Popn is number of counting units in the study area

helicopter approached; observers reported that both rams (n = 5) and a ewe hid under rimrock or in caves to escape the approaching helicopter. Volunteers reported that some bighorns that were observed feeding or resting prior to the helicopter survey, fled while the helicopter was still "a mile away." Bighorns probably traveled far greater distances than the straight-line measurements we made between locations determined aerially. Ground observers noted that sheep ran about in an unorganized pattern sometimes crossing the same draw several times.

The sightability model also estimated population parameters. Early July lamb survival was 49 lambs/100 ewes. Many rams were present, in fact there were about the same number of rams as ewes (100.7/100). There were 81 rams with less than ¾ curl and 20 rams greater than ¾ curl per 100 ewes.

DISCUSSION:

Bighorn sheep movements during surveys create sampling problems. Bighorns that run from the helicopter may travel long distances (Bleich et al. 1990) making their detection difficult. To offset the impact of such emigration, Bodie et al. (1995) suggested eliminating sampling units and expanding the survey area so that such out-migration was minimized. However, this approach masks an unstated assumption (5): that animals moving away from the helicopter will remain in the survey area. Almost all (13 of 14) radiocollared bighorn ewes changed counting blocks before being observed from the helicopter, some left the survey area. Bighorn movements out of survey blocks during sightability surveys will result in conservative population estimates.

Bighorn sheep behavior at Leslie Gulch was similar to behavior of bighorns used to develop the model (assumption 4). Bighorn sheep managers faced with lower counts in the last few years are concerned that bighorns may have learned to avoid aerial surveys. However, the sheep used to develop the sightability model were subjected to far more helicopter activity in a shorter period than is experienced by sheep during management surveys. Bodie et al. (1995) developed their model using radiocollared sheep that had been drive-trapped and net-gunned before the first survey flight. Then, these already experienced sheep virtually became grizzled veterans of helicopter surveys by the end of the study having experienced 14 sightability and 6 survey flights, yet the estimated population in the Little Jacks Creek study area did not differ through all these flights (Bodie et al. 1995, table 2). Further, if significant learning occurs, two closely spaced counts might be expected to yield different estimates with the second count being lower. The June 1994 helicopter survey of bighorn sheep in the Owyhee River area was so low and unexpected that a different crew was used to repeat the survey in the same month. The second survey counted 11 fewer sheep (336) than the first survey (347) but estimated the population to be slightly higher (532 as compared with 486).

The bighorns at Leslie Gulch were also experienced with helicopters. Our survey followed several exposures of those sheep to helicopters earlier in the same year and annual surveys before that, yet we estimated about the same number of sheep (172) as estimated during the March count (160) and sightability of radiocollared ewes (66%) was about the same as reported by Bodie (57%). If sheep learn to avoid surveys after being exposed to helicopters, this learning had probably already occurred before our survey. All these sheep surveys were of experienced bighorns. What is lacking and will be rare by definition is sightability estimates for naïve sheep.

Data collected during this survey failed to satisfy a previously stated assumption and identified a new assumption that was also violated. Assumption (1) that the population is demographically closed during the survey was violated as almost all (13 of 14) radiocollared ewes within survey blocks moved out of those blocks before they were observed, presumably due to being disturbed by the helicopter. At least 4 of these radiocollared ewes moved completely out of the survey area. The new assumption that (5) bighorn sheep disturbed by helicopters remain available for observation is also unsupported.

Volunteers on the ground thought we violated assumption (2) by double counting some sheep. They saw the helicopter fly over the same bighorns more than once and assumed a double count was made. Careful checking of the data sheets showed that no similar groups were counted twice. If the same group was flown over more than once, the observers must have recognized that they were the same animals and did not double count or they misclassified one of the groups. The possibility remains that some individual sheep may have been double counted if they changed groups. Double counting would result in an over-estimate of true population. No radiocollared ewes were counted more than once.

We attempted to increase survey efficiency by stratifying sampling blocks based on the probability that sheep would be counted in each block. Our stratification was unsuccessful because we were unable to predict in which blocks sheep would be counted. Our sampling blocks may have been too small. Larger blocks would make it less likely that sheep could change blocks. Bodie et al. (1995) used larger blocks (mean = 24.3 km^2) when they attempted to stratify their study area but they recommended that such efforts be abandoned due to inability to predict where sheep would be counted. We concur, but suggest that stratification may increase survey efficiency in some habitats where survey methodology encourages animals to select escape habitat, which can be easily identified. There may also be an advantage to moving quickly to a sampling block to reduce time available for sheep to leave the area.

CONCLUSIONS

This survey is one attempt to validate the Idaho sightability model for bighorn sheep (Bodie et al. 1995). We found that at least one model assumption was violated, and identified a fifth assumption, previously unstated, which also appeared to be violated. The significance of violating these two model assumptions may be minimal, resulting in a slight under-estimate of true population size in easily surveyed, clearly bounded habitats. However, large blocks of homogenous habitat might provide many escape opportunities and allow more bighorn sheep to remain undetected. We saw no evidence that sheep become more proficient at escaping helicopter surveys with experience. The Idaho model was developed with experienced sheep.

We suggest that helicopter surveys be conducted in such a way to minimize the potential for sheep to escape from the survey area. Specifically, helicopter search patterns should begin at the highest elevations within a survey area, and then follow parallel transects to lower elevations. Where possible, search blocks should be selected with borders that are less likely for sheep to cross undetected. Observers should not focus exclusively on those habitats most likely to provide bighorn sheep security habitat or visible sheep in more open terrain may be missed.

ACKNOWLEDGEMENTS

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STATUS REPORTS

Kirby Smith - Moderator

The Status Of Mountain Goats In Canada's Northwest Territories

ALASDAIR VEITCH, Department of Resources, Wildlife & Economic Development, Government of the Northwest Territories, P.O. Box 130, Norman Wells, NT, Canada X0E 0V0
ELLEN SIMMONS, ET Enterprises, Site 9B, Comp. 20, RR1, Kaleden, BC, Canada V0H 1K0
MIKI PROMISLOW, Sahtu Geographic Information System Project, P.O. Box 130, Norman Wells, NT, Canada X0E 0V0
DOUGLAS TATE, Nahanni National Park Reserve, P. O. Box 348, Fort Simpson, NT, Canada X0E 0N0
MICHELLE SWALLOW, Department of Resources, Wildlife & Economic Development, P.O. Box 130, Norman Wells, NT, Canada X0E 0V0
RICHARD POPKO, Department of Resources, Wildlife & Economic Development, P.O. Box 130, Norman Wells, NT, Canada X0E 0V0

Abstract: Mountain goats (*Oreamnos* americanus) are the least studied ungulate species that occurs in the Northwest Territories. The distribution of goats in the territory – both historically and at present - is limited to the lower half of the 130,000 km^2 Mackenzie Mountains between the Yukon-NWT border and the east edge of the range, including a portion of Nahanni National Park Reserve. Due to the limited annual harvest of goats and the extremely high cost for doing research in this remote region - few surveys to estimate size of mountain goat populations have occurred in the Mackenzie Mountains. Biologists working with federal and territorial wildlife agencies, Parks Canada, and private environmental consulting companies have sporadically collected limited information about mountain goats during the course of studies on other species in the Mackenzies since 1966. In 2001, we interviewed each of the 8 outfitters licenced to provide services to non-resident hunters in the Mackenzie Mountains to document their knowledge about mountain goat distribution and estimated numbers in their zones. Of the eight outfitting zones, five have at least some goats present. Information provided by outfitters and Parks Canada biologists suggests that there are between 768 and 989 mountain goats in the NWT. The outfitter interviews and biologists' records were digitized for mapping and analysis. Mountain goats occupy approximately 9.5% of the total area of the Mackenzie Mountains in the NWT. Harvest of mountain goats in the NWT by resident, non-resident, and non-resident alien hunters began in 1965. There is no annual quota to regulate the number of mountain goats that may be harvested in the NWT. Resident and non-resident hunters are permitted to take one goat of any age and sex annually during a season that lasts from 15 July to 31 October. Holders of General Hunting Licences (primarily aboriginal people) are allowed to take unlimited numbers of goats throughout the year. For the 35-year period 1967 to 2001, we have records of 149 mountain goats harvested by non-residents and an additional 25 goats were taken by resident hunters for the period 1981-2001. There is no current or historic known subsistence harvest of mountain goats in the Mackenzie Mountains of the NWT. For 96 harvested goats for which sex is known, 43% were female and 57% male. Over the last 10 years, an annual mean of 18.7 ± 9.9 tags to hunt mountain goats have been purchased by non-resident hunters (range 6 to 35 tags). During that same period, the mean annual harvest has been 4.1 ± 2.5 goats (range 1 to 9 goats).

Key words: Northwest Territories, Mackenzie Mountains, mountain goat, *Oreamnos americanus*, status, distribution, harvest

INTRODUCTION

Mountain goats (*Oreamnos americanus*) are the least known and least studied ungulate species within Canada's Northwest Territories (NWT). They occur only within rugged and remote areas of the Mackenzie Mountains between the Mackenzie River and the Yukon/NWT border (Figure 1).

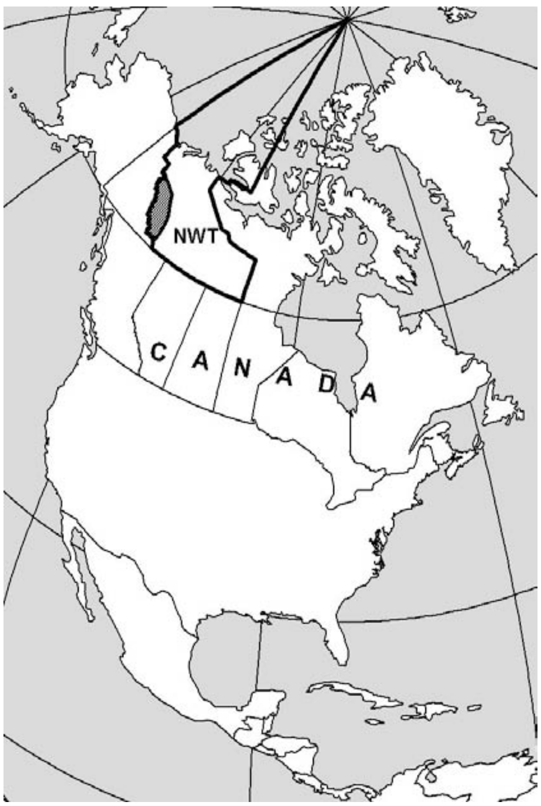

Figure 1. The Mackenzie Mountains in Canada's Northwest Territories

The Mackenzie Mountains cover both the western NWT and eastern Yukon of northwestern Canada. The NWT portion of the range covers approximately 130,000 km^2 between the Mackenzie River and the border with the Yukon. The Mackenzies are a system of irregular mountain masses resulting primarily from deformation and uplift (Simmons 1968). Since they are comprised primarily of limestone, dolomite, and shale they have been heavily eroded, which has produced unstable rubble slopes over large areas (Simmons 1982) and many spectacular canyons, ravines, and rock outcrops. Along the Yukon-NWT border some peaks reach 2700 m and a few active glaciers occur (the Backbone Range), whereas along the eastern front range (the Canyon Range) the topography is generally more gentle (1000-2000 m). The average frost-free season lasts only 70-75 days and total annual precipitation is between 25 and 30 cm (Simmons 1968).

The major large mammal species that occur across most of the mountain range are: Dall's sheep (*Ovis dalli dalli*), mountain-ecotype woodland caribou (*Rangifer tarandus caribou*), moose (*Alces alces gigas*), grizzly bear (*Ursus arctos*), wolf (*Canis lupus*), and wolverine (*Gulo gulo*). The estimated population of Dall's sheep in the Mackenzies is 14,000 to 26,000 (Veitch et al. 2000). Black bears (*U. americanus*) occur at very low density in the southern half of the range (Simmons 1968; Veitch and Simmons 2001). In 1997, a lone bull muskox (*Ovibos moschatus*) was reported at the northern end of the mountain range (Kelly Hougen, Arctic Red River Outfitters, personal communication). This is the only known occurrence of muskoxen in the Mackenzies, but muskox numbers and range are expanding west of Great Bear Lake (Veitch 1997) and animals have been seen near the bank of the Mackenzie River in 2000-2001 (Department of Resources, Wildlife & Economic Development (DRWED) unpublished files).

Reports of mule deer (*Odocoileus hemionus*) have been received in the vicinity of Nahanni Butte at the south end of the range and there have been reports of mule and white-tailed deer within the borders of Nahanni National Park Reserve since the 1970's and 1980's. In recent years both mule deer and white-tailed deer have been moving northwards in the Yukon (Hoefs 2001) and white-tailed deer along the Mackenzie River Valley in the Northwest Territories (Veitch 2001). Within the last few years, elk (*Cervus elaphus*) have also been seen and harvested near the community of Nahanni Butte at the south end of the Mackenzie Mountains.

There are only two short (<20 km) active roads in the Mackenzie Mountains of the NWT, both along the Yukon-NWT border. In 1943-44, the Canol Road was constructed as part of a project to move oil from Norman Wells across the Mackenzie Mountains to Alaska. At the end of the project in 1945, the road was left to deteriorate over virtually its entire 357 km length on the NWT side of the border (Fradkin 1977), such that now the Canol Heritage Trail in the NWT is considered one of the premier backcountry hikes in North America (Howe 1996). Plans have been developed to make the trail a territorial park (Downie 2003). On the Yukon side, the Canol Road has been maintained as a summer-use road. An all-season highway skirts the southeastern edge of the Mackenzies in the vicinity of the communities of Nahanni Butte and Fort Liard in the NWT, and another summer-use road crosses the Yukon-NWT border at the abandoned mining community of Tungsten west of Nahanni National Park Reserve (Figure 2) and continues for <20 km within the NWT.

No people live year-round within the Mackenzie Mountains; however, recently the mine at Tungsten was re-opened and approximately 100 workers live at the mine site on a scheduled rotational basis. Five communities along the Mackenzie River, with a combined population of 1913 (Government of the Northwest Territories (GNWT) 1996; range 75 to 798), are located within 50 km of the Mackenzies in the NWT. In 1991, 63% of the residents of those communities identified themselves as aboriginal, primarily Dene and Metis (GNWT 1996).

The Tungsten mine, an inactive mine site at MacMillan Pass near the Yukon border on the Canol Road, and exploration at Prairie Creek north of Nahanni National Park Reserve are the principle ongoing industrial activities within the mountains. Many other mining claims have been staked and exploration is ongoing. Recreational tourism is also increasing in the mountains, primarily hunting, fishing, hiking, sightseeing, canoeing, kayaking, and skiing. Snowmobiles and all-terrain vehicles are used along the eastern and western fringes of the mountain range gaining access via summer roads and rivers, and high-powered jet boats are used primarily by subsistence hunters to access the mountains through some of the larger rivers.

All mountain goat populations in the NWT are native - no mountain goats or Dall's sheep have been transplanted to, from, or within the NWT (Veitch 1998). No domestic sheep or goats are farmed anywhere within 50 km of the Mackenzie Mountains in the NWT, nor are there any plans to develop or promote a domestic sheep or goat industry in the NWT (John Colford, Fish/Agriculture Coordinator, DRWED, personal communication).

DISTRIBUTION AND POPULATION ESTIMATE

The main challenge to aerial or ground surveys to assess mountain goat population distribution and numbers in the NWT is their remote location in isolated sections of the Mackenzie Mountains and their low and sparsely distributed numbers. As a result of this inaccessibility, the high cost and safety

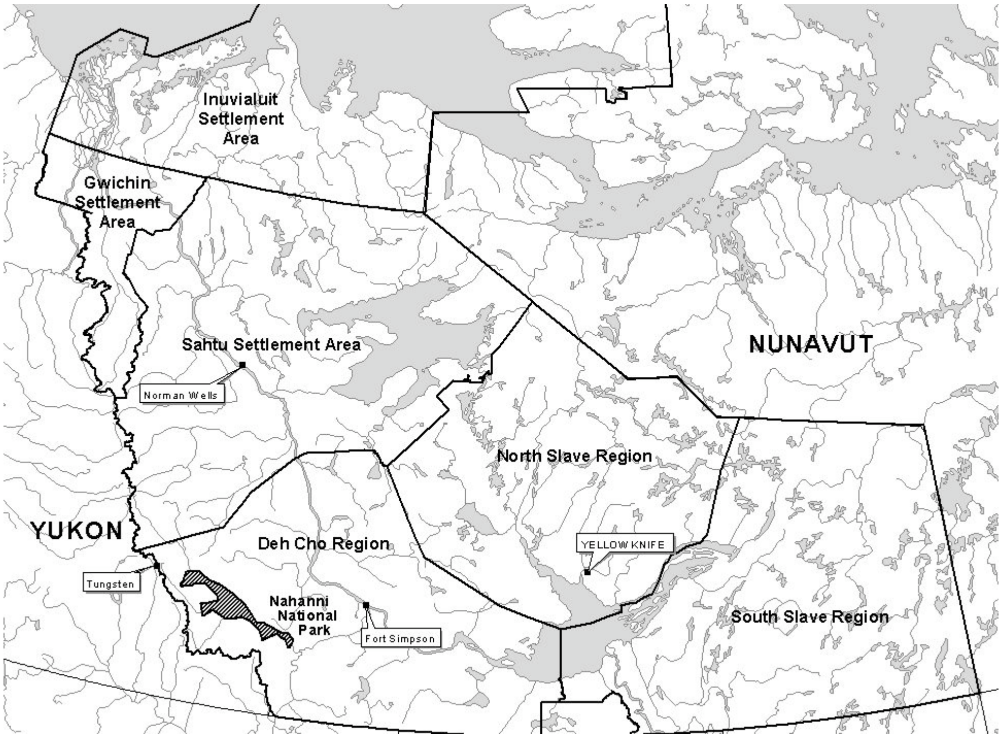

Figure 2. Political regions of Canada's Northwest Territories

risks of doing aerial survey in such a remote area, and the low annual harvest - there has been little goat research done in the Northwest Territories. Biologists working with the Canadian Wildlife Service (CWS), GNWT, and private consulting firms have kept some records of goat observations and numbers during the course of studies on other species – much of this work was done from 1968 through 1973 by Dr. Norm Simmons and his colleagues with the CWS. Their observations were compiled for this report and are included with observations collected from big-game hunting outfitters (discussed below and shown in Figure 4).To date, the only previously published estimate of mountain goats in the Mackenzie Mountains was 400+ for a review of the status of mountain goats in North America by jurisdiction (Johnson 1977). Johnson indicates this estimate was provided by Simmons based on limited work by Simmons and others in the late 1960's to mid-1970's. It was not based on any structured surveys for mountain goats.

Recent interest in the NWT goat population led us to do an informal survey of outfitters. The Association of Mackenzie Mountain Outfitters (AMMO) has 8 members who operate excusive hunting zones across the entire mountain ranges, except within Nahanni National Park Reserve (Figure 3). Some of the outfitters have been operating their zones for two and three decades – thus they have accumulated considerable knowledge about the distribution and numbers of wildlife, particularly big game species, in their zones. We decided that interviews with the

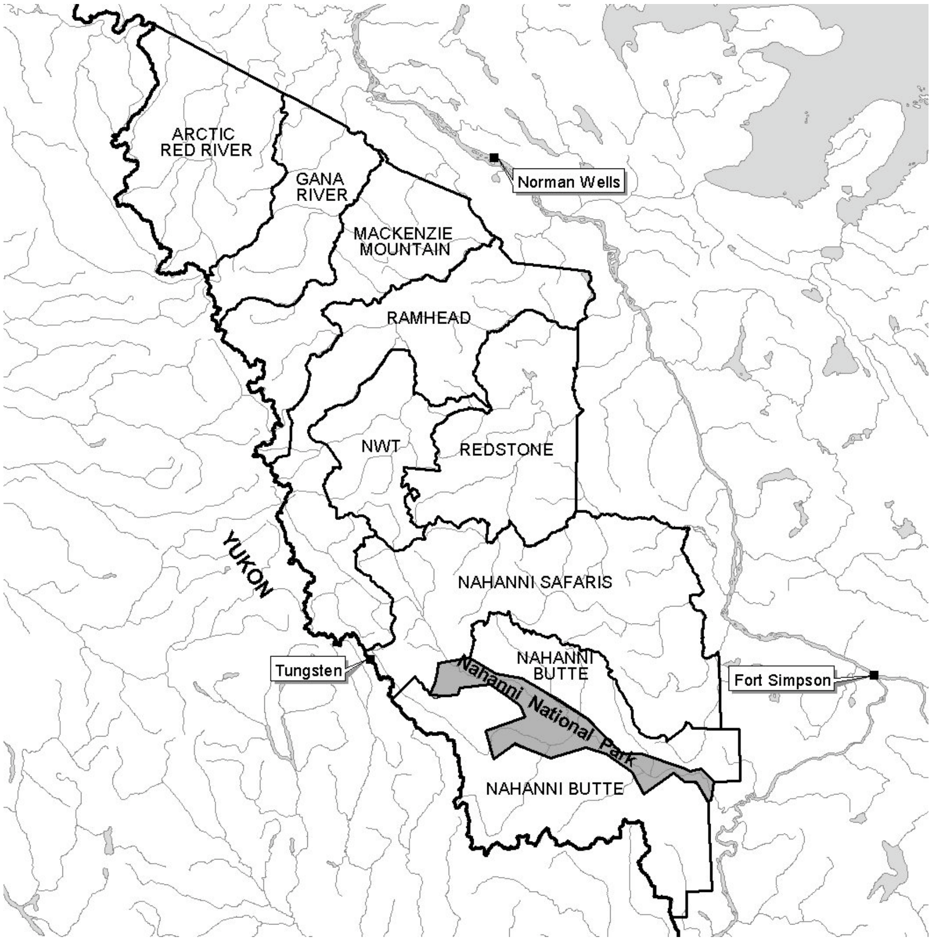

Figure 3. Licensed outfitting zones for non-resident big game hunting in the Mackenzie Mountains, Northwest Territories

outfitters about mountain goats presented a quick and inexpensive alternative to a formal population survey.

In January 2001, all 8 members of AMMO were interviewed by the senior author in Reno, Nevada at the Foundation for North American Wild Sheep's annual convention. Outfitters were asked to provide information on where in their zones mountain goats occur and to estimate numbers of goats within in each of those areas to provide a population estimate for their zone. Using GIS, we had prepared individual topographic maps for each outfitting zone on which all data were recorded.

Five outfitters confirmed having at least some mountain goats within their zones. The core area is from 61^{o} 30' N to 63^{o} 00' N and from 126^{o} 30' W to the Yukon/NWT border (Figure 4). Areas around the headwaters of the South Nahanni River are of particular importance for mountain goats. The total area covered by mountain goats in the NWT is 12,414 km^2, which represents 9.5% of the total area of the Mackenzie Mountains in the NWT and only 1.1% of the total area of the territory (1,171,918 km^2). One outfitter

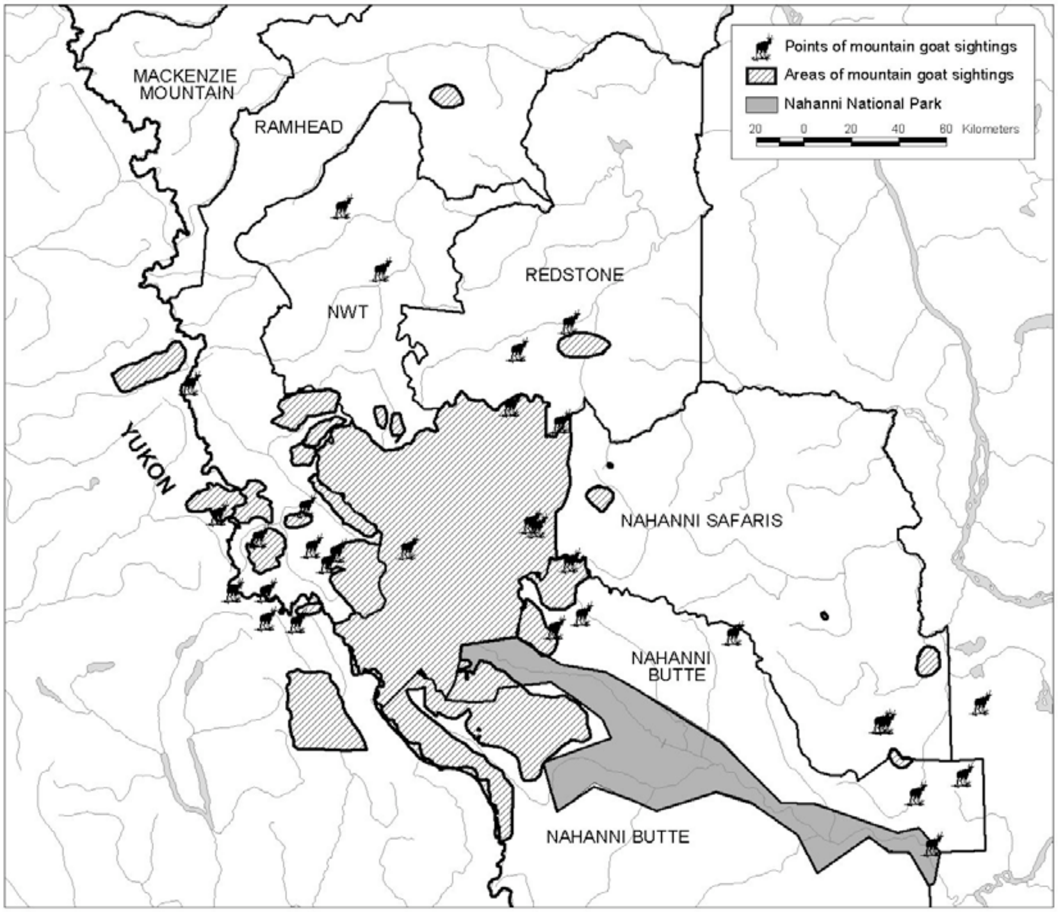

Figure 4. Known current and recent historical mountain goat distribution and sightings in the Mackenzie Mountains, Northwest Territories as recorded by biologists and members of the Association of Mackenzie Mountain Outfitters.

reported that there was a small and isolated group of mountain goats in his zone just north of 64° 00' N from about 1980 to the late 1990's – this is the northernmost reported area with goats in the NWT (Stan Simpson, RamHead Outfitters, personal communication).

Distribution of goats in the Mackenzie Mountains, NWT is patchy, particularly in the north and east sides of the species range in the territory. Hoefs et al. (1977) noted similar distribution patterns in the Yukon and also mentioned that within that territory there were areas where goats had existed in small populations until 'recent history', but had subsequently disappeared.

The outfitters' information provided an estimate of 898 to 919 mountain goats within their operating zones, of which the highest population occurs in the southernmost zone, Nahanni Butte (Table 1). An additional 70 to 80 goats is estimated to occupy Nahanni National Park Reserve, to raise the total estimate for the NWT to 768 to 989 goats.

It is evident from Table 1 that mountain goat densities in the NWT are highly

Table 1. Population estimate and density of mountain goats in the Mackenzie Mountains, Northwest Territories.

Area	Area (km^2)	Area Occupied By Goats (km^2)	Estimated Goat Population	Goat Density ($/100\ km^2$)
Nahanni Butte	21,936	2,243	351-424[a]	15.6-18.9
Nahanni Safaris	24,976	8,461	116-130[a]	1.4-1.5
RamHead	19,697	1,462	200-315[a]	13.7-21.5
Redstone	13,988	<100	1-10[a]	1.0-10.0
NWT	8,109	77	30[a]	39.0
Mackenzie Mountain	12,700	0	0[a]	0
Gana River	9,259	0	0[a]	0
Arctic Red River	14,727	0	0[a]	0
Nahanni National Park Reserve [b]	4,819	171	70-80[b]	40.9-46.8
Total	130,211	12,414	768-989	6.2-8.0

Data sources:
[a] Personal interview with license-holder January, 2001
[b] Comin, L, A. Cochrane, S. Cooper, C. Hammond, and T. Elliot. 1981.

variable. The highest density recorded is within the borders of Nahanni National Park Reserve with 41 to 47 goats/100 km^2; however, only a relatively small proportion of the park (3.5%) is occupied by mountain goats. Discussions and negotiations are underway between Parks Canada and the First Nations of the Deh Cho that may see a significant increase in the size of NNPR, with potential for much more of the NWT's best habitat for mountain goats to be put under protection.

HARVEST

The hunting license year in the NWT runs from 01 July to 30 June and those who wish to hunt big game within the territory must annually obtain a big game hunting license and be at least 16-years-old (GNWT 2001). There are four classes of licensed big game hunters in the NWT:

1) *General* – subsistence harvesters (primarily aboriginal people)
2) *Resident* - Canadian citizens or landed immigrants who have lived in the NWT for at least two consecutive years prior to application for the license;
3) *Non-resident* - Canadian citizens or landed immigrants who live outside the NWT, or have not lived within the NWT for two consecutive years prior to application for the license; and
4) *Non-resident Alien* - non-Canadian citizens or landed immigrants.

All non-residents and non-resident alien hunters must use the services of an outfitter and must be accompanied by a licensed guide at all times while hunting. For simplification, we will call both non-resident and non-resident alien hunting license holders 'non-residents' and combine their harvest statistics. The season for mountain goats for both resident and non-resident hunters lasts from 15 July to 31 October and there is a bag limit of one goat per year (any age and sex). A tag for mountain goats costs ^{CAN}\$10.00 for residents, ^{CAN}\$20.00 for non-residents, and ^{CAN}\$50.00 for non-resident aliens. All non-resident hunters must also pay a trophy fee of ^{CAN}\$200.00 to the Government of the NWT upon harvest of a mountain goat; resident hunters are not required to pay a trophy fee.

Resident and non-resident hunters are allowed to hunt for mountain goats within all eight outfitting zones in the Mackenzie Mountains but are not allowed to hunt within the borders of Nahanni National Park Reserve (NNPR). However, holders of a General Hunting License are permitted to hunt within NNPR.

Annual harvest data for mountain goats are obtained by several different methods dependent on license class and jurisdiction. Within the Sahtu Settlement Area (Figure 2), monthly harvest by beneficiaries of the Sahtu Dene and Metis Comprehensive Land Claim (Government of Canada 1993), or those that provide for beneficiaries of that claim, are recorded by the Sahtu Settlement Harvest Study – a project run by the Sahtu Renewable Resources Board (Tulita, NT). Subsistence harvest data within the Deh Cho Region (Figure 2) are estimated by staff with the Department of Resources, Wildlife & Economic Development (DRWED) and within Nahanni National Park Reserve (Figure 2) subsistence harvests of mountain goats are estimated by park staff.

Resident hunter tag sales and harvest data are maintained by staff with DRWED in Yellowknife; harvest is recorded by a questionnaire mailed out at the end of each hunting season. Submission of this form to DRWED by resident hunters is voluntary; follow-up letters and duplicate forms are sent to non-respondents at 6 and 12 weeks after the initial mailing.

Outfitters are required to collect and submit non–resident harvest data to DRWED as a condition for their holding an outfitting license. Outfitters must submit a report to the GNWT for every client for whom they provide outfitting services whether the client harvests any animals or not. In addition, hunters with outfitters may submit a voluntary 'Wildlife Observation Report' to DRWED using a standard form prepared by DRWED staff and sent to the outfitters annually. These data are compiled in an annual summary report on hunting activities in the Mackenzie Mountains (e.g., Veitch and Simmons 2001).

Non-resident Hunter Harvest

The Mackenzie Mountains were designated as a Game Preserve in 1938 in order to protect the hunting grounds of Dene living in villages along the Mackenzie River (Simmons 1968). However, local use of the mountains for hunting and subsistence had declined substantially by the early 1950's and the Game Preserve status was removed in 1953. In 1965, the Mackenzie Mountains were opened to non-resident sport hunting and have remained open to this activity since then. Each outfitter is responsible for management of his area to ensure that hunting activity is spread out and localized over-harvest does not occur.

Dall's sheep and mountain-ecotype woodland caribou are by far the most popular species sought-after by outfitted hunters. For the 1999-2001 hunting seasons, 69% of license-holders purchased tags for Dall's sheep, 59% for woodland caribou, 20% for moose, 38% for wolf, 24% for wolverine, and only 3% for mountain goat.

Table 2. Non-resident harvest of mountain goats in the Mackenzie Mountains, NWT: 1967 to 2001.

Period	Tags Sold	Males	Females	Unknown	Total
1967-1971	No Data	17	12	6	35
1972-1976	No Data	6	5	19	30
1977-1981	No Data	8	4	4	16
1982-1986	No Data	3	1	3	7
1987-1991	No Data	4	5	12	21
1992-1996	113	10	12	7	29
1997-2001	83	7	2	2	11
Total		55	41	53	149

The low interest in mountain goat hunts may be attributed to the expense of accessing remote and rugged mountain goat territory and the fact that no mountain goat taken in the NWT has made it into the Boone and Crockett record book (Byers and Bettas 1999)

Although current levels of mountain goat hunting are low, this has not always been the case (Table 2). The highest recorded harvest by non-residents in one year was in 1972 when 11 mountain goats were taken. Conversely, in 1976, 1985, and 1987 no mountain goats harvests were recorded.

As there is little difference in the body shape and horn length of male and female mountain goats, it is difficult to differentiate sex of the animal from a distance (Rideout 1978). The difficulty hunters have in identifying sex is reflected in the statistics of harvested animals. For goats harvested and for which sex was known, 43% were female (Table 2).

Considerable fluctuation is evident between and within outfitting zones in terms of harvest pressure since 1967 (Table 3). Two outfitting zones – Nahanni Butte and Nahanni Safaris, account for 74% of all mountain goats harvested. For the three zones that have harvested virtually all of the goats taken by non-residents, it is apparent that there are considerable shifts in numbers of goats taken over the five-year intervals starting in 1967. The reason for these fluctuations is unknown.

Hunter harvest success was estimated by comparison of tag sales for mountain goats with actual harvest for the period 1991 to 2001. During this period, an annual mean of 18.7 $\pm$ 9.9 tags were purchased (range 6 to 35 tags) while the mean annual harvest has been 4.1 $\pm$ 2.5 goats (range 1 to 9 goats), which gives a success rate of approximately 22%.

Resident and Subsistence Hunter Harvest

Since access to mountain goat populations is both difficult and expensive, and as mountain goat meat has a rather poor reputation, hunters from the NWT are much less likely to hunt mountain goats than non-resident hunters.

We were unable to locate any records or personal accounts of mountain goats taken

Table 3. Non-resident harvest of mountain goats by outfitting zone in the Mackenzie Mountains, NWT: 1967 to 2001.

Period	Nahanni Butte	South Nahanni	RamHead	Redstone	Mackenzie Mountain
1967-1971	13	21	0	0	1
1972-1976	0	27	0	0	3
1977-1981	3	7	3	1	0
1982-1986	0	5	0	0	0
1987-1991	0	4	17	0	0
1992-1996	7	10	12	0	0
1997-2001	1	9	1	0	0
Total[a]	24	83	33	1	4

[a] an additional 4 goats were taken for which outfitting zone of harvest was unknown

Table 4. Tag sales and Resident Hunter Harvest of Mountain Goats in the Mackenzie Mountains, NWT: 1982 to 2001.

Year	No. Tags Sold	Reported Harvest	Estimated Total Harvest
1982	25	0	3
1983	21	5	7
1984	35	3	3
1985	35	3	4
1986	20	1	2
1987	10	0	0
1988	6	0	0
1989	20	0	0
1990-1995	55	0	5
1996-2001	15	0	1
Total	242	12	25

by subsistence hunters in the Deh Cho, Sahtu, or Gwich'in areas. Parks Canada officials are not aware of any harvest of mountain goats occurring within Nahanni National Park Reserve. The Sahtu Settlement Harvest Study recorded subsistence harvest for Sahtu Dene and Metis beneficiaries from 1999 to 2001 – no mountain goats were reported as harvested by that study (Bayha and Snortland 2002; Bayha 2003).

Interest in hunting mountain goats by Resident hunters occurred primarily in the 1980's during which a mine was operated at the community of Tungsten on the Yukon-NWT border (Figure 2). The population of the town grew to 450 during the mine's operating peak, but was reduced to zero when the mine closed in 1987. Tungsten's residents would have had the closest access to mountain goat populations. The mine recently reopened; however, it is unlikely that any mine workers will qualify for Resident hunter status as the company uses rotational shift workers rather than re-opening the community (Paul Kraft, Superintendent – DRWED, Deh Cho Region, personal communication).

Mountain goats were removed from the Resident Hunter questionnaire in 1990 because the questionnaire is not structured in such a way as to provide unbiased estimation of those species for which harvest is sporadic and rare (Ray Case, Manger – Technical Support, DRWED, Yellowknife, personal communication). Because of the nature of the survey and of resident mountain goat hunting, the numbers of goats 'estimated' as being harvested (Table 4) is also likely to be biased (Ray Case, personal communication).

Hunter success by resident hunters has remained low since 1982, with an overall rate of 10.3%. This is the lowest estimated success rate for NWT Resident hunters recorded for any big game species.

In summary, for the 35-year period 1967 to 2001, we have records of at least 174 mountain goats harvested, of which 86% were taken by non-resident hunters.

Characteristics of Harvested Mountain Goats in the NWT

There has been limited information of age, sex, and measurements compiled for mountain goats in the Mackenzie Mountains. Outfitters record horn length of the goat following a kill by a non-resident hunter. No mountain goat harvested within the NWT is recorded in the top 500 mountain goat trophies in the record book of the Boone and Crockett Club (Byers and Bettas 1999).

Of 31 male mountain goats with right horn length measurements recorded, the mean is 20.3 $\pm$ 2.5 cm; 6 had horns $\geq$ 23.0 cm. For 28 female mountain goats with right horn length measurements recorded, the mean is 19.5 $\pm$ 2.5 cm; 2 had horns $\geq$23.0 cm (Table 5). Growth curves for Yukon mountain goats based on horn length found that females with horns that are 19.5 cm in length are between 4 to 5 years of age, whereas males with slightly larger horns (20.3 cm) are approximately 3 to 4 years of age (Hoefs et al. 1977).

Aging of mountain goats by tooth cementum was done on 17 of 18 mountain goats taken by non-resident hunters in 1972 and 1975. That study found males ranged in age from 3 to 7 years of age and females ranging in age from 2 to 12 (Murphy 1976). The mean age was 5.4 years (N = 11) and 5.0 years (N = 6) in 1972 and 1975, respectively.

ACKNOWLEDGEMENTS

We extend our appreciation to all members of the Association of Mackenzie Mountain Outfitters for their providing details about mountain goat distribution and numbers in each of their outfitting zones. Suzanne Carriere and Adrian d'Hont (Department of Resources, Wildlife &

Table 5. Horn length data for mountain goats harvested by non-resident hunters in the Mackenzie Mountains, NWT: 1967 to 2001.

Period	N	Length Right Horn (cm)	
		Mean	SD
1972-1976	16	19.5	2.4
1977-1981	12	20.2	1.9
1982-1986	4	19.7	2.4
1987-1991	17	20.7	17
1992-1996	19	21.1	2.5
1997-2001	11	19.4	4.2
Total	79	20.3	2.4

Economic Development, Yellowknife, NT) provided recent Resident hunter harvest data. We thank Janet Bayha and Jody Snortland (Sahtu Renewable Resources Board) for searching their records to determine subsistence harvest of mountain goats by beneficiaries of the Sahtu Dene and Metis Comprehensive Land Claim. Finally, we acknowledge Steve Cote whose enquiries about the status of mountain goats in the NWT initiated the process that ended with this paper.

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Status Of Oregon Rocky Mountain Goats

VICTOR L. COGGINS, Oregon Department of Fish and Wildlife, 65495 Alder Slope Road, Enterprise, OR 97828, USA
PATRICK E. MATTHEWS, Oregon Department of Fish and Wildlife, 65495 Alder Slope Road, Enterprise, OR 97828, USA

Abstract: Mountain goats (*Oreamnos americanus*) were reintroduced to the Wallowa Mountains of northeast Oregon in 1950. This population increased to an estimated 40 animals by 1966. Hunting seasons from 1965-68 resulted in the harvest of 20 animals. This herd stagnated and low productivity resulted in low population numbers through 1985. Three supplemental transplants from 2 sources totaling 33 animals were conducted in 1985, 1986, and 1989. A dramatic increase in kid productivity starting in 1990 has resulted in a 2001 population estimate of 200 mountain goats. The Elkhorn herd started in 1983 with a total of 21 animals from 3 sources and now numbers an estimated 170 goats. Limited hunting was initiated in 1997 and 4 tags were authorized in 2001 with nearly 4,800 applicants for these permits. Sixteen goats were trapped in the Elkhorn Mountains in July, 2000 and moved to the Hat Point Plateau on the western rim of Hells Canyon.

Mountain goats are indigenous to Oregon but were extirpated during or prior to European settlement (ODFW 2001). Elliot (1901) references a mountain goat specimen from the early 1800's obtained from "mountains adjacent to Brant Island, Columbia River, Oregon." Grant (1905) discussed the taxonomy of mountain goats and reports: "The first specimens of the mountain goat to be described, came from the Cascade Mountains on the Columbia River in Oregon and of course now stand as the type of *Oreamnos montanus*, having been first described by Rafinesque in 1817". Other early reports by Richardson (1829), Townsend (1839), Suckley and Gibbs (1860), Grinnell and Fannin (1890), Hornaday (1906), and Miller (1924); coupled with recent archaeological findings reported by Randolph and Dahlstrom (1977), Leonhardy and Thompson (1991) demonstrate mountain goats were indigenous to northeast Oregon and the northern portion of the Oregon Cascades.

Mountain goats have been actively managed in Oregon following reintroduction efforts initiated in 1950. Although mountain goat numbers were low and static through the 1980's, populations have increased dramatically during the past decade and current status of Oregon populations are discussed in this paper.

SURVEY TECHNIQUES

From 1962 through 1982, goats were counted and classified annually from fixed-wing aircraft during mid to late summer. Summer ground surveys were occasionally incorporated with aerial surveys from 1983-1995. Since 1996 ground surveys have become the predominant method of surveying goats in the Wallowa and Elkhorn Mountains. Fixed-wing flights are currently used to compliment ground surveys and search for goats in habitats adjacent to core use areas. Though time consuming, ground surveys allow observation of a greater number of animals and provide more accurate classification information. Count and classification surveys are conduced from late July through September, and goats are generally classified as adults or kids. However, in the Wallowa Mountains yearling animals are classified when possible to provide information on annual recruitment.

POPULATION STATUS

Wallowa Mountains

The Wallowa mountain goat herd originated from 4 separate releases (Coggins et al, 1996). The population grew from the original transplant of 5 animals in 1950 to a minimum population of 30 animals by 1966. The population declined following 4 years of hunting in the mid 1960's, and remained static with low kid recruitment through 1989. During this time period total count from annual surveys did not exceed 32 animals (Table 1). Additional transplants in 1985, 1986, and 1989 totaled 33 animals (Coggins et al, 1996)). Late summer kid to adult ratios increased following the 1989 release and have remained moderately high with a mean of 39 kids/100 adults since 1990 (Table 1). Observations of nannies with twins have not been uncommon. The 2001 population estimate for the Wallowa Mountains was 200 goats. Mountain goats continue to pioneer habitats adjacent to traditional core use areas, establishing subpopulations in vacant areas of the Wallowa's.

Elkhorn Mountains

The Elkhorn Mountains encompass approximately 126 km², and lie west of Baker City, Oregon. Mountain goats were established from 3 releases during 1983-86 totaling 21 goats (Coggins et al, 1996). Late summer kid to adult ratios have been good since 1987 with a mean of 46 kids/100 adults for the 1987-2001 period (Table 2). This population has increased rapidly and continues to pioneer vacant habitat within the Elkhorn Mountains. The 2001 population estimate was 170 mountain goats. During July 2000, 16 goats were captured and relocated to a new site in Hells Canyon, Oregon.

Hells Canyon

In July 2000, 16 goats were transplanted from the Elkhorn Mountains to the Hat Point Plateau on the western rim of Hells Canyon. Monitoring of radio collared individuals and ground observations indicate most individuals remained near the release site. Kid production during 2001 was of concern since the transplant contained only yearling males. However, summer ground surveys during 2001 documented 6 new kids. Hells Canyon 2001 population estimate was 20 goats.

Dispersal

Small numbers of mountain goats have recently been observed in mountain ranges 30-110 km from the Wallowa and Elkhorn Mountains. Single goats have periodically been observed in the Wenaha-Tucannon area 110 km north of the Wallowa's. The Vinegar Hill and Strawberry Mountain ranges lie 30 km and 70 km, respectively, southwest of the Elkhorn Mountains. In each area 3-6 goats have been observed on a regular basis and are believed to be year round residents. This natural dispersal demonstrates the ability of mountain goats to pioneer available habitat in nearby ranges.

HUNTER HARVEST

Regulated hunting of mountain goats was initiated in the Wallowa Mountains in 1965 and continued annually through 1968. A total of 23 tags were issued and 20 animals, including 13 males and 7 females, were harvested. During that time period the goat population declined and hunting was stopped following the 1968

Table 1. Late summer count and classification information for Mountain Goats in the Wallowa Mountains, Oregon, USA, 1962-2001.

Year	Total Count	Adults	Kids	Kids/100 Adults[a]
1962	12	8	4	50
1963	--	--	--	--
1964	26	18	8	44
1965	--	--	--	--
1966	29	18	11	61
1967	21	17	4	24
1968	12	9	2	22
1969	10	8	2	25
1970	17	12	5	42
1971	22	17	5	29
1972	18	17	1	6
1973	18	16	2	13
1974	15	13	2	15
1975	20	17	3	18
1976	19	17	2	12
1977	17	11	5	45
1978	22	18	4	22
1979	24	20	4	20
1980	32	23	8	33
1981	19	14	5	36
1982	15	13	2	15
1983	12	11	1	9
1984	10	8	2	25
1985	17	12	2	17
1986	--	--	--	--
1987	26	20	6	14
1988	8	8	0	0
1989	7	8	1	13
1990	31	23	8	35
1991	28	21	7	33
1992	25	19	6	32
1993	37	28	9	32
1994	51	38 (b)	13	34
1995	68	51 (c)	17	33
1996	73	47 (a)	26	55
1997	106	75 (d)	27	36
1998	101	66 (e)	26	39
1999	126	88 (f)	38	43
2000	163	113 (g)	50	44
2001	162	119 (h)	43	36

[a]Yearlings are included in adult ratio.

Table 2. Late summer count and classification information for Mountain Goats in the Elkhorn Mountains, Oregon, USA, 1992-2001.

Year	Total Count	Adults	Kids	Kids/100 Adults[a]
1992	31	21	10	48
1993	25	15	10	67
1994	47	28	19	68
1995	26	20	6	30
1996	75	50	25	50
1997	88	68	20	29
1998	97	64	33	52
1999	113	84	29	35
2000	92	64	28	44
2001	156	102	54	53

[a]Yearlings are included in adult ratio.

Table 3. Hunter harvest of mountain goats taken in Oregon, USA, 1965-2001.

			Harvest	
Hunt Year	Area	Tags Issued	Male	Female
1965	Hurricane Divide	5	4	1
1966	Hurricane Divide	5	3	2
1967	Hurricane Divide	5	3	2
1968	Hurricane Divide	8	3	2
1997	Hurricane Divide	1	1	0
1997	Elkhorn Mts.	1	1	0
1998	Hurricane Divide	1	1	0
1998	Elkhorn Mts.	2	2	0
1999	Hurricane Divide	1	0	1
1999	Elkhorn Mts.	2	2	0
2000	Hurricane Divide	1	1	0
2000	Elkhorn Mts.	2	2	0
2001	Hurricane Divide	2	2	0
2001	Elkhorn Mts.	2	2	0
	Total	38	27	8

season. From 1969 to 1996 no legal harvest of mountain goats occurred in Oregon. In 1997 the goat season reopened in the Wallowa and Elkhorn Mountains with one goat tag issued in each area. Annual hunting seasons continue with 2 tags issued in each area during 2001, and 4800 persons applying for these tags. As of October 2001, 35 goats have been legally harvested in Oregon (Table 3).

Oregon law currently allows an individual to hold only one mountain goat tag in a lifetime, and tags are not available to nonresidents. In 2001 the cost of a resident hunting license was $17.50 and $91.50 for a goat tag. All tags are issued through a public drawing. The bag limit is currently one mountain goat, and hunters are required to attend a mandatory pre-hunt orientation class, to encourage the harvest of male goats. All hunters are required to check out through the local ODFW field office within 72 hours of completing their hunt. Currently the goat season occurs during mid September and runs a length of 12 days.

At this time goat hunting opportunities in Oregon are very limited. Tag quotas are applied to small goat hunting areas to ensure an even distribution of harvest and avoid overharvest in areas of easy access. Harvest is focused on adult males to protect adult females. Hunter orientation classes are mandatory to help tag holders distinguish between male and female goats. Oregon's interim mountain goat management plan describes the following criteria to determine hunt areas and tag numbers:

1. The herd must have 5 continuous years of population survey data prior to initiation of harvest.
2. The population within a hunt area must be equal to or greater than 50 animals, and comprise a minimum of 15% males.
3. If the number of observed goats from annual surveys drops below 50 animals for 3 consecutive years no tags will be issued for that hunt area. If annual surveys indicate the number of males is below 15% of the hunt area population, tag numbers shall be reduced.
4. No greater than 5% of a population will be available for annual harvest, and no greater than half of that harvest should comprise adult females. If more than 50% of the annual harvest is made up of adult females then the following years tag quota shall be reduced.

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NUTRITION

Vic Coggins - Moderator

Bighorn Sheep Lamb Survival, Trace Minerals, Rainfall, And Air Pollution: Are There Any Connections?

PATRICK A. HNILICKA, Wyoming Game & Fish Dept., 260 Buena Vista, Lander WY 82520 USA.[1]
JOHN MIONCZYNSKI, Wildlife Consultant, 70 Three Forks Road, Atlantic City, WY 82520 USA.
BRUCE J. MINCHER, Idaho National Engineering and Environmental Lab, P.O. Box 1625, Idaho Falls, ID 83415-7111 USA.
JACK STATES, Mycologist Consultant, 2 Canyon Shadows Road, Lander, WY 82520 USA.
MARK HINSCHBERGER, USDA Forest Service, Shoshone National Forest, P.O. Box 186, Dubois, WY USA.
SUE OBERLIE, Bureau of Land Management, P.O. Box 589, Lander WY USA.
COLE THOMPSON, Wyoming Game & Fish Dept., P.O. Box 596, Dubois, WY USA.
BOB YATES, Wyoming Game & Fish Dept., 260 Buena Vista, Lander WY 82520 USA.
D. DUANE SIEMER, Idaho National Engineering and Environmental Lab, P.O. Box 1625, Idaho Falls, ID 83415-7111 USA

[1]US Fish and Wildlife Service, 170 N. First St, Lander, WY 82520, pat_hnilicka@fws.gov

Abstract: A pneumonia outbreak during the winter of 1990/91 caused a 30% decline in the Whiskey Mountain Bighorn Sheep Herd near Dubois, Wyoming, USA. In subsequent years, lamb ratios on winter range were depressed well below the long-term pre-dieoff average of 37. Between 1997 and 2001, 56 ewes were marked and tested using Pregnancy Specific Protein (92% pregnant). During the summer of 1998, several key observations included: most lambs were sickly and exhibited rough coats, swollen eyes, coughing, congestion, nasal secretions, high respiration rates, slow growth, slumped shoulders and stiff-legged gaits. These were identical to symptoms of Nutritional Muscular Dystrophy known to occur in domestic lambs consuming a diet with < 20 ppb selenium on a dry matter basis. When these symptoms were displayed, selenium content of summer forage was 5 ppb dry matter. Selenium, a component of selenoproteins, is vital to healthy immune function, disease resistance, growth and milk production. Eighteen of 19 marked ewes were observed moving back and forth bimonthly between high elevation summer and fall range to lower elevation winter range in order to eat soil at natural mineral licks. Winter range forage was much higher in selenium because soils were derived from sedimentary rock. These findings suggested a selenium deficiency was occurring. Between 1998 - 2000, mortality rate for sick lambs was 4.7 X higher than healthy lambs (Chi-square = 8.35, $P = 0.004$). Lambs that survived suckled 50% longer per suckling event and had mothers with more "full" udders based on subjective observations. Beginning in 1999, mineral blocks containing 17 ppm selenium were placed on all seasonal ranges. This was increased to 60 ppm in 2000. Sheep readily found and consumed blocks. Sheep that had access to blocks during the summer and fall (i.e., Middle Mountain) ceased summer movements to lower elevation winter range and natural mineral licks, displayed dramatic improvement in lamb health and survival, and had ewes that shed earlier and lambs that weaned later. In contrast, sheep that did not have access to blocks during the summer and fall (Arrow Mountain) continued summer movements to lower elevation winter range and had lower lamb ratios ($P = 0.003$). Pure salt blocks (NaCl) on Arrow Mountain in 2001 stopped sheep movements to lower winter range. However, lamb survival was 67% lower than Middle Mountain. Between 1998 and 2001, lamb ratios correlated well with summer forage selenium ($r = 0.84$) on Middle Mountain. The lowest years of lamb ratios tended to occur in the wettest years. This suggested a possible connection between forage selenium and rainfall. We investigated possible factors effecting plant uptake of selenium including changes in soil pH from rainfall-derived nitrate and sulfate deposition, changes in soil redox potentials from differing levels of soil moisture and changes in microbial cycling of selenium from increased rainfall-derived nitrate deposition. We suspect that in granitic soils, wetter summers produce conditions unfavorable for selenium uptake by forage plants due to lowered soil redox potential thus converting selenite and selenate into chemical species (e.g., elemental selenium) unavailable for plant uptake. We also suspect that artificially enhanced nitrate deposition stimulates microbial decomposition processes including microbial transformation of selenite and selenate to unavailable forms of gaseous and elemental selenium. Ultimately, we suspect that wetter conditions result in less selenium uptake by bighorn sheep from forage growing on granitic summer range, thus lowering lamb health and survival.

Key words: Bighorn sheep, selenium, lamb survival, Whiskey Mountain, nitrates, nutritional muscular dystrophy.

The northern Wind River Mountains in Wyoming, USA support one of the larger herds of Rocky Mountain bighorn sheep (*Ovis canadensis*) in the world, numbering about 1,600 animals in the early 1990's. A primary wintering area is the Whiskey Mountain Wildlife Habitat Management Unit located near the town of Dubois. Due to a combination of land ownership, the unit and accompanying bighorn sheep are managed cooperatively by an interagency technical committee composed of US Bureau of Land Management, US Shoshone National Forest and Wyoming Game and Fish Department biologists. This herd is popular because wintering sheep are readily observable to the general public. The National Bighorn Sheep Interpretive Center is located in nearby Dubois, further attesting to the herd's attractiveness. In addition to its aesthetic value, the herd is an important game population and has served as a significant source of transplanted sheep (N ~ 1,900) for locations in Arizona, Idaho, Nevada, South Dakota, Utah and Wyoming.

During the winter of 1990/91, about 30% of the herd died in an apparent pneumonia outbreak (Ryder *et al.* 1992). Recruitment remained relatively poor in subsequent years based on an average winter ratio of 21 lambs:100 ewes since the dieoff. This was well below the long-term pre-dieoff average of 37 between 1958 - 1990. Consequently, the population has declined and is currently estimated at around 800 sheep. Beginning in 1997, we began to investigate the causes of low lamb ratios.

Trace minerals are chemical elements needed by higher animals in "trace" amounts, i.e. in the range of parts per million, billion or even less (Berger 1993). For many years, extensive research by agricultural scientists of trace mineral requirements has been conducted to enhance health and production of domestic animals (National Research Council 1983). Only in the last few decades has the importance of trace minerals to wildlife been investigated. Selenium is of particular interest, and plays an essential physiological role in higher animals, with deficiency maladies reported in domestic cattle, sheep and hogs (Underwood and Suttle 2000). Nutritional Muscular Dystrophy (NMD), also known as White Muscle Disease, is a degenerative disease of striated muscles associated with selenium deficiency known to occur in domestic lambs on selenium deficient forage at < 8 weeks of age (National Research Council 1985).

It was hypothesized that episodic selenium deficiency limits recruitment in this bighorn sheep population and is affected by soil properties, rainfall amounts and possibly nitrate deposition from anthropogenic (man caused) sources. The goals of this research were to document factors affecting recruitment, including pregnancy rates and lamb mortality, evaluate the effect of supplemental selenium on recruitment and to understand the environmental chemistry of selenium in the alpine environment.

STUDY AREA

The main study area was situated on summer range near the summit of Middle Mountain (3,350 m, 11,000 ft) in the Fitzpatrick Wilderness Area of the Shoshone National Forest, Wind River Mountains, Wyoming (Fig. 1). Elevations range from 2,271 m (7,450 ft) along Torrey Valley to 3,713 m (12,180 ft) on Torrey Peak. Average annual precipitation ranges from 41cm (16 in) in the lower portions to 102 cm (40 in) in the higher elevations. Temperatures generally range from -20 to 0^0 C (-4 to 32^0 F) in winter to 5 to 30^0 C (40 to 86^0 F) in summer. Middle Mountain geology is characterized by glacial deposits and granite outcrops. Soil is shallow, often only a few centimeters deep. Summer range consists of widespread fell-fields, intersected by alpine meadows associated with snow fields and runoff. Fifty percent or more of the total ground cover is exposed pre-Cambrian granite outcrops, boulder fields and expansive fell-fields. Vegetation in the fell-fields is dominated by thickets of *Geum rossii* and a variety of alpine cushion plants (*Silene acaulis*, *Phlox* spp. and *Trifolium nanum*) as well as a variable mixture of grasses and sedges, often dominated by *Poa alpina* and *Carex* spp. Above 3,350 m (11,000 ft) elevation, much of Middle Mountain is transitional fell-field/alpine meadow composition. The alpine meadows consist predominantly of grasses (*Deschampsia caespitosam*) with variable sedge (*Carex* spp.) and forbs (*Polygonum bistortoides*). The fell-field sites are mesic, but took on the appearance of xeric sites during 2001, following 2 years of severe drought.

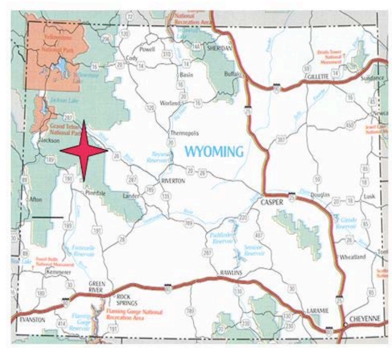

Fig. 1. Location of the Whiskey Mountain bighorn sheep herd.

Arrow Mountain (3,565 m, 11,693 ft) is separated from Middle Mountain by East Torrey Creek and served as a control area for experiments involving sheep treatment with mineral supplements. It is dominated by Gros Ventre-formation soil with pre-Cambrian granite. Summer range vegetation consists of approximately 80% alpine meadow and 20% fell-fields. The meadows are dominated by *Carex* spp., *Poa secunda, Calamagrostis purpurascens and Aster* spp.

METHODS

Bighorn sheep were captured on winter range during March 1998 – 2001 using immobilizing drugs administered from a

Dan-Inject pneumatic rifle (Wildlife Pharmaceuticals Inc., Fort Collins, CO). Sheep were approached by pickup with capture personnel situated in the bed. Hay was distributed from the bed while the truck was slowly backed away. Sheep generally approached the hay within a 10 minute period. Ewes that presented a clear target were randomly selected from the group. Sheep were darted using a 2 cc "cocktail" generally comprised of the following drug mixture: 3 mg carfentanil, 80 mg ketamine and 20 mg xylazine. Darted ewes became immobile within 5 minutes. Ewes were marked using combinations of neckbands, traditional radio-collars and/or GPS-collars. Blood and fecal samples were collected. Blood samples were tested for pregnancy specific protein (Bio Tracking, Moscow, Idaho), copper, iron, manganese, selenium, zinc, Vitamin A, Vitamin E and other constituents (Wyoming State Veterinary Lab, Laramie, Wyoming). Sheep were antagonized using a cocktail containing 200 mg naltrexone and 20 mg yohimbine.

Fecal samples were collected from captured ewes, cooled as quickly as possible and analyzed for lungworm (*Protostrongylus* spp.) and nitrogen levels. In addition, an observer collected fresh samples (< 10 minutes old) opportunistically throughout the summer and fall from both ewes and lambs. Two to ten pellets from each sheep were analyzed for lungworm using a modified Baermann technique (Samuel and Gray 1982) (Wyoming State Veterinary Lab). A second sample of 5 - 10 pellets was collected concurrently and analyzed for fecal nitrogen. Samples were air dried at room temperature for a minimum of 2 weeks, ground using a mortal and pestle and analyzed by the Analytical Services Lab, Wyoming Department of Agriculture in Laramie, using the Kjeldahl method (Horwitz 2000).

Forage samples consisted of a "bread bag" sized collection of forage from spring, lambing, summer, fall and winter ranges. For lambing, summer and fall ranges, samples mimicked the diet composition and proportion of plants and plant parts used by sheep based on close observations (< 15m, 50 ft). Samples from spring and winter ranges were collected randomly along historic production/utilization transects. Samples were oven dried and analyzed for total digestible nutrients, acid detergent fiber, nitrogen, 14 trace and macro minerals, and Vitamin A by the Analytical Services Lab, Wyoming Department of Agriculture in Laramie. Forage was also analyzed for selenium content. Values for 1998 - 2000 were measured at the University of Wyoming, Veterinary Science Laboratory using hydride generation atomic emission spectroscopy. For 2001, forage selenium measurements were made by Olson Biochemistry Laboratory (Brookings, SD) by derivitization and flourimetry. In both cases, samples were first prepared by oxidative digestion. Both laboratories have NIST-traceable quality control programs.

Soil oxidation-reduction potential was recorded versus time using an Ag/AgCl electrode immersed to a depth of 3 cm (1.2 in) in the soil, saturated with 0.005 Molar NaCl solution and exposed to room air at the surface. After 1 month, analysis of available selenium was obtained from a subsample of this soil collected from the probe depth in a nitrogen-filled glovebox to prevent any re-oxidation of reduced selenium.

Groups of ewes with lambs were followed daily or as frequently as possible between late May and late October in order to monitor visual signs of disease in ewes and lambs and record the number and length of suckling attempts by lambs. Suckling times were used as an indication of milk production in the mother (Horejsi 1972, Shackleton 1972, Thorne *et al.* 1979, Hass 1990, Hogg *et al.* 1992), with greater lengths of suckling inferring greater amounts of available milk. Lambs that displayed symptoms of disease (e.g. persistent coughing, eye swelling and infections, stiff legged gaits, general weakness, etc.) were considered "sick" in the analysis of lamb health versus survival. Survival of a lamb from a marked ewe was defined as a lamb that was observed alive at the end of October at which time observer monitoring ceased and is termed "Lambs That Survived." Mortality of a lamb from a marked ewe was defined as a lamb that disappeared prior to the end of October and is termed "Lambs That Died."

The Palmer Modified Drought Severity Index (PMDSI) (Heddinghause and Sabol 1991) was acquired from the National Climatic Data Center web site and represents the Wind River Basin, within which the study occurred. These data were acquired from the website www.ncdc.noaa.gov/oa/climate/onlineprod/drought/xmgr.html. PMDSI is calculated monthly and indicates the severity of a wet or dry spell. A range of 0 to -1 is normal, -1 to -2 is mild drought, -2 to –3 is moderate drought, -3 to –4 is severe drought, and anything below –4 is extreme drought. Conversely, positive numbers indicate wet spells with corresponding adjectives (i.e., +4 is extreme wetness). Satellite imagery was acquired from the Cooperative Institute for Research in the Atmosphere (http://goes-10-gems.cira.colostate.edu/). GOES-10 satellite images taken every 2 hours were copied into PowerPoint® and animated to show a summer's worth of weather patterns in several minutes. General air flow could then be readily assessed.

During summer of 2001, 9 plots measuring 51 cm X 51 cm (20 in X 20 in) were established on a 0.02 ha (0.05 ac) area on Middle Mountain to test the effects of various chemical additions and watering regimes on the uptake of selenium by alpine plants. Plots were selected to contain, as nearly as possible, equal composition and density of vegetation while avoiding high percentages of non-forage species. Two plots were covered with a rainshield constructed of 123 cm X 123 cm (48 in X 48 in) greenhouse fiberglass and mounted on an aluminum frame. The rainshield was raised above the ground 25 cm (10 in) at the back edge and 41 cm (16 in) on the front edge to allow for air flow. Select plots were watered every 4^{th} day (Table 1). All forage was clipped in the entire plot at setup on June 18 and again following 30 days of manipulations on July 17. The percentage change in forage selenium was then calculated and compared between plots. The nitrate plot and sulfate plot had 0.3 ml of 1 Molar solutions of nitric and sulfuric acid, respectively, added to each liter of water to produce nitrate and sulfate ions. The additions were designed to simulate a pH of 3 – 4. A pH of 4 was the lowest rainfall pH recorded during the summer of 2000.

Individual rain events were collected in a US Weather Bureau All-Weather Rain Gauge and analyzed within 1 day on-site using a Hach® spectrophotometer. To ensure accuracy, standardized solutions of known nitrate concentrations were periodically tested prior to analyzing rainwater samples. A Hubbard-Brooke collector (Galbraith *et al.* 1991) (Fig. 2) captured rainfall over 2-week intervals. Samples were analyzed within 3 days off-site by the US Forest Service's Biogeochemistry Lab in Ft. Collins, Colorado, as well as on-site to allow

Table 1. Selenium forage test plots, Middle Mountain, Wyoming, 2001.

Plot Name	Type of water added	Additional Chemicals	Forage Selenium (ppb) for 1st Clipping (6/18/01) on Dry Matter basis	Forage Selenium (ppb) for 2nd Clipping (7/17/01) on Dry Matter basis	% Change Between 1st and 2nd Clippings	Total Water cm/month	Total NO3 in ka/ha/month	Total Water as compared to a "Normal" June rainfall	Total Water as compared to a "High" June rainfall	Total NO3 as compared to a "Normal" June rainfall	Total NO3 as compared to a "High" June rainfall
# 6 Covered Distilled Double Watering	distilled (0.34 mg/l NO3)	none	20.8	33.0	59%	16.43	0.56	153%	61%	19%	8%
# 3 Uncovered Sulfuric Acid	rain/snow	0.8 ml sulfuric acid	29.1	40.8	40%	12.09	1.07	113%	45%	37%	15%
# 4 Uncovered Sodium Bicarb	rain/snow	1.07 g Na bicarb	34.1	45.7	34%	12.09	1.07	113%	45%	37%	15%
# 1 Uncovered Control	rain/snow	none	34.9	44.9	29%	12.09	1.07	113%	45%	37%	15%
# 5 Uncovered Rain/Snow Double Watering	rain/snow	none	38.8	41.0	6%	20.31	1.26	189%	75%	44%	17%
# 8 Covered Distilled Matching Rainfall	distilled (0.34 mg/l NO3)	none	36.7	31.1	-15%	3.88	0.13	36%	14%	5%	2%
# 7 Uncovered Rainfall	none	none	40.6	33.9	-17%	3.88	0.88	36%	14%	31%	12%
# 2 Uncovered Nitric Acid[a]	rain/snow	0.8 ml nitric acid	48.1	39.1	-19%	12.09	18.38	113%	45%	638%	252%
# 9 Saturated by Streamside	none	none	84.1	27.7	-67%	saturated	0.88	saturated	saturated	30%	12%

[a] Since no high elevation analysis of nitrate concentrations in rainwater had been done near the study area previously, we were uncertain as to what levels of nitrate we should add to our plots. Hence, several plots had nitrate levels lower than what fell during the summer of testing and 1 plot that was much higher.

comparisons of methods. The Lab followed protocol established by the National Atmospheric Deposition Program (NADP). Because these collection devices were continuously exposed to the atmosphere, both wet and dry depositions were collected. Due to the remoteness of Middle Mountain, monthly precipitation data had never been collected previously. Therefore, estimates of "normal" and "high" June precipitation were extrapolated from rainfall data acquired at the Gypsum Creek NADP site located upwind and 32 km (20 mi) southwest of Middle Mountain and precipitation isopleths as detailed in Gibson (1990).

Fig. 2. Hubbard-Brooke rain collector, Middle Mountain, Wyoming, 2001.

A 5 cm X 2 cm (2.0 in X 0.8 in) soil core was extracted from each forage plot using a metal core borer and returned to the lab for analysis. Samples were diluted and spread on agar petri dishes. Bacterial colonies were counted after 72 hours of incubation at room temperature. Samples were amended with potassium nitrate (as 0.25%) and selenate to test for effects on bacterial colonies.

Soil samples were collected just below the detritus layer, at a depth of 7 - 15 cm (2.8 - 5.9 in). The principal sample site (MM#1) on Middle Mountain summer range was a relatively level, damp depression, with alpine meadow vegetation where sheep had previously been observed foraging. A nearby fell-field (MM#2) was also sampled. Soil sampling increased with time as it became apparent that there was a possible link between forage selenium and lamb recruitment. Arrow Mountain (AM) and Goat Flat (GF) summer range was also sampled. Natural licks used by bighorns were sampled at Torrey Valley (TV) and Beck's Bridge (BB#1 and BB#2) at 2,270 m (7,445 ft). Samples were spread and air dried in an aluminum tray then sieved to 50 mesh. Total selenium was measured by hydride-generation atomic absorption spectrophotometry (AA). Samples were oxidatively digested by boiling 1 g in concentrated nitric acid to near dryness, followed by the addition of hydrogen peroxide. This was heated to dryness and the NO_x-free ash was redissolved in hot concentrated hydrochloric acid then diluted to 4 – 6 Molar for AA. The absolute detection limit was approximately 2 ppb (parts per billion), with repetitive analyses resulting in a relative standard deviation of 15%. The addition of ferric iron and/or nitrate did not suppress the generation of H_2Se and are not regarded as interferences. Samples were also analyzed for pH using a standard combination electrode after 45 minutes of stirring at a ratio of 6 g of sample to 35 ml demineralized water.

Available selenium was defined as the sum of freely soluble and readily exchangeable selenium. Soluble selenium (probably selenate) was extracted from 1 g samples using 10 ml of a non-complexing salt solution (0.01 Molar $CaCl_2$). Exchangeable (probably surface-bound selenite) selenium was next determined by extracting from the same 1 g sample with a pH 7, 0.25 Molar phosphate/0.20 Molar citrate buffer solution.

Two-tailed t-Tests for the equality of 2 population means for normal populations with unequal variance were used to analyze fecal lungworm, fecal nitrogen levels, length of lamb suckling events, lamb ratios and PMDSI values. A Paired t-Test was employed to compare lamb ratios between Arrow Mountain and Middle Mountain over time and nitrate concentrations in rainfall on Middle Mountain and at the Gypsum Creek NADP site. Pearson Correlation was used to correlate forage selenium with lamb ratios. A 2 X 2 contingency table with Yates' Corrected Chi-square was used to compare lamb health to lamb survival. Statistix7 software provided all results.

RESULTS

Ewes were marked on winter range during March 1997 – 1998, and March and May 2001 using neckbands (N = 34), neckbands with radio-collars (N = 22) and neckbands with GPS-collars (N = 3). Whole blood selenium levels of ewes captured in late March (N = 40) and early May (N = 3) were 0.13 ppm (parts per million) (SD = 0.025) and not deficient when compared to domestic sheep (Underwood and Suttle 2000) or other bighorns (Puls 1994). Iron and zinc were ~30% below recommended levels. There were no significant differences in any blood constituents between ewes with Lambs That Survived and ewes with Lambs That Died. Pregnancy Specific Protein testing showed that 92% of 62 ewes tested were pregnant during March 1997 – 1998, and March and May 2001. Some ewes were tested in multiple years. Observations on lambing range revealed that lamb drop occurred normally.

In mid-July, 1998, the majority of lambs ($N \geq 30$) observed on Middle Mountain became ill and displayed the following symptoms: unthrifty coats, swollen eyes, coughing, nasal secretions, high respiratory rates, slumped shoulders and a stiff-legged gait (Fig. 3). They also exhibited general weakness and poor growth, diarrhea and secondary infections. Abnormalities observed in ewes included small udder size, poor milk production, early weaning of lambs in August, late shedding of winter coats and periodontal abnormalities (observed in 10 ewe skulls found on winter range during winter of 1998/99). Complete recovery of the sickest, most debilitated lambs followed movements to natural mineral licks. All of these symptoms have been displayed by domestic sheep and goats that were severely deficient in dietary selenium and developed NMD (National Research Council 1985, Smith 1994, Underwood and Suttle 2000). Selenium content of summer forage was 5 ppb dry matter (Table 2). Domestic sheep consuming forage with < 20 ppb selenium dry matter typically develop NMD (National Research Council 1985, Underwood and Suttle 2000).

More specifically, sick lambs appeared hyperactive with associated muscular weakness, uncoordination and/or apparent "sag" of the triceps brachii muscle from the normal 35 - 45º to < 0º with respect to a horizontal plane. In very severe cases this was associated with a marked protuberance of the cleidobrachial muscle from the point of the shoulder down into the muscle mass where it joins the radius, on both right and left forelegs equally. Lambs displayed severely stiff muscle movement in the shoulder and hind quarters that created an unstable wobbly appearance when walking or standing.

Table 2. Analysis of bighorn sheep forage from the Whiskey Mountain area near Dubois, Wyoming, on a dry matter basis during 1998 - 2001. Foraging sheep were observed closely to determine composition and proportion of plants in the diet. Samples were then collected to reflect diet composition and proportion. Additional random samples were collected for selenium analysis. Samples are compared to the National Research Council's (1985) recommendation for maximum production in domestic sheep.

	Domestic Lamb NRC[a] Requirement	Lambing Range (June: Lake Louise, Middle Mtn)				Summer Range (June, July & August: Middle Mtn, Arrow Mtn, Goat Flat, Torrey Peak)				Fall Range (September & October: Whiskey Mtn, Osborn Mtn, Fremont Glacier, Middle Mtn)				Winter Range (March, May, September, October, November & December: Torrey Rim, Sheep Ridge, BLM Ridge, Trail Lake Meadow)			
		N	Mean	SD	Range	N	Mean	SD	Range	N	Mean	SD	Range	N	Mean	SD	Range
ADF[a] %		4	32.5	1.24	31.1 - 34.4	13	32.9	6.22	23.7 - 42.6	6	35.5	2.09	33.1 - 38.0	12	46.4	4.38	38.8 – 53.3
Calcium %	0.82	4	0.52	0.075	0.42 - 0.60	13	0.62	0.170	0.41 - 1.00	6	1.01	0.173	0.70 - 1.20	10	0.37	0.085	0.28 – 0.54
Carotene ppm[a]		4	165	20.8	140 - 190	13	175	52.4	110 - 270	6	90	23.2	55 - 113	10	23	18.9	0 - 61
Copper ppm	Mo < 1, then Cu 7-8; Mo > 3 , then Cu 17-21	4	18	7.6	12 - 28	13	16	6.0	8 - 29	6	12	2.7	8 - 15	10	16	6.7	8 – 29
Iron ppm	30 – 50	4	157	30.3	121 - 190	13	181	182.0	98 - 780	6	237	67.4	180 - 370	10	185	118.1	88 – 510
Magnesium %	0.12	4	0.15	0.033	0.11 - 0.19	13	0.18	0.049	0.13 - 0.29	6	0.18	0.033	0.14 - 0.23	8	0.09	0.008	0.08 – 0.10
Manganese ppm	20 - 40	4	92	21.4	70 - 121	13	140	80.1	35 - 360	6	71	23.4	41 - 110	10	40	18.0	20 – 78
Molybdenum ppm	> 0.50	4	1.5	0.50	0.9 - 2.1	13	0.9	0.52	0.3 - 2.3	6	1.0	0.52	0.6 - 1.9	10	1.2	0.21	0.9 – 1.6
Phosphorus %	0.38	4	0.33	0.057	0.26 - 0.40	13	0.19	0.035	0.12 - 0.24	6	0.10	0.017	0.08 - 0.13	10	0.13	0.076	0.06 - 0.30
Potassium %	0.5	4	2.0	0.31	1.7 - 2.4	13	1.7	0.21	1.3 - 2.0	6	0.91	0.131	0.72 - 1.10	10	0.81	0.577	0.20 – 2.20
Protein %	12.8	4	17.1	1.22	15.9 - 18.1	15	16.6	3.97	10.7 - 23.6	6	8.0	1.23	6.1 - 9.3	12	6.3	3.61	2.8 – 14.0
Selenium ppb[ab]	100 – 200	3	51[a]	41.4	25 - 99	49	42[a]	21.4	5 – 128	15	52[a]	29.0	19 – 109	14	150[b]	121.0	63 – 479
Sodium %	0.3600 – 0.4700	1	0.0049			1	0.0019			1	0.0008						
Sulfur %	0.140 – 0.180	1	0.145			1	0.113			1	0.098						
TDN[a] %	65.0	4	63.1	0.88	62.0 - 64.0	13	63.0	4.91	55.2 - 70.0	6	61.0	1.70	59.0 - 63.0	12	52.2	3.38	47.0 – 58.0
Vit A IU/kg[a]	2,380	4	66,000-116,100		57,200 - 134,600	13	69,100 - 121,100		44,700 - 185,000	6	35,900 - 63,300		21,700 - 79,600	10	32,600	33,100	0 – 100,300
Zinc ppm	33	4	39	2.6	36 - 41	13	41	10.7	22 - 58	6	19	5.1	12 - 25	9	20	5.0	12 - 27

[a] NRC = National Research Council's (1985) national standards of recommended requirements for domestic sheep. ADF = Acid detergent fiber is the most indigestible portion of fiber and is comprised primarily of cellulose. Ppm = Parts per million. One ppm is equivalent to 0.0001%. Ppb = Parts per billion. One ppb is equivalent to 0.0000001%. TDN = Total digestible nutrients is the most digestible portion of the sample. IU = International Units. Results for Vit A are a range. No SD given.

[b] Significant differences between means were tested only for selenium using 2-tailed t-Test with unequal variances. Means with a different letter are significantly different at $P<0.05$.

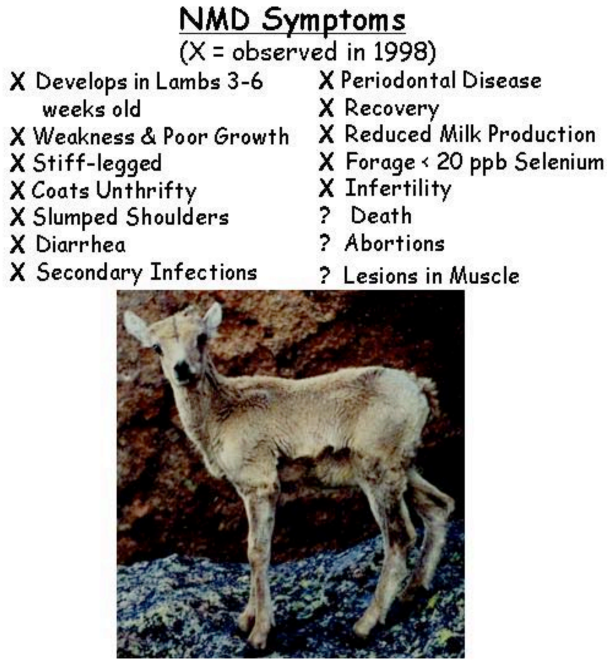

Fig. 3. Sick lamb and NMD symptoms, Middle Mountain, 1998.

The above symptoms were strikingly sudden and ubiquitous in lambs. Some lambs subsequently developed bacterial infections such as apparent pneumonia and eye infections. Though lambs displayed sickness (primarily coughing) in subsequent years (1999 - 2001), 1998 was the only year in which lambs displayed the symptoms described above.

During 1998, 18 of 19 marked ewes were observed between June 15 and September 30 moving back and forth between high elevation summer and fall range to lower elevation winter range in order to eat soil at natural mineral licks located on Torrey Valley winter range (Fig. 4). Typically, several marked ewes and their lambs were accompanied by 10 - 20 other unmarked ewes and lambs. Licks were visited nearly continuously throughout the summer, suggesting that the entire Torrey Rim contingent of wintering sheep (N = 150 - 180 sheep) were utilizing the natural licks. Licks were located on soils originating from glacial sediments higher in available selenium for plant uptake. The 13 km (8 mi) one-way-trip involved a 792 m (2,600 ft) drop, then a 701 m (2,300 ft) climb and finally a 900 m (2,955 ft) drop in elevation and was done on a bimonthly basis. At 2 locations along the route, observations of mountain lions (*Felis concolor*), lion sign and sheep remains in lion scat were noted. On several occasions (N < 5), ewes displayed "lost-lamb behavior" (i.e., regular bleating associated with extreme nervousness and agitation), at both of these locations (Akenson and Akenson 1992). The ewes' lambs were not observed again indicating mortality. Though determination of exact cause of death was not possible, these observations indicated that lambs were susceptible to lion predation at these locations. The sickest lambs lagged behind increasing the likelihood of predation.

Fig. 4. Summer migration of bighorn sheep from Middle Mountain to natural mineral licks, Wyoming, 1998.

In response to this, we placed mineral blocks that contained 78% salt (NaCl), 2% magnesium, 0.4% potassium, 17 ppm selenium and 17 ppm cobalt on lambing, summer and fall range. Sheep readily found and consumed blocks. Sheep that had access to blocks during the summer and fall (i.e., Middle Mountain) ceased summer movements to lower elevation winter range and natural mineral licks entirely and displayed dramatic improvement in lamb health and survival. Also, ewes shed winter coats ~1 month earlier and weaned lambs ~1 month later. No evidence of mountain lion predation was observed. In contrast, sheep that did not have access to blocks during the summer and fall (i.e., Arrow Mountain) continued summer movements to natural licks on lower elevation winter range and had lower lamb survival. A paired t-Test showed lamb ratios at the end of October in 1999, 2000 and 2001 were significantly greater ($P = 0.003$) for sheep on Middle Mountain (Mean = 27, SD = 10.1) than Arrow Mountain (Mean = 16, SD = 10.0) (Table 3). No significant difference in forage selenium was found between mountains.

In 2000 and 2001, selenium and cobalt content of blocks was increased to 60 ppm. This was done to provide a multiple-day dose since sheep were visiting blocks only once every 10 to 14 days. Similar differences between groups of sheep with and those without blocks were observed both years. In addition, we placed pure salt blocks (NaCl) on Arrow Mountain in 2001 to help assess the effect of salt alone on migration and lamb survival. Sheep from Arrow Mountain discontinued movements to lower winter range and had a fall lamb ratio that was 67% lower than Middle Mountain.

Between 1998 and 2001, lamb:ewe ratios on Middle Mountain correlated well with summer forage selenium concentration ($r = 0.84$). When data were considered for years 1998 - 2001 on both Middle Mountain and Arrow Mountain, this correlation decreased to $r = 0.64$. A loss of lambs during September 2001, most likely unrelated to forage selenium, confounded results. A wet summer in 1998 and low forage selenium was in sharp contrast to dry summers in 1999, 2000 and 2001 and higher forage selenium (Table 3). The 1998 forage selenium level of 5 ppb falls well below the 99.9% lower confidence interval of 31 ppb for the combined years of 1999 - 2001 on Middle Mountain. This suggested a possible connection between forage selenium and rainfall.

PMDSI was analyzed for 42 of 44 years between 1958 - 2001 and compared to lamb ratios. Two years of lamb ratios were not available. Generally, poor lamb ratios were associated with wetter years (Fig. 5), although not correlated well ($r = -0.43$) year-to-year. In a different approach, the 42 years were sorted by PMDSI into the lower (drier) and the higher (wetter) half. The PMDSI for the years with the lowest values was significantly lower (Mean = -3.48, SD = 1.49, $P = 0.000$) than the higher half (Mean = +1.30, SD = 1.84). The corresponding lamb ratios were significantly higher ($P = 0.005$) in the drier half (Mean = 39, SD = 12.7) than the wetter half (Mean = 28, SD = 12.1). This process was repeated with the lowest 10 (Mean = -4.67, SD = 0.67, $P = 0.000$) and highest 10 years (Mean = +2.95, SD = 1.37) of PMDSI. Comparison of corresponding lamb ratios showed even greater separation with 37 lambs:100 ewes for the driest 10 years (SD = 13.2) and 23 lambs:100 ewes for the wettest 10 years (SD = 12.6, $P = 0.021$).

Of 41 lambs monitored closely between June - October 1998 - 2000, 27 were Lambs That Survived and 14 were Lambs That Died. Of the Lambs That Survived, 20 were healthy and 7 were sick. Of the Lambs That Died, 3 were healthy and 11 were sick. For

Table 3. Lambs:100 bighorn ewes at the end of October, summer forage selenium in parts per billion, presence/absence of supplemental mineral blocks, and soil conditions on Middle Mountain (MM) and Arrow Mountain (AM), Wyoming, 1998 - 2001.

	1998	1999	2000	2001[a]
MM lambs:100 ewe	12	38	26	18
MM forage Se (ppb)	5 (N = 1)	58 (N = 2, SD = 18)	34 (N = 10, SD = 13)	43 (N = 22, SD = 16)
Blocks present	No	Yes (17 ppm Se)	Yes (60 ppm Se)	Yes (60 ppm Se)
AM lambs:100 ewe	No data	26	16	6
AM forage Se (ppb)	No data	58 (N = 2, SD = 17)	20 (N = 3, SD = 0)	38 (N = 10, SD = 17)
Blocks present	No	No	No	Yes (NaCl only, no Se)
Soil condition both sites	Very wet	Dry	Dry	Dry

[a] An additional, undetermined source of mortality affected lambs at both locations.

healthy lambs, 3 of 23 died (13%) while for sick lambs 11 of 18 died (61%). Therefore, the mortality rate was 4.7 X higher for

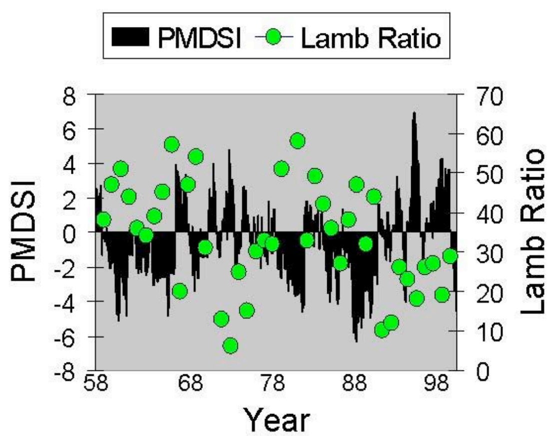

Fig. 5. Palmer Modified Drought Severity Index for the Wind River Basin, Wyoming, and lamb:ewe ratios from Whiskey Mountain, Wyoming 1958 - 2001.

sick lambs (Chi-square = 8.35, P = 0.004). Between June - August 1998 - 2000, lamb suckling averaged 17.0 seconds (N = 49, SD = 10.2) per attempt for Lambs That Survived versus 11.3 seconds (N = 29, SD = 11.2) for Lambs That Died (P = 0.030). Lambs That Survived generally had better overall suckling history and mothers with more "full" udders based on subjective observations. Fecal lungworm levels varied greatly between samples. However, there was no significant difference between the mothers of Lambs That Survived and Lambs That Died in 1998 (P = 0.214), 1999 (P = 0.358), 2000 (P = 0.531), or when all years were combined (P = 0.305) (Table 4). Fecal nitrogen levels also showed no significant difference between the mothers of Lambs That Survived and Lambs That Died in 1998 (P = 0.692), 1999 (P = 0.690) or when all years were combined (P = 0.887) (Table 5). The lambs' mothers were used to infer fecal lungworm and fecal nitrogen levels because data were insufficient for the lambs themselves.

Two lambs that died on summer range were necropsied within 36 hours of death. Ultimate cause of death was pneumonia. Selenium content in liver tissue was not

Table 4. Comparison of *Protostrongylus* spp. larvae per gram of feces in marked ewes with lambs that survived to late October and those whose lambs did not, 1998 – 2000. Samples were collected between March 15 - November 15 and were collected on Torrey Rim, Middle Mountain, Arrow Mountain, Goat Flat, and Whiskey Mountain, Wyoming, from sheep associated with the Torrey Rim wintering area.

Year	Status of lamb	Mean LPG	Std. Dev.	Range	No. of ewes	No. of samples	% of samples Infected (>0 LPG)	P[a]
1998	Survived	149	179	0 - 470	4	13	85	0.214
	Died	264	365	0 - 1,247	9	23	87	
1999	Survived	240	360	0 - 1,613	12	54	81	0.358
	Died	334	412	0 - 1,604	4	22	82	
2000	Survived	41	128	0 - 533	8	17	65	0.531
	Died	20	35	0 - 109	4	10	70	
All years	Survived	186	311	0 - 1,613	14	84	79	0.305
	Died	247	365	0 - 1,604	12	55	82	

[a] Means are compared using a 2-tailed t-Test with unequal variances.

deficient. These lambs died in 1999 and 2000 during which the mean summer forage selenium was 11 and 7 X higher, respectively, than 1998 when NMD was suspected. Mineral blocks supplemented with selenium were also available on summer range in 1999 and 2000.

Forage analysis for 17 parameters indicated that summer range forage was low in selenium and averaged 42 ppb (N = 49, SD = 21.4) between 1998 – 2001 (Table 2). This was not significantly different from lambing or fall range, but was significantly lower (P = 0.005) than the average winter range forage of 150 ppb (N = 14, SD = 121.0) where natural licks utilized by sheep were situated (Torrey Valley). In addition to selenium, phosphorus was low and sodium was very low on summer range when compared to domestic sheep recommendations. Iron, manganese and potassium were above recommended levels, but were below the maximum tolerable limit for domestic sheep (National Research Council 1985).

Selenium test plots that had nitrate depositions that were less than the "expected" deposition during June with "normal" rainfall showed increases in forage selenium (range of 6 - 59%). None of these plots had nitrate added artificially. In contrast, the plot with 638% of the "expected" nitrate deposition (and 252% of what would theoretically fall during a very wet June, as in 1998) showed a 19% decrease (Fig. 6). On this plot, nitrates were

Table 5. Comparison of percent fecal nitrogen in marked ewes with lambs that survived to late October and those whose lambs did not, 1998 – 2000. Samples reflect the primary lactating period from June 1 - August 31 and were collected on Torrey Rim, Middle Mountain, Arrow Mountain, Goat Flat, and Whiskey Mountain, Wyoming, from sheep associated with the Torrey Rim wintering area.

Year	Status of lamb	Mean Fecal Nitrogen	Std. Dev.	Range	No. of ewes	No. of samples	P[a]
1998	Survived	3.09	0.40	2.48 - 3.57	4	6	0.692
	Died	3.17	0.48	2.40 - 4.14	8	18	
1999	Survived	3.39	0.26	2.78 - 3.73	11	19	0.690
	Died	3.28	0.50	2.77 - 3.74	3	4	
2000	Survived	3.01	0.18	2.75 - 3.23	3	5	0.026
	Died	3.55	0.51	2.42 - 4.05	4	8	
All years	Survived	3.26	0.32	2.48 - 3.73	12	30	0.887
	Died	3.28	0.50	2.40 - 4.14	12	30	

[a] Means are compared using a 2-tailed t-Test with unequal variances.

added. The aforementioned plots had precipitation levels between 113 - 153% of a "normal" June (Table 1). Conversely, plots that received sulfate and sodium bicarbonate showed increases in forage selenium of 40% and 34%, respectively. These plots had identical levels of watering as the nitrate plot.

Precipitation and associated soil wetness were also varied on select selenium test plots (Fig. 7). The saturated plot showed a 67% decrease in forage selenium. Conversely, plots receiving 113 - 153% of normal precipitation showed increases of 29 - 59%. These plots had nitrate levels between 19 - 44% of a "normal" June.

Analysis of rainfall chemistry was done on 5 Hubbard-Brooke samples and 19 individual rainfall events from Middle Mountain. Monitoring period was June 18 to August 28, 2001. Results from the on-site Hach® spectrophotometer and off-site Biogeochemistry Lab agreed well. In addition, an independent study concurrently documenting rainfall chemistry corroborated our findings. This study site was located 48 km (30 mi) southwest of Middle Mountain

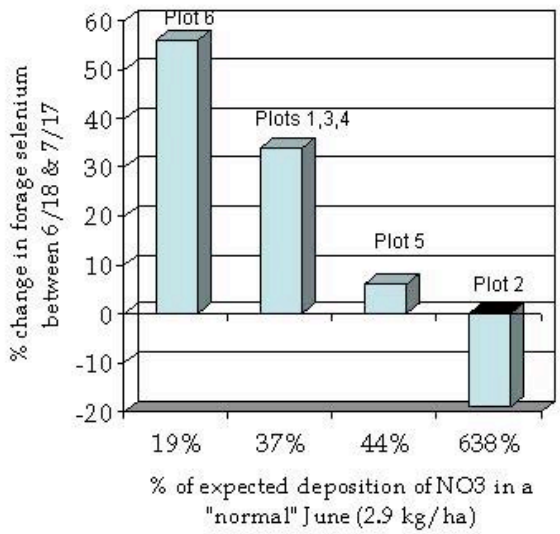

Fig. 6. Percent change in forage selenium as related to nitrate deposition on selected plots, Middle Mountain, Wyoming, 2001.

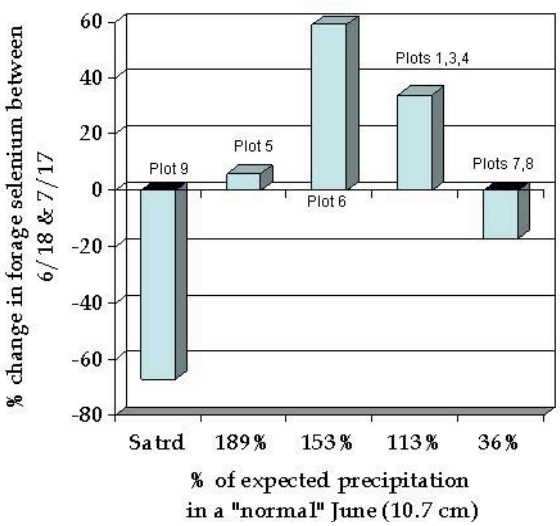

Fig. 7. Percent change in forage selenium as related to precipitation on selected plots, Middle Mountain, Wyoming, 2001.

at a similar elevation within the same mountain range and used the same protocol. Precipitation amounts from Middle Mountain and nitrate concentrations as determined by the Biogeochemistry Lab were compared to the Gypsum Creek NADP levels from June - August 1985 – 2001 (Table 6). Amount of precipitation, nitrate concentration and nitrate deposition were all higher on Middle Mountain when compared to Gypsum Creek in 2001 and the 1985 - 2001 long-term means. Paired t-Tests showed significant differences in deposition only ($P = 0.076$). Deposition is a function of nitrate concentration in rainwater and amount of precipitation. Our data suggested that deposition rates might be multiple times higher on Middle Mountain than at lower elevation sites because of higher nitrate concentrations and higher amounts of rainfall.

Preliminary tests of lab-cultured microbes from Middle Mountain soils indicated that addition of nitrate increased growth of actinomycetes, which accounted for 52% of the microbial population. Addition of selenate to the colonies resulted in volatilization to dimethyl selenide and a pinkish coloration of some colonies. Pinkish coloration was indicative of microbial conversion to elemental selenium (States 1966). Both would result in a net loss of selenium for plant uptake.

Summer range soil from Middle Mountain (MM#1) was black and contained 25.2% (SD = 10) by weight organic material and 2.8% by weight iron as Fe_2O_3 (Table 7). It was acidic, ranging in pH from 5.29 (MM#2) to 6.88 (GF). Values as low as 4.7 pH have been recorded from other locations in the Wind River Mountains (Clayton *et al.* 1991). In contrast, mineral lick soils were alkaline, ranging from a pH of 9.20 (TV) to 10.25 (BB#1). Total selenium content of the soils ranged from a low of 58 ppb (SD = 34) at the TV mineral lick to a high of 1,072 ppb (SD = 116) at BB#1 lick. This range of values brackets those of summer range with a low of 155 ppb (SD = 43) at MM#2 to a high of 640 ppb (SD = 51) at MM#1. A single value for soil from the control area at

Table 6. Comparison of nitrate concentration (ppm) and deposition (kg/ha) in rainfall between Middle Mountain, elevation 3,292 m (10,800 ft) and Gypsum Creek NADP site, elevation 2,439 m (8,000 ft) near Dubois, WY, 2001. Gypsum Creek NADP site was located 32 km (20 mi) upwind of Middle Mountain.

		Gypsum Creek NADP Site					Middle Mountain	
Type	Month	1985-2001 Mean Precip (cm)	1985-2001 Weighted Mean	1985-2001 Range	2001 Mean Precip (cm)	2001 Weight-ed Mean	2001 Mean Precip (cm)	2001 Weight-ed Mean
Concentration (ppm)	June	4.00	0.67	0.21 – 1.86	1.01	0.21	1.15[a]	2.69[a]
	July	3.14	1.10	0.02 – 4.37	0.85	2.23	3.07	2.42
	August	3.04	1.35	0.55 – 3.08	1.63	1.23	2.36	1.72
	Total	10.18	1.01		3.49	1.18[b]	6.58	2.22[b]
Deposition (kg/ha)	June		0.26	0.02 – 0.59		0.02		0.31[a]
	July		0.34	0.01 – 1.07		0.19		0.74
	August		0.37	0.15 – 0.75		0.20		0.41
	Total		0.97			0.41[b]		1.46[b]

[a] Data from June 18th-30th only.

[b] Paired t-test showed no significant differences for 2001 weighted mean concentrations (P = 0.280) between Gypsum Creek and Middle Mountain. Deposition, however, was nearly significant (P = 0.076).

Arrow Mountain (399 ppb) and the mean value for summer range at nearby Goat Flat (Mean = 209 ppb, SD = 75) fell within the range found for the MM sites. However, summer range soils were found to have no measurable soluble selenium content. In contrast, the BB lick soils contained from 4 - 13% of total selenium in the soluble form, presumably as selenate. Summer-range soils contained 11 - 30% phosphate-extractable selenium, while lick soils contained 11 - 67%. This fraction presumably represents available selenite. These values for air-dried soil represent those to be expected in the field during dry years.

The effect of water saturation on the redox potential for 3 MM soil samples showed a rapid drop in potential. Redox potential is a measure of the oxidizing power of the soil and is related to the amount of available oxygen. As soils become wetter, gaseous oxygen is replaced with water in the soil pores. Presumably, microbial action also depletes oxygen. Consequently, redox potential drops and anaerobic conditions prevail in a matter of hours. When a sample of MM#1 soil was maintained under these conditions for 1

Table 7. The total selenium concentration in ppb and % selenium availability for selected study area soils, Wind River Mountains, Wyoming, 2001.

Site	N	Total Mean Se ppb (SD)	pH	% Soluble Se	% Exchangeable Se	Total Available for Plant Uptake
MM #1	5	640 (51)	5.49	<1	11	11
MM #1R				<1	5	5
MM #2	4	155 (34)	5.29			
AM	1	399	6.67			
GF	2	209 (75)	6.88	<1	30	30
TV[a]	2	58 (34)	9.20	0	67	67
BB #1[a]	2	1,072 (116)	10.25	13	14	27
BB #2[a]	2	213 (19)	10.18	4	11	15

[a] Natural mineral licks used by bighorn sheep and located on winter range in Torrey Valley.

month in the laboratory (MM#1R), a 50% decrease in the amount of available selenium was found. This is the value to be expected during a wet field season. In 2001, 4 redox probes were installed on Middle Mountain. Soils had a mean redox potential of 511 mV (N readings = 68, SD = 53). During saturated conditions, redox potential dropped to a low of 350 mV. Redox potentials this low are at the threshold of where selenite (available to plants) would be converted to elemental selenium (unavailable to plants) at the pH of these soils (Geering *et al.* 1968).

DISCUSSION

Lamb survival is affected by many factors including forage quality and quantity (Festa-Bianchet 1988, Dunbar 1994), nutritional and health status of mother and lamb (Thorne *et al.* 1979, Festa-Bianchet 1984, Festa-Bianchet 1991), inbreeding (Hass 1989), weather (Wehausen *et al.* 1987, Ryder *et al.*1992) and predation (Hass 1989, Wehausen 1996). Survival of lambs in this study appeared to be highly related to health, as mortality rate for healthy lambs was nearly 1/5 that of sick lambs. Health of wild and domestic lambs is intimately related to adequate nutritional intake obtained from mother's milk (Horejsi 1972, Shackleton 1972, National Research Council 1985). This was confirmed in our study by the fact that Lambs That Died had much higher rates of poor health and lower intake of milk as inferred by average suckling time and milk production (i.e., from subjective qualification of udder size).

The shedding of lungworm larvae through the intestine and measured in feces has been used as an inference to the potential level of stress in bighorns and impacts on reproduction and lamb survival (Ellenberger 1976, Thorne *et al.* 1979, Samuel and Gray 1982, Festa-Bianchet 1989, Festa-Bianchet 1991). Festa-Bianchet (1984) reported that ewes with lambs that survived until October had statistically lower lungworm densities (mean = 642 l/g in 1982, mean = 455 l/g in 1983) than ewes with lambs that died (mean = 967 l/g in 1982, mean = 1,130 in 1983, $P < 0.03$ using Mann-Whitney U test). Festa-Bianchet (1984) implied that the density of lungworm may not have been the cause of lamb loss but that higher levels may be simply an indication of ewes in poorer condition and thus not as capable of producing healthy lambs. In contrast, our means were much lower and showed no statistical differences. Consequently, we believe that lungworm loads inferred by fecal lungworm counts did not have an effect on lamb survival. Data were insufficient to compare lambs directly thus the lambs' mother was used.

Fecal nitrogen levels have been utilized as an indicator of animal health and forage quality (Hebert *et al.* 1984, Kie and Burton 1984, Leslie *et al.* 1989, Irwin *et al.* 1993, Hodgman *et al.* 1996, Kucera 1997). We used fecal nitrogen to infer protein intake between mothers with Lambs That Survived and mothers with Lambs That Died. Protein intake is important for milk production and growth (National Research Council 1985). If protein intake as reflected by fecal nitrogen were effecting lamb survival due to impairment of milk production and lamb growth, then we expect lower fecal nitrogen levels in mothers with Lambs That Died. Our data did not support this as there were no significant differences in fecal nitrogen levels between groups in 1998, 1999 or 1998 - 2000. Means for all 3 years combined were identical. We expected to find no difference since both groups occupied identical summer ranges. A significant difference did occur in 2000. However, mothers with Lambs That Died had the higher mean, counter to the reasoning stated above.

Selenium levels in whole blood were not deficient in ewes captured during March or May on winter range. Winter range, comprised of alkaline soils derived from sedimentary rock, produced forage that had adequate levels of selenium (mean = 150 ppb dry matter). Ewes were not deficient simply because they had been feeding for 5 months on this forage.

Selenium, a component of selenoproteins, is vital to general health and proper immune function (Berger 1993, Underwood and Suttle 2000), disease resistance, growth (Langlands *et al.* 1990), milk production (Smith 1994) and regulation of body temperature (Underwood and Suttle 2000) of domestic sheep and goats. Stabel *et al.* (1989) stated that domestic calves from mothers fed a diet marginally deficient in selenium (30 - 50 ppb dry matter) showed an increased susceptibility to *Pasteurella hemolytica* than calves from mothers fed 100 ppb selenium dry matter and injected with sodium selenite every 60 days. Donald *et al.* (1993) found an increase in survival of newborn domestic lambs from 61% to 91% once selenium supplementation was provided.

Selenium is also an essential constituent of several variants of the blood enzyme glutathione peroxidase. The glutathione peroxidases act as selenium storage and as antioxidants that help protect cells from oxidative damage as well as damage from heavy metal poisoning (Rosenfeld and Beath 1964, National Research Council 1983, Underwood and Suttle 2000). As muscles utilize oxygen, peroxides are produced and if not removed result in the destruction of lipids, including subcellular membranes. In extreme cases, breakdown of cellular tissue will result in the degeneration of muscle resulting in NMD. NMD has been common in places throughout the world, but especially in New Zealand and Australia, accounting for dozens of publications related to its study (National Research

Council 1983, National Research Council 1985, Underwood and Suttle 2000).

Subclinical deficiency may exist in wild animals, with apparent symptoms resulting only after stress (Robbins *et al.* 1985). For example, mountain goats (*Oreamnos americanus*) in Canada did not develop symptoms until after being captured (Hebert and McTaggart-Cowan 1971). Further, fawn survival was improved from 32 to 83 fawns:100 does for symptomless black-tailed deer (*Odocoileus hemionus columbianus*) provided with selenium supplements in an area of northern California (Flueck 1994). Increases in glutathione peroxidase activity due to selenium supplementation have been demonstrated for mountain goats and bighorn sheep (Robbins *et al.* 1985, Samson *et al.* 1989), white-tailed deer (*Odocoileus hemionus*) (Brady *et al.* 1978) and black-tailed deer (Flueck 1991).

We believe that lambs on Middle Mountain had NMD during the summer of 1998. Forage selenium was only 5 ppb dry matter and lambs:100 ewes was 12 at the end of October. In subsequent years (1999 - 2001), lambs did not display NMD symptoms. Forage selenium values were > 34 ppb dry matter and lamb ratios ranged from 18 - 38. In addition, mineral blocks supplemented with selenium were available on summer range and readily used by ewes and lambs. Lamb survival during these subsequent years was still low to moderate and may have been affected by a subclinical deficiency (i.e., sheep may have been deficient and were adversely affected by this deficiency, but were not deficient enough to develop full-blown NMD).

Although the exact concentration of forage selenium required by bighorns is unknown, an extensive review of New Zealand publications showed NMD in grazing domestic lambs occurred where selenium content of spring pastures was < 20 ppb dry matter (National Research Council 1985). Deficiency resulting in symptoms similar to those of livestock has been reported for mountain goats using forage species of which most contained < 45 ppb dry matter (Hebert and McTaggart-Cowan 1971). Caution must be used when using forage concentrations of selenium as the only indicator of possible deficiency. Selenium is affected by many other variables including general health of animal, level of stress, diseases present in animal, digestive absorption as a function of the form of selenium intake, and dietary intake of sulfur, sulfur-containing amino acids, and Vitamin E (Rosenfeld and Beath 1964, National Research Council 1985, Underwood and Suttle 2000).

Robbins *et al.* (1985) rightly expressed caution when using domestic livestock standards as guidelines for wildlife, as many wildlife species have evolved in low selenium habitats and consequently have developed compensatory mechanisms. Though selenium deficiency affecting wildlife production may have been present for thousands of years and hence wildlife species have adapted to it, Flueck (1991) contends, that "…there is growing evidence that anthropogenic (man caused) manipulation of ecosystems can rapidly alter selenium cycling and availability or requirements of free-ranging herbivores." Impacts might result from acidification of soils, exposure to heavy metals and deposition of sulfur and nitrogen (Flueck 1991).

Nitrate deposition does appear to be increasing in the Wind River Mountains based on the Gypsum Creek NADP site. Our analysis of rainfall chemistry indicated that the study area received multiple times more deposition than the Gypsum Creek site in 2001. Analysis of animated cloud movements from GOES-10 satellite images indicated most air masses from which summer precipitation fell on the upper Wind River Mountains during 2000 and 2001 first traveled through major urban and pollution centers in Mexico, Arizona, southern California and Utah. Potential upwind local sources (< 450 km, 275 mi) of nitrates included the Salt Lake Valley, extensively developed oil/gas fields in southwestern Wyoming, Interstate Highways, fertilizer, gas and trona processing plants, and coal-fired electric generating plants. Williams and Tonnessen (2000) documented the adverse affects of nitrate deposition on alpine environments near Denver, Colorado. This publication showed that Lincoln County in southwestern Wyoming, located upwind of the Wind River Mountains, was among the top counties in Arizona, Colorado, New Mexico, Utah and Wyoming for nitrate emissions in 1990. They state, "…nitrate emissions associated with this energy development might well have effects on nitrogen loading to Wilderness Areas in both northern Colorado and southern Wyoming."

In our study, forage plots on Middle Mountain that received less than "expected" nitrates and "normal" precipitation showed increases in forage selenium of 6 - 59% during 1 month of the growing season. In contrast, plots that received heavy additions of nitrate or were saturated decreased in forage selenium. Extremely dry plots also showed a decrease in selenium. This may be due to the roots difficulty in absorbing soil moisture (and hence, soluble forms of selenium) since there was so little soil moisture present. The % decrease was greatest under saturated soil conditions. The heaviest loaded nitrate plot showed a 19% decrease in forage selenium. The level of nitrate deposition on this plot would be about ½ of what would theoretically fall during a very wet summer, such as the summer of 1998 when heavy rainfall resulted in boggy, saturated conditions across Middle Mountain. Lab analysis of Middle Mountain soils showed a 50% decrease in available selenium under saturated conditions. All of these results supported our hypothesis. However, no plots showed less than 28 ppb forage selenium. Thus, our manipulations did not reproduce conditions found in 1998 during which there was only 5 ppb forage selenium on summer range. The reductions in forage selenium on the plots would not likely be low enough to cause NMD, but may be low enough to create subclinical deficiency capable of affecting lamb survival. Other as-yet unknown factors may have influenced such low levels in 1998. Further research is needed to confirm the effects of soil wetness and nitrate deposition on selenium availability.

Certain soils are susceptible to producing forage low in selenium. In Scotland, low blood selenium levels in domestic sheep and cattle were attributed to a combination of granitic soils, high elevation, high rainfall and slightly acidic soils (Anderson *et al.* 1979, Arthur *et al.* 1979). Forage selenium concentrations are not related to total soil selenium concentration, but rather to the fraction of total soil selenium in the available form. Alkaline, dry soil conditions are thought to favor available selenium (Mincher *et al.* in preparation). Factors which lower either pH or redox potential of soil can theoretically change the form of selenium from available (selenite SeO_3^- and selenate SeO_4^{-2}) to unavailable (selenide or elemental selenium) (Geering *et al.* 1968). Available forms are water-soluble and hence absorbable by plant roots. Elemental selenium (Se^0) and selenides (Se^-) are not readily water-soluble and thus not easily absorbed by plants. (Fisher *et al.* 1987).

Lamb recruitment data from Whiskey Mountain support the hypothesis that years of higher precipitation are related to lower lamb recruitment. Higher precipitation would cause wetter soil conditions, lowering soil redox potential and resulting in less available selenium. Also, higher precipitation would result in greater biomass of forage creating a "dilution" effect (i.e., available selenium in the soil would be absorbed by roots, but assimilated into more biomass above ground causing lower concentration of forage selenium). Greater precipitation would also result in greater amounts of nitrate deposition. Nitrates would likely fertilize plants, further exacerbating the "dilution" effect. Preliminary tests of lab-cultured microbes from Middle Mountain soils indicated that addition of nitrate increased growth of soil microbes. Soil microbes appeared to convert available forms of selenium into elemental selenium and to volatilize dimethyl selenide (States 1966, Holzinger-Love 1974). Both would result in a net loss of selenium for plant uptake. Although elemental selenium may convert back to available forms under certain conditions, volatilized selenium leaves the ecosystem.

Sheep behavior may also affect selenium uptake. We observed bighorns selecting for the most succulent forage. This forage tended to grow in the wettest places, likely resulting in lower forage selenium for the reasons listed above. It is likely that the most succulent forage would also be the most digestible and hence have the shortest passage time in the gut. As a result, trace minerals like selenium would have less time to be absorbed in the digestive tract (Ron Dean, pers. comm.). Figure 8 details factors that may influence selenium assimilation in bighorns.

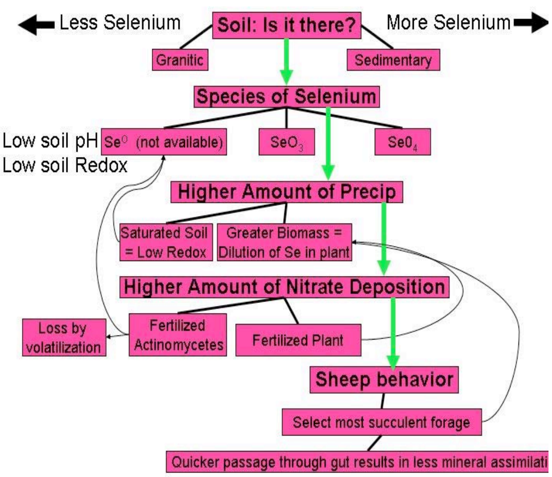

Fig. 8. Factors affecting selenium uptake by bighorn sheep.

In 2002, work conducted by Mionczynski (2002) showed additional support for a possible link between herd status and forage selenium. Summer range forage samples were collected from declining herds (Wind River Mountains in Wyoming, Lemhi Mountains in Idaho and Fraser River in British Columbia) and compared to stable/increasing herds (Owl Creek Mountains and Absoraka Mountains in Wyoming and Sierra Nevada Mountains in California). Mean forage selenium was statistically lower ($P = 0.042$) for declining herds (mean = 60 ppb dry matter, $N = 19$, $SD = 61$) as compared to stable/increasing herds (mean = 237 ppb dry matter, $N = 7$, $SD = 181$).

In summary, the connection between dietary selenium and lamb survival cannot be proven by this study. However, numerous facts point toward its connection and include: (1) mineral cravings by ewes and huge expenditures of energy to acquire mineral soil containing selenium at natural licks (2,270 m, 7,450 ft elevation) located 13 km (8 mi) away from summer range (3,354 m, 11,000 ft elevation); (2) near absence (5 ppb dry matter) of selenium in summer forage in 1998 when lambs were critically ill and exhibited all 9 external symptoms of NMD displayed in domestic sheep. Recovery from symptoms occurred following visits to natural licks; (3) summer range forages in other years that were 20 to 50% of the National Research Council's (1985) lowest recommended level for domestic sheep (100 ppb dry matter); (4) the marked relationship between health of bighorn lambs and increased survival. Selenium is critical in maintaining health of domestic lambs; (5) increased survival of lambs following placement of supplemental selenium blocks on summer range; (6) higher survival and overall health of lambs on sites with blocks as compared to sites without blocks; (7) greater time spent suckling for Lambs That Survived inferring greater milk production. Selenium deficiency can impair milk production in domestic livestock; and (8) lack of relationship between lamb survival and other important factors like dietary intake of protein as inferred by fecal nitrogen and lungworm infestation as inferred by fecal lungworm loads.

We suspect that in granitic soils, wetter summers produce conditions unfavorable for selenium uptake by forage plants due to lowered soil redox potential, thus converting selenite and selenate into chemical species (e.g., elemental selenium) that are unavailable for plant uptake. We also suspect that artificially enhanced nitrate deposition stimulates microbial decomposition processes including microbial transformation of selenite and selenate to unavailable forms of gaseous and elemental selenium. Ultimately, we suspect that wetter conditions result in less selenium uptake by bighorn sheep from forage growing on granitic summer range, thus lowering lamb health and survival. A possible selenium deficiency is not the only factor affecting lamb survival at Whiskey Mountain, however. Poor lamb recruitment still continues even with mineral supplementation. Monitoring of marked sheep, additional analysis of rainfall chemistry, expansion of plot treatments, feeding trials of captive ewes and lambs on low and high selenium diets, sampling blood from sheep on summer range, and necropsy of lambs displaying NMD should be done to further expand current knowledge of the relationship between bighorns and selenium.

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An Investigation Into The Selenium Requirement For Rocky Mountain Bighorn Sheep

RON DEAN, Wyoming Game and Fish Department, Box 3488, Alpine, WY 83128, U.S.A.
PAT HNILICKA, Wyoming Game and Fish Department, 260 Buena Vista, Lander, WY 82520, U.S.A.
Current address is U.S. Fish and Wildlife Service, 170 N. First St. Lander, WY 82520 USA
TERRY KREEGER, Wyoming Game and Fish Department, 2362 Highway 34, Wheatland, WY 82201, U.S.A.
TIM DELCURTO, Eastern Oregon Agricultural Experiment Center , Box E, Union, OR, 97883 U.S.A.

Abstract. Causes for declines in bighorn sheep populations often go undetermined. Selenium deficient forage has been suspected as a possible contributing factor on several occasions. Generally, the basis for this concern results when the selenium content of the forage is compared to the nutritional requirement for domestic sheep. Hay with 20-30ppb of selenium was fed to captive bighorn ewes and their lambs for approximately two months following the birth of the lambs. Both lambs and ewes were monitored for physical signs of a deficiency. In addition, levels of blood selenium and glutathione peroxidase (GPX) were monitored as well. Physical signs of selenium deficiency were not detected in either the ewes or lambs. Lambs showed a decrease in blood selenium and GPX levels. While the study did not attempt to identify selenium requirements for bighorn sheep, the results did show that hay low in selenium caused drops in both blood selenium and GPX, particularly with lambs. Some limitations of the application of nutritional information to wild bighorn sheep, which has been taken from domestic animals, are discussed, as are some possible relationships.

Rocky Mountain Bighorn sheep (*Ovis canadensis canadensis*) that winter on Whiskey Mountain and summer on Middle Mountain, near Dubois, Wyoming have experienced several years of low lamb survival. Close surveillance of the lambs revealed signs similar to those seen with selenium deficiencies in domestic livestock. An examination of forage consumed by the sheep showed selenium levels to be greatly below minimum requirements of domestic sheep. A review of the literature revealed that the dietary nutrient requirement for selenium by bighorn sheep apparently was not available. This study was designed to feed hay low in selenium and make the following observations. One, monitor the blood levels of indicators used to assess the status of selenium in animals (blood selenium and GPX) while the sheep were being fed a diet low in selenium and, second, monitor both ewes and lambs for the various signs known to be associated with selenium deficiencies, particularly those seen with the Whiskey Mountain sheep.

METHODS

The study was designed to mimic, as close as possible, the situation that was felt to exist on Whiskey Mountain-Middle Mountain sheep, i.e., ewes being on forage with adequate selenium until after they gave birth to their lambs, followed by spending the summer foraging on feed low in selenium. Seven pregnant ewes were held in common pasture (forages in this geographical area have adequate selenium) and supplemented with hay that had 500 ppb of selenium. As each ewe gave birth to a lamb, these sheep were put into a common pen with a concrete floor and fed hay with 20-30 ppb of selenium.

The hay was fed ad libitum and its nutrient composition is shown in Table 1.

Table 1. Nutrient analysis of hay fed to bighorn ewes and lambs.

TDN	64%
ADF	30.9%
Protein	16.8%
Ca	1.3%
P	0.25%
K	1.2%
Fe	200ppm
Cu	14ppm
Zn	16ppm
Mg	0.34%
Mn	32ppm
Se	20ppb/30ppb
Mo	2.1 ppm
Vitamin E	3.87 IU/g

Blood samples were taken from each ewe on May 16, which was just after the first ewe gave birth to her lamb (May 14). Blood samples were taken from each ewe four other times during the summer. The lambs had blood samples taken four times (on the same dates as the ewes) over the course of the summer. The Wyoming Game & Fish Department Veterinarian observed the animals, looking for physical signs of selenium deficiencies, throughout the course of the study.

RESULTS

The first ewe to lamb was on May 14 and the last was on June 2nd. The range of time that the ewes were fed the hay with low selenium varied from 59 to 78 days. The lambs on Middle Mountain exhibited rough coats, swelling around the eyes, nasal secretions, high respiratory rates, slumped shoulders, and a stiff gait approximately 6-8 weeks after ewes were on a low selenium diet. None of the signs seen with these sheep were detected with the bighorns in this study.

The results of the selenium blood tests are shown in Table 2 and Figure 1. The level of selenium in the blood of the ewes showed a slight elevation (0.04ppm) following their initial exposure to the hay with low selenium levels. The level returned to the pre-treatment level (0.24ppm) and remained there throughout the remainder of the study, showing only minor changes (0.01ppm). The level of selenium in the blood of the lambs dropped steadily throughout the study, being 0.19ppm in the beginning and ending with 0.12ppm.

Table 3 and Figure 2 show the results of the response of serum GPX to the low selenium diet. The ewes showed an initial drop of 86 millimoles/s/l during the first 35 days which then remained fairly stable through the remainder of the study. The level of GPX with the lambs declined throughout the study, with the exception of the third sampling period, where an increase of 89 millimoles/s/l occurred. This increase was the result of one lamb showing a value of 865 millimoles/s/l while the remainder of the group averaged 171 millimoles/s/l, which is intermediate between the previous and following levels.

CONCLUSIONS

The level of selenium in the hay was below the deficiency level of 50ppb for domestic sheep on good quality feed as reported in Underwood and Suttle (1999), but was 6 times higher than for most summer forages sampled on

Table 2. The average and range of blood selenium levels (ppm) taken from bighorn sheep.

	EWES		LAMBS	
Date	Average	Range	Average	Range
May 16	0.24	0.22-0.28		
June 20	0.28	0.24-0.31	0.19	0.14-0.22
July 6	0.24	0.22-0.25	0.18	0.17-0.21
July 17	0.23	0.21-0.25	0.13	0.11-0.14
July 30	0.23	0.21-0.25	0.12	0.10-0.14

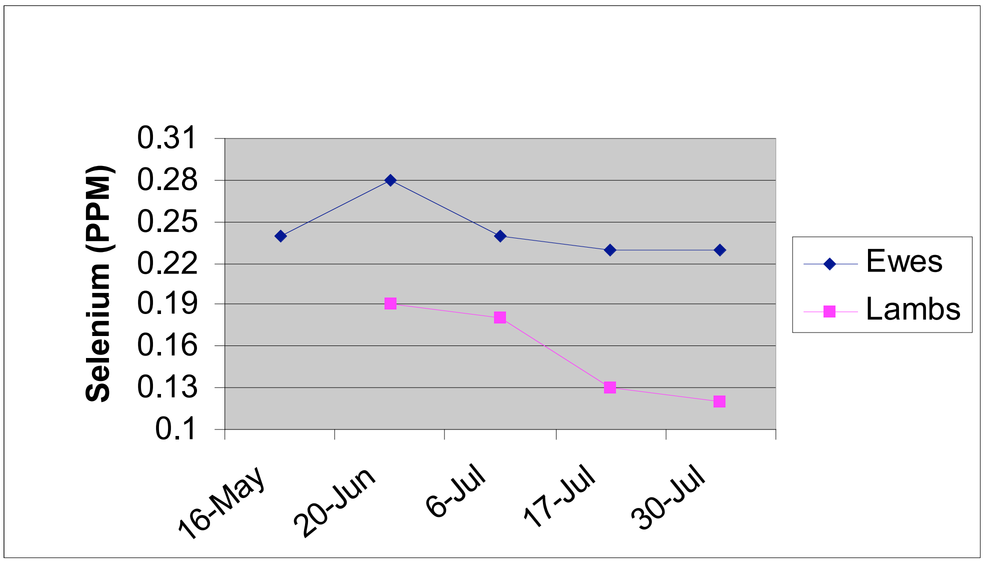

Figure 1. Blood selenium changes for bighorn ewes and lambs.

Middle Mountain. For this reason, the data cannot be used to help evaluate the field observations of free ranging sheep in the Whiskey Mountain herd. They do, however, provide some insight into the selenium metabolism of bighorn sheep.

The conditions of this study did not produce deficiency signs to lambs when born from ewes in good selenium at the time of parturition and subsequently fed low selenium hay for the first couple of months of life. It should be pointed out that selenium deficiency problems commonly develop with domestic animals when pregnant females are on deficient diets during late pregnancy. Signs are seen with the offspring in the subsequent months following parturition.

It appears that, with the lambs, 20-30ppm of selenium in the feed caused a drop in both selenium and GPX, each of which is used as an indicator of the selenium status of animals (Underwood and Suttle, 1999). The cause of increase in the blood selenium observed with the ewes on June 20 (the first sampling following the consumption of low selenium hay) is not known, but may have arisen from the mobilization of stored selenium from the liver following the sudden switch in diet from one of

Table 3. The average and range of glutathione peroxidase (millimoles/s/l) taken from bighorn sheep.

	EWES		LAMBS	
Date	Average	Range	Average	Range
June 20	311	252-401	343	197-341
July 6	281	242-299	198	94-362
July 17	308	258-388	287	96-865
July 30	286	254-334	153	135-179

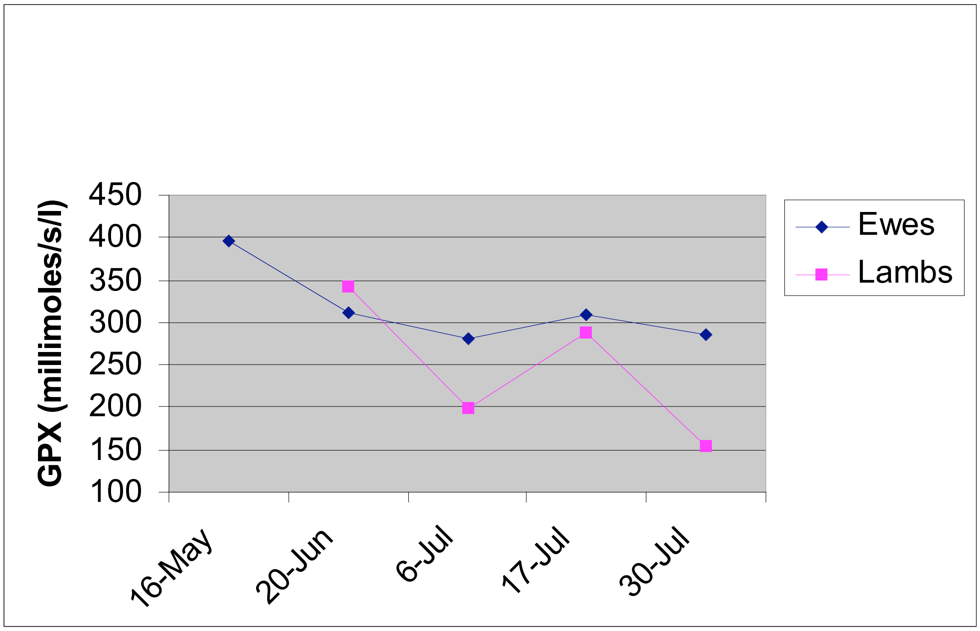

Figure 2. Changes in serum glutathione peroxidase levels in bighorn ewes and lambs.

500ppb to one of 20-30 ppb of selenium. Also, the increase in the serum GPX seen with the lambs during the third sampling period was the result of one individual having a very high reading of 865 millimoles/s/l. Excluding this lamb, the average serum GPX was 171 millimoles/s/l, resulting in a decreasing trend over the time period of the study. The blood levels of both selenium and GPX appear to indicate animals were in an adequate nutritional state with regard to dietary selenium during this study (approximately 2 months in duration). This would be consistent with observations from bighorns in Alberta where blood selenium levels that were considerably lower (0.025ppm) were found in sheep that had good reproduction and herd health (Samson, et. al. 1989). However, caution should be used when assessing nutritional state of an animal with regard to selenium. The nature of the selenium deficiencies is varied, but typically results in reduced reproductive efficiency and reduced immune responsiveness of offspring. The presence or absence of environmental stresses may have a significant effect on dietary requirements for selenium and offers a possibility as to why selenium may affect herd health in one situation and not another. While blood selenium levels for the ewes in our study would not be considered deficient for domestic animals, the levels seen in the bighorn lambs would be considered as marginal in domestic cattle (calves). Calves with blood selenium levels between 0.1 and 0.2ppm would be predisposed and would be susceptible to challenges from environmental stresses (parasites, cold weather, etc.).

Observations with domestic livestock indicate that a difference may exist between individuals based on their previous exposure to low levels of dietary selenium. For example, cattle on a given ranch may live and reproduce successfully for years on forage low in selenium. When cattle accustomed to higher levels of selenium are added this herd, deficiency signs may develop. This possibility of trace mineral adaptation may have been seen with the bighorns in this study. While deficiency symptoms did not develop, the decreasing levels of blood selenium and GPX indicate that 20-30ppb of dietary selenium were not adequate to maintain the levels of these indicators. The bighorns used in our study were accustomed to forage very high in selenium when compared to that received during the study. The sudden switch in dietary selenium may have elicited a response that sheep accustom to forage with low selenium may not have shown. This raises questions regarding the transplanting of bighorns from areas of higher levels to areas of lower areas and the possibility of increased susceptibility to environmental stresses.

In summary, the identification of required levels of trace minerals is difficult, especially with free ranging animals. Trace minerals are required in such small amounts. Sources of variation in measuring intake, the interactions of trace minerals with other nutrients, differences in laboratory analysis, possible adaptation differences, and varying levels of environmental stresses are all factors that confound the measurement of actual requirements. If mineral imbalances are thought to have a significant affect on bighorn sheep herds, perhaps the best method of identifying deficiencies will be to evaluate the responsiveness or the lack of responsiveness of these herds to treatments, such as mineral supplementation. Given the inherent difficulties of determining trace mineral requirements by other techniques, this approach was suggested for domestic animals by Underwood and Suttle, 1999.

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TRANSPLANT ASSESSMENT

Glenn Erickson - Moderator

Ecological Assessment Of Reintroduced Bighorn Sheep Along The Wasatch Front

JERICHO WHITING, 915 north 150 east #304 Provo, UT 84604 U.S.A.

Abstract: In the last three years, herds of Rocky Mountain bighorn sheep have been reintroduced along the mountain ranges adjacent to the heavily populated Wasatch Front in central Utah. During the same period, in the same area, mountain lion harvest permits were doubled to facilitate the establishment of these herds. Since their reintroduction, data has been collected on habitat use and preference, population status (i.e. parturition timing, lamb survival, and recruitment), causes of mortalities, foraging selection and preference, and population demographics of the mountain lions harvested.

Predation And Bighorn Sheep Transplants In New Mexico: A Tale Of Two Herds

ERIC M. ROMINGER, New Mexico Department of Game and Fish—Contract Biologist P. O. Box 704 Santa Fe, New Mexico 87504, U.S.A.
HEATHER A. WHITLAW, New Mexico Department of Game and Fish, P. O. Box 25112 Santa Fe, New Mexico 87504, U.S.A.
DARREL WEYBRIGHT, New Mexico Department of Game and Fish, P. O. Box 25112 Santa Fe, New Mexico 87504, U.S.A.
WILLIAM C. DUNN, New Mexico Department of Game and Fish, P. O. Box 25112 Santa Fe, New Mexico 87504, U.S.A.

Abstract: Transplantation is considered imperative for the restoration of bighorn sheep (*Ovis canadensis*) to historic habitats in North America. During 1992-93, New Mexico Department of Game and Fish established a new population of desert bighorn sheep (*O. c. mexicana*) in the Sierra Ladron Wilderness Study Area in central New Mexico, and during 1993 a new population of Rocky Mountain bighorn sheep (*O. c. canadensis)* was established in the Wheeler Peak Wilderness Area of northern New Mexico. Both populations were established with similar numbers of bighorn sheep (n=32 in Wheeler Peak; n=31 in Sierra Ladron). The post-lambing population estimates in 2000 are 180 in the Wheeler Peak population and 21 in the Sierra Ladron population. Starkly contrasting adult survival and recruitment rates combine to produce these 2 very different population sizes. Annual adult survival rate was higher (z=3.703; P<0.005) in the Wheeler Peak population (0.955) than in the Sierra Ladron population (0.784). Annual lamb:ewe ratios were significantly higher (P< 0.0001) in the Wheeler Peak population (79.9 vs. 30.5). Mean annual exponential growth rate (r) in the Wheeler Peak population was r = 0.25 compared to r = -0.01 for the Sierra Ladron population. Predation by mountain lions (*Puma concolor*) was the major (75%) source of known-cause mortalities of radiocollared bighorn sheep in the Sierra Ladron population; the annual cause-specific mortality rate due to mountain lion predation was 0.13 for rams, 0.09 for ewes, and 0.11 for all adult bighorn. Domestic cattle were preyed upon by mountain lions in the Sierra Ladron population and may 'subsidize' this predator. No predation was documented in the Wheeler Peak population. No fatal disease outbreaks or permanent emigrations were documented in either population. High mountain lion predation may require mitigation for the successful restoration of bighorn sheep in areas of historic habitat.

The Landscape Of Fear And Its Implications To Sheep Reintroductions

JOHN W. LAUNDRÉ, Instituto de Ecología, A.C., Km 33.3 Carr. Chihuahua-Ojinaga, Aldama, Chih. 32900, México.
LUCINA HERNÁNDEZ, Instituto de Ecología, A.C., Km 33.3 Carr. Chihuahua-Ojinaga, Aldama, Chih. 32900, México
ITZEL ARÍAS del Razo, Escuela de Biología, Benemérita Universidad Autónoma de Puebla, Puebla, Pue. 72570, México.
GRETCHEN FOWLES, Department of Biological Sciences, Idaho State University, Pocatello, ID 83209 U.S.A.

Abstract: The record for bighorn sheep (*Ovis canadensis*) reintroductions is not stellar; recent analyses indicate a less than 50% success rate. Most models to evaluate potential release sites center on assessing the amount of "escape habitat" available. Escape habitat has been defined as steep, rocky areas where sheep can outmaneuver their predators. This may be a good definition for predators that chase their prey such as coyotes (*Canis latrans*) or even wolves (*C. lupus*). However, in most areas of sheep reintroductions, the main predator is the puma (*Puma concolor*). Pumas stalk their prey and the definition of escape habitat overlaps substantially with what definitions of excellent hunting habitat for pumas. This indicates that a possible reassessment of escape habitat, especially in reference to sheep reintroductions, might be warranted. Many studies have shown that vigilance behavior is a good indicator of predation risk. Based on this, we are assessing predation risk of different habitat types relative to vigilance levels sheep exhibit. We are conducting this study in southern Idaho on a newly reintroduced California Bighorn Sheep (*O. c. californiana)* population that is preyed on by pumas. We monitored vigilance (head up and alert) of sheep for 20 minute time blocks in different habitat types, e.g. rock, cliff, open grass, etc. We found significantly higher vigilance rates in rocky (32.3 ± 3.1 %) and cliff habitats (30.1 ± 4.5%) than in sage (16.7 ± 1.8%) and grass/sage (22.1 ± 2.8 %) areas. Our data indicate sheep perceive defined escape habitat as highly risky while open grass slopes as relatively safe. Results of our final analysis should help us assess the landscape of fear for sheep relative to puma predation and provide a more realistic assessment of potential release sites.

Key words: Bighorn sheep, pumas, predation risk, vigilance.

Bighorn sheep (*Ovis canadensis*) were once widely distributed in their range (Krausman 2000). However, during the last century, they have declined dramatically (Enk et al. 1998, Krausman 2000) for a variety of reasons (Gross et al. 2000). To try and reverse this trend, numerous agencies and organizations began an extensive effort to reintroduce bighorn sheep into historic range. Since the initiation of those efforts, 100's of translocations have occurred. However, various assessments of these transplants indicate they are often not very successful, ranging from 41 to 53% (Leslie 1980, Singer et al. 2000a). Considering the tremendous time, effort and money involved in transplant efforts, an approximately 50 % success rate is not very good. Additionally, the number of transplanted sheep and their potential offspring involved in these failed efforts represents a staggering loss of animals.

The reasons for this low success rate are varied, with epizootic outbreaks of bronchopneumonia considered the greatest contributing factor (Singer et al 2000b). Apart from the impact of diseases, likely the second most commonly recognized factor is predation, specifically by pumas (*Puma concolor*) (Enk et al. 1998, Hayes et al. 2000, Logan and Sweanor 2001).

To counter these problems, the various models to evaluate release sites incorporate minimum distance from domestic sheep to reduce the transmission of diseases and maximum distance from "escape terrain" to reduce the threat from predators. With regards to escape terrain, however, its definition has been somewhat ambiguous. Van Dyke et al. (1983) described it as "Cliffs, rock rims, rock outcroppings and bluffs…." Later, Smith et al. (1991) expanded the definition to include "… slopes greater than 60% that have occasional rock outcroppings whereon bighorn can outmaneuver predators." This definition not only gives a physical aspect to escape terrain but also indicates how we think it functions in the avoidance of predation. However, being able to better "outmaneuver predators" is only reasonable if the predator primarily chases its prey, e.g. wolves (*Canis lupus*) or coyotes (*C. latrans*).

Pumas, however, are the prime predators on bighorn sheep and they stalk their prey. Not only do they stalk their prey, various studies have demonstrated pumas need specific "stalking habitat" to be successful. Such habitat consists of "…canyons, draws and steep ridges…." (Logan and Irwin 1985). Additionally, Koehler and Hornocker (1991) observed "…mountain lions, commonly associated with areas (of) cover for stalking, occupied…rocky terrain….". Finally, Enk et al. (1998) added "…they (lions) relied on… topographic complexity (i.e. rocky reefs and steep terrain for traveling and stalking prey".

Consequently, "escape terrain" for sheep and "stalking habitat" of pumas have many characteristics in common. Not surprisingly, it is in this type of habitat where pumas are successful at killing sheep. Rechel et al. (1997) found "…mortality locations of mountain sheep… (had) a strong positive relationship with proximity to …escape cover". Enk et al. (1998) reported "all sheep kill sites were located either in riparian corridors or adjacent to escape terrain". And finally, Jalkotzy et al. (2000) stated "kills were found… in areas with greater terrain ruggedness". Essentially, these data suggest that far from being safe, "escape terrain" may actually represent one of the riskiest habitats available. In fact, Enk et al. (1998) at the 11th NWSGC symposium concluded that escape terrain likely did not provide adequate protection from predation by pumas and advised that "it may be necessary to re-evaluate "escape terrain" and sheep-predation dynamics…." This re-evaluation is especially urgent considering that escape terrain has become and still is the most important element in assessing the adequacy of an area for sheep (Smith et al. 1991, Johnson and Swift 2000, Singer et al. 2000c). It is essential to determine if we are releasing sheep in the most secure habitat possible or into the jaws of their predators.

However, how do we evaluate the predation risk faced by sheep in escape or other habitat types? We propose to let the sheep tell us their perception of predation risk. There are ample studies demonstrating that prey are aware of the predation risk they face in different habitat types (Mech 1977; Edwards 1983; Stephens and Peterson 1984; Altendorf et al. 2001). Additionally, they respond to this predation risk by being more alert (Laundré et al. 2001). Thus, we used the level of vigilance sheep exhibited as an estimate of the predation risk they faced in different habitat types. Additionally, we demonstrate how to map the resulting landscape of fear (Laundré et al. 2001) for sheep relative to pumas. Finally, we suggest how such a map could be useful in evaluating the overall level of predation risk of potential release sites.

STUDY AREA

This study area was the Jim Sage mountain range located in southern Idaho (Fig. 1). This range historically contained sheep which were extirpated in the early 1900's. In 2000 and 2001, various agencies and organizations participated in the reintroduction of 45 California bighorn sheep (*O. c. californiana*) into the area. The area is also part of a long term study of puma ecology and behavior.

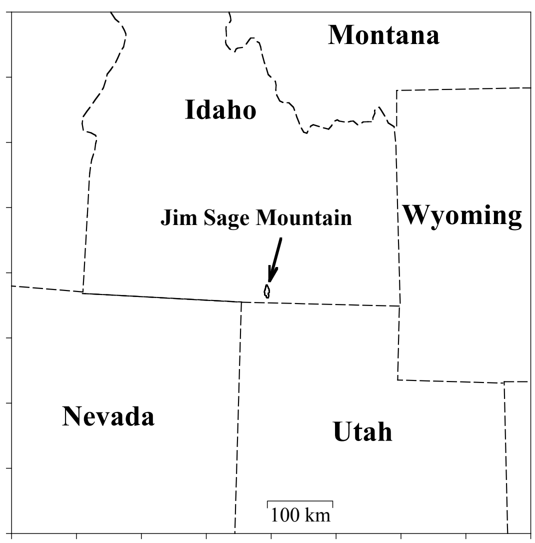

Fig. 1. Location of Jim Sage study site in southern Idaho.

METHODS

We observed vigilance behavior (head up and alert) in the released sheep during the summers in 2000 and 2001 and in the winters of 2000-2001 and 2001-2002. We made the observations with spotting scopes from existing roads. We maintained sufficient distance from the animals (>1.0 km) to minimize our influence on their behavior.

Observations consisted of 20 minute long focal samples in which we recorded to the second changes in the animal's behavior, e.g. feeding, surveying, etc. We limited the samples to animals that were actively feeding. We then calculated the total time of each behavior and then expressed it as a percentage of the total time observed. We also recorded the habitat type the sheep were using during the sample blocks. We identified 5 different habitat types: grass/sage (mainly open slopes with low growing grass and sagebrush; *Artemisia* spp.), sage (draws between slopes with higher growths of sage); scree (areas of loose small rocks); rocky (areas with varying amounts and sizes of rock outcrops); and cliffs (areas of 90^0 rock faces).

We compared arcsine transformed percent vigilance sheep exhibited within the different habitat types with a one-way ANOVA design. All means are $\pm$ standard error and the rejection level was set at $P \leq 0.005$.

RESULTS

We found significantly higher vigilance rates in rocky (32.3 $\pm$ 3.1 %) and cliff habitats (30.1 $\pm$ 4.5 %) than in sage (16.7 $\pm$ 1.8 %) and grass/sage areas (22.1$\pm$ 2.8 %; Fig. 2).

DISCUSSION

Based on our findings, sheep perceive open grass slopes as relatively safe. These results correspond to the observations of Risenhoover and Bailey (1985) and reinforce the concept that sheep prefer open habitats with short vegetation (Van Dyke et al. 1983). However, contrary to the existing perception, our data indicate sheep find traditionally defined escape terrain to be highly risky.

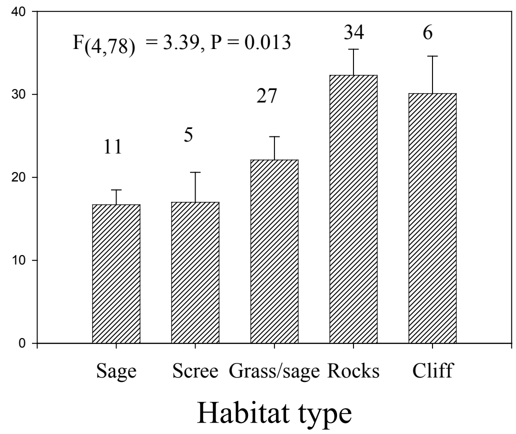

Fig. 2. Percent vigilance of sheep while foraging in the 5 habitat types of the study area.

MANAGEMENT IMPLICATIONS

Because our data indicate escape terrain represents areas of high predation risk, evaluating potential release sites may not be as simple as putting a 300 m buffer around identified escape habitat (Smith et al. 1991). Escape habitat is not safe and more is not better. We suggest we need to discard the concept of escape terrain from evaluation procedures. In place of escape terrain, we need to evaluate levels of predation risk sheep perceive in different habitat types. To do this, first we need to identify the different habitat types (Fig. 3). Once we have this information, we couple these habitat types with their appropriate risk levels and we can map the landscape of fear relative to this predation risk (Fig. 4). We can then add the other features of importance, i.e. distance to water, etc. (Singer et al. 2000c). Based on the final amount and configuration of the various habitat types (= risk levels) we can then assess if the area has adequate habitat safe from puma predation. All of this analysis should lend itself well to traditional modeling of sheep habitat with only substitution of risky habitat for escape terrain. We suggest such a change in evaluation is essential if we want to improve our success rate for sheep transplants.

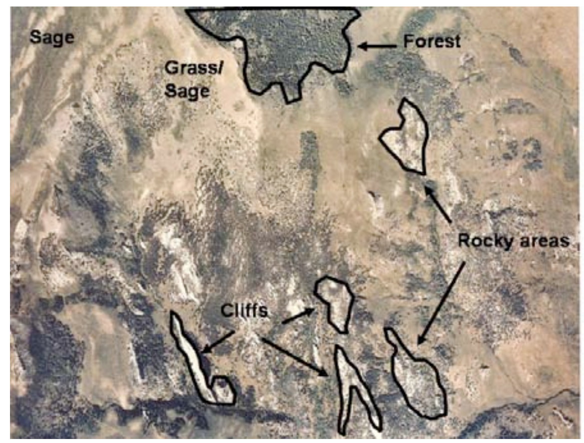

Fig. 3. Example of outlining some of the different habitat types from an aerial photo of sheep range.

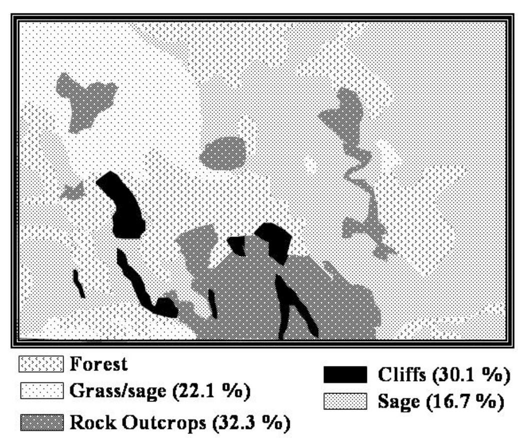

Fig. 4. Map of the landscape of fear where the different habitat types are represented by the corresponding levels of vigilance sheep exhibited in each area.

ACKNOWLEDGEMENTS

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HABITAT USE

Tim Schommer - Moderator

GIS-based Habitat Models for Bighorn Sheep Winter Range in Glacier National Park, Montana

GORDON H. DICUS, Glacier National Park, West Glacier, MT 59936, USA

Abstract: I used logistic regression to construct bighorn sheep winter range habitat models for 2 study areas in Glacier National Park (GNP), Montana. During 2 winters, habitat use was described through systematic ground surveys supplemented with focal observations, lasting 1-3 days, of recognizable individual sheep. Available habitat was evaluated using 12 habitat parameters, each measured at a 30-by-30 meter grid-cell resolution with GIS software. For each study area, a set of candidate models was constructed and then validation tested at the other study area. Using habitat parameters common to the best model from each study area, I then pooled all data to construct 2 versions of a final winter range model applicable across GNP. I compared the performance of the final GNP models to that of a regional model (the Smith model GIS application). The GNP models correctly classified 75% and 38% of grid-cells with observed winter use at the 2 study areas. The Smith model GIS application correctly classified 10% and 11% of grid-cells with observed winter use at the 2 study areas. Habitat parameters in the final GNP models were distance-to-escape terrain, snow cover, solar radiation index, slope, and either land-cover type (from a classified satellite image) or horizontal visibility and 2 satellite wavelength-band reflectance values. The final models will be useful to GNP managers for identifying suitable bighorn sheep winter range potentially threatened by conifer encroachment, livestock trespass, exotic plants, and/or illegal hunting pressure.

Key words: bighorn sheep, *Ovis canadensis*, GIS, logistic regression, habitat model, winter range

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Considerable bighorn sheep (*Ovis canadensis*) research over the past few decades has focused on creating and improving habitat models. Models can help wildlife managers assess potential reintroduction sites and evaluate habitat improvement options. Initial bighorn sheep habitat models were developed for desert bighorns (*O. c. nelsoni*) (Hansen 1980, Holl 1982, Armentrout and Brigham 1988). Smith et al. (1991) adapted desert bighorn habitat models to address the habitat requirements of Rocky Mountain bighorn sheep (*O. c. canadensis*). The Smith et al. (1991) model (hereafter referred to as the Smith model) was developed from observed habitat use by radio-collared sheep on a 6,900-hectare study area in northeastern Utah, and was intended as a generalized procedure for delineating suitable Rocky Mountain bighorn sheep habitat.

Recent developments in wildlife habitat models have taken advantage of Geographic Information System (GIS) computer software packages. GIS packages, using overlay capabilities and proximity functions, can rapidly and quantitatively assess large land areas to allow objective comparisons of potential habitat (Bleich et al. 1992, Singer and Gudorf 1999). The National Park Service (NPS) used a GIS application of the Smith model (with 8 primary habitat parameters, Table 1) for evaluation of potential reintroduction sites in and adjacent to national parks in the Rocky Mountain region (Johnson 1995, Sweanor et al. 1996, Singer and Gudorf 1999).

Escape terrain – steep, rocky terrain – is a critical bighorn sheep habitat component (Geist 1971, Hansen 1980, Holl 1982, Smith et al. 1988). Able to identify predators at great distances with their excellent eyesight, bighorns evade predators by retreating into escape terrain (Geist 1971). Escape terrain has generally been defined as continuous steep slopes ($\geq 27^{o}$) possessing rocky outcrops and/or cliffs $\geq$1.6 hectares in size and $\geq$15 m in height (Geist 1971, Tilton 1977, Smith et al. 1991). Except for some migration movements, bighorn sheep seldom venture more than 300-500 m from escape terrain (Gionfriddo and Krausman 1986, Wakelyn 1987, Smith et al. 1988). Especially rugged portions of escape terrain function as lambing habitat; the lack of such terrain can be a limiting factor on lamb survival (Geist 1971, Smith et al. 1988, Sweanor et al. 1996).

Horizontal visibility is another important habitat component because it allows bighorn sheep to detect predators at a distance and influences how far sheep are willing to stray from escape terrain (Geist 1971, Risenhoover and Bailey 1980, Krausman 1997). The minimum level of horizontal visibility established by researchers describing suitable bighorn sheep habitat has ranged from 55% to 90% (Smith et al. 1991, Johnson 1995, Sweanor et al. 1996). Even narrow tracts of very low visibility habitat (e.g., thick shrubs or dense timber with horizontal visibility below 30%) can act as barriers to bighorn sheep movement (Risenhoover and Bailey 1980, Smith et al. 1991). Fire influences horizontal visibility and historically played a central role in the maintenance of climax grassland communities. Decades of fire suppression have allowed shrub and conifer encroachment into grassland habitats, degrading bighorn sheep habitat and compromising migratory corridors between seasonal ranges and between subpopulations (Goodson 1980, Wakelyn 1987, Schirokauer 1996).

The availability of adequate forage resources is a basic habitat requirement. Smith et al. (1991) described the forage needs of a bighorn sheep population of 125 animals as 250-300 kg in dry weight of grasses and forbs per hectare; or, as an alternative, 14% canopy cover of grass and forb species. Managers, however, often need to evaluate habitat suitability across large geographic areas for which they do not have accurate estimates of forage quantity. Consequently, most efforts to evaluate or model the suitability of potential bighorn sheep ranges have foregone estimates of forage quantity and focused on the extent of escape terrain and the level of horizontal visibility within or adjacent to grassland habitats (Risenhoover and Bailey 1980, Holl 1982, McCarty 1993, Johnson 1995, Schirokauer 1996, Sweanor et al. 1996).

Some other habitat components of importance to bighorn sheep include water sources, barriers to sheep movements, human disturbance, and presence of domestic livestock (Smith et al. 1991, McCarty 1993, Sweanor et al. 1996, Singer and Gudorf 1999). While free water may act as a limiting factor only in extremely arid sites, most bighorn sheep habitat models have incorporated proximity to free water as a criterion for habitat suitability (Hansen 1980, Holl 1982, Armentrout and Brigham 1988, Smith et al. 1991). Potential barriers to bighorn sheep movement may be natural or man-made and include large rivers and lakes, dense vegetation, non-traversable

Table 1. Smith model GIS application habitat criteria used by the National Park Service in evaluating bighorn sheep habitat in Colorado, Utah, Wyoming, South Dakota, North Dakota and Montana. Additional criteria specified by the Smith model for delineating winter range are also shown. Taken from Sweanor et al. (1996).

Habitat Parameter	Definition
Escape terrain	Areas with slope > 27^o, < 85^o.
Escape terrain buffer	Areas within 300m of escape terrain and areas < 1000m wide that are bounded on at least 2 sides by escape terrain.
Vegetation density	Areas must have horizontal visibility > 60%.
Water sources	Areas must be within 3.2 km of water sources.
Natural barriers	Areas that bighorn sheep cannot access, e.g., rivers > 2000 cfs, areas with visibility < 30% that are >100 m wide, cliffs with slope > 85^o.
Human use areas	Areas covered by human development (e.g., roads, parking lots, and buildings).
Man-made barriers	Areas that cannot be accessed due to man-made barriers, e.g., major highways, wildlife-proof fencing, aqueducts, major canals.
Domestic livestock	Areas must be over 16 km from domestic sheep.
Winter Range – Areas meeting above criteria, with aspect between 120^o and 245^o, and snow depth <25 cm.	

cliffs, wide valleys and plateaus, canals, reservoirs, aqueducts, impassable fencing, major highways and roads, and high-use human development (Smith et al. 1991, Singer and Gudorf 1999). The impacts to bighorn sheep associated with domestic livestock include competition for space and forage, and transmission of disease. The greatest threat is posed by domestic sheep as they are capable of using steep slopes and have the greatest potential for transmitting disease to bighorn sheep (Singer and Gudorf 1999).

I constructed winter range habitat models for Rocky Mountain bighorn sheep on 2 study areas in Glacier National Park (GNP), Montana. Selection of habitat parameters was based on literature review and discussion with colleagues involved in wildlife habitat modeling. Each of 12 habitat parameters (Table 2) was measured at a 30-by-30 m grid-cell resolution using GIS software. I used logistic regression to construct candidate models, and assessed the significance of variable coefficients with likelihood-ratio tests. Candidate model performance was evaluated through validation tests. Using the habitat parameters from the best-performing candidate models, I constructed 2 versions of a final winter range habitat model applicable across GNP. I then compared the prediction accuracies of my final models to the accuracy of the winter range component of the Smith model GIS application used by the NPS in the Rocky Mountain region.

STUDY AREA

The 2 study areas (approximately 4,500 and 6,200 hectares in size) lie entirely within GNP and are situated along the Rocky Mountain Front, a topographically and biologically diverse transition zone between the Continental Divide and the Northern Great Plains. Study area elevation ranges from 1,480-2,830 m and annual precipitation averages 67 cm, about half of which falls as snow. On average, January is the coldest month with a mean minimum temperature of –14 C^O, and July is the warmest month with a mean maximum temperature of 23 C^O (Finklin 1986). Exceptionally strong, warm (chinook) winds are common along the Rocky Mountain Front, especially during winter and spring.

The montane zone along the Rocky Mountain Front typically hosts extensive aspen (*Populus tremuloides*) forests, with wetter sites often supporting black cottonwood (*Populus trichocarpa*). Grasslands, which in GNP occur as a broad band within the montane and subalpine zones, are primarily found on south to west facing slopes and often extend from the montane zone to above treeline. Cool-season bunchgrasses and shrubs dominate these grasslands. Forests of the subalpine zone are dominated by subalpine fir (*Abies lasiocarpa*), Engelmann spruce (*Picea engelmannii*), and/or lodgepole pine (*Pinus contorta*); lower subalpine forests often have Douglas fir (*Pseudotsuga menziesii*), while higher subalpine forests may hold whitebark pine (*Pinus albicaulis*) or limber pine (*Pinus flexilis*). Avalanche chutes are common on steep, warm slopes within the subalpine zone, are dominated by shrubs and herbaceous vegetation, and are typically associated with long, steep ravines that are moister than adjacent slopes. Along the upper edge of the subalpine zone, subalpine fir, spruce and whitebark pine are stunted and dwarfed by ice-scouring wind or heavy snow accumulation, resulting in sparse "krummholz" forests interspersed with alpine tundra or heath.

The alpine zone in GNP holds sparse vegetation because steep slopes and heavy snow accumulation constrain soil development. The most extensive alpine vegetation is comprised of fellfields dominated by alpine dryad (*Dryas octopetala*), arctic willows (*Salix* species), and alpine varieties of forbs, grasses, and sedges. Fellfields grade into turf on more protected slopes were deeper soils have developed. Dry turf communities are dominated by grasses, sedges, and forbs. Wet turf communities, which often develop below permanent snowfields, support dwarf shrubs, alpine dryad, and arctic willows as well as sedges and forbs. Talus and scree slopes are common in the alpine zone, and hold only very sparse plant cover (typically alpine dryad and some forbs).

METHODS

Ground Surveys

Ten systematic survey routes were established – 5 on each study area. Each route was surveyed once every 12-16 days during January-April of 2000 and 2001. Survey routes followed ridgelines and valley bottoms, using vantage points to scan for sheep with binoculars and spotting scopes. Each study area was broken into survey units on the basis of topography and vantage point perspectives, and each survey unit received survey effort proportionate to its size, ruggedness and vegetation density. Each bighorn sheep group was mapped as a point location, which represented the center of the group. When individual sheep were separated by less than 15-20 m, they were mapped as a single group. When the distance between sheep exceeded 20 m, they were mapped as separate groups. If a large group, with all individuals within 20 m of another sheep, was spread out across a distance of more than 50-60 m, I recorded and mapped the sheep as more than 1 group.

To ensure that sheep use of some cover types was not under-represented, I supplemented systematic surveys with focal observations of individual sheep during daylight hours for 1 to 3 consecutive days. Focal individuals were selected for recognizable traits (horn features or pelage patterns). To the extent possible, tracks in snow were used to infer unobserved movements.

GIS Data Layers

To facilitate the construction and validation of winter range habitat models, I superimposed a grid of 30-by-30 m cells over each study area. To each cell, I assigned values for each of 12 habitat parameters (see Table 2) identified as potentially important components of bighorn sheep habitat (Smith et al. 1991, McCarty 1993, Johnson 1995, Sweanor et al. 1996).

Digital Elevation Models and Digital Line Graphs.--A digital elevation model (DEM) consists of a georeferenced grid-cell layer, with each cell assigned an elevation value. DEMs are constructed at various scales, the most common and useful of which are a 7.5-minute (1:24,000) and a 30-minute (1:100,000) scale. For the purposes of habitat modeling, the 7.5-minute DEM is preferable as it characterizes slope and aspect and delineates escape terrain more accurately than the 30-minute DEM (Johnson 1995). Another product available from the U.S. Geological Survey (USGS) is the digital line graph, a grid-cell layer depicting linear features such as streams and roads.

I used Arc View GIS software to derive several habitat parameter theme layers from a 7.5-minute DEM coverage. I derived slope, aspect, and elevation theme layers in which each 900 m^2 grid-cell in the study areas was assigned a value for each of these parameters. Using the Sweanor et al. (1996) definition of escape terrain (see Table 1), I designated each cell as either meeting or not meeting escape terrain criteria. I then used an Arc View proximity function to generate a theme layer in which each cell was assigned a distance-to-escape terrain value. Similarly, I used a 7.5-minute digital line graph to create a distance-to-water theme layer.

I calculated a solar radiation index for each grid-cell in the study areas. The solar radiation index (SR_i), calculated by the equation shown below, incorporated the latitude (l_i), slope (s_i) and a transformed aspect (ta_i, computed as 180 – aspect, so that south is 0, westerly aspects range from 0 to –180, and easterly aspects range from 0 to +180) for each grid-cell (Kim Keating, USGS, personal communication).

$$SR_i = \cos(l_i)*\cos(s_i) + \sin(l_i)*\sin(s_i)*\cos(ta_i)$$

This solar radiation index is especially helpful because it offers an alternative method of entering aspect into a regression analysis. The traditional measure of aspect (0-360^o) is problematic because it is on a circular scale that has no absolute ordering of values (i.e., 360 is not greater than zero). To explore different methods of entering aspect into the modeling of a resource selection function, I also computed a transformed aspect variable, using the equation $TAsp_i = 1000*(\cos(a_i - 45) + 1)$ where a_i is the aspect (on a 0-360^o scale) for a given grid-cell (Beers et al. 1966).

Digital Raster Graphic Topographic Maps.--The USGS also produces digital versions of topographic maps. Again, these are georeferenced arrays of grid-cells

Table 2. Habitat parameters used for evaluating bighorn sheep winter range habitat at two study areas in Glacier National Park, Montana. Sources of information are also shown.

Habitat Parameter	**Source**
Continuous Variables	
Slope (°)	USGS digital elevation model
Aspect (°) - cosine transformed	USGS digital elevation model
Elevation (m)	USGS digital elevation model
Distance to escape terrain (m)	USGS digital elevation model
Distance to water (m)	USGS digital line graph
Distance to development (m)	USGS digital raster graphic 7.5-min. map
Distance to livestock (m)	USGS digital raster graphic 7.5-min. map
Horizontal visibility (%)	Field measurement
Solar radiation index	USGS digital elevation model
Vegetation composition index	Satellite imagery – spectral reflectance values
Categorical Variables	
Mid-winter snow cover (Y/N)	Satellite imagery – band 3 & 5 reflectance ratio
Land cover type classification	Satellite imagery – reflectance classification categories

and the finest resolution available is a 7.5-minute (1:24,000) map. Using Arc View GIS software, I selected all areas of human development (buildings, roads and parking lots) within or adjacent to the study areas, and then used a proximity function to assign each 900 m^2 grid-cell a distance-to-human development value. Similarly, taking advantage of an existing GIS theme layer depicting livestock grazing allotments on Blackfeet Indian Reservation lands bordering GNP's eastern boundary, I assigned each grid-cell in the study areas a distance-to-livestock use value. While domestic sheep were prevalent on the Blackfeet Indian Reservation throughout the first half of the 20th century, these grazing allotments have been used only for cattle and horses over the past several decades.

Satellite Imagery.--Also available from the USGS are Thematic Mapper (TM) image data from the Landsat satellite series. These TM images are georeferenced grid-cell layers containing light radiance values. Each grid-cell contains a radiance value for each of 7 wavelength-bands, and each radiance value is stored in binary format, which means the value can range from 0 to 255. While there is some flexibility in selecting a grid-cell size, most users deal with 30-by-30 m grid-cells. Because there is considerable variation in the magnitude of radiance values for the 7 wavelength-bands, it is helpful to transform the radiance values into reflectance values, which are more readily comparable across wavelength-bands. Reflectance values are essentially a calculation of the amount of light radiance detected by the satellite sensors for a given wavelength-band relative to the total amount of light available for that wavelength-band (Carl Key, USGS, personal communication). Furthermore, reflectance value calculations can take topography into consideration, thereby making the reflectance values more representative of vegetative or snow cover differences rather than topographic differences. The following equation calculates a cell by cell reflectance value (R_i) from the radiance value (L_i) and incorporates the eccentricity (d^2, the earth-to-sun distance), sun zenith angle (z_s) and sun azimuth angle (a_s) specific to the TM image being used, as well as the mean upper-atmosphere radiance for each wavelength-band (I_b), and the slope (s_i) and aspect (a_i) for each grid-cell (Carl Key, USGS, personal communication).

$$R_i = (3.1416*L_i*d^2)/(I_b*(\cos(z_s)*\cos(s_i) + \sin(z_s)*\sin(s_i)*\cos(a_s - a_i)))$$

Using this reflectance equation, I calculated topographically-adjusted reflectance values from 6 wavelength-bands (bands 1-5 and band 7) for both a spring (May 23, 1999) TM image and a summer (July 7, 2001) TM image. Some researchers have found TM reflectance values useful in modeling resource selection functions, especially in the absence of vegetation cover type data (Kim Keating, USGS, personal communication). Finally, I used a TM image classification completed by USGS personnel at the Glacier Field Station to assign 1 of 8 land-cover types (Table 3) to each grid-cell within the study areas. Image classification procedures involve an iterative process of grouping cells based on similarities in their reflectance values, and are quite useful in distinguishing among land-cover types (Carl Key, USGS, personal communication).

Most researchers modeling bighorn sheep habitat have specified that suitable winter range must be relatively snow-free; Smith et al. (1991) defined suitable winter range, in part, as areas with snow depths of less than 25 cm. I used TM imagery to characterize snow deposition across my study areas. A ratio of the difference in wavelength-band 3 and 5 reflectance values [(3-5)/(3+5)] performs well in delineating snow cover (Carl Key, USGS, personal communication). I calculated this ratio to accentuate areas covered by snow in 2 TM images -- April 1, 1992 and May 23, 1999. These images were selected from a set of images available at the USGS Glacier Field Station, and were chosen for their clarity (no cloud cover) and a lack of recent snowfall immediately proceeding their date of data capture. For all areas covered by snow in both or either of the 1992 and the 1999 images, I assigned a snowbound value (Yes) to each grid-cell. Conversely, for all areas that were free of snow in both images, I assigned a snow-free value (No) to each grid-cell.

Horizontal Visibility.--To characterize horizontal visibility on my 2 study areas, I assigned visibility values to land-cover types (see Table 3). At least 10 transects were sampled in each land-cover type, then every grid-cell was assigned a horizontal visibility (averaged to the nearest 10%) on the basis of its land-cover type designation. Along 40 m transects at representative sites in each land-cover type on both study areas, I estimated horizontal visibility in 4 cardinal directions at 10 m intervals. Percent horizontal visibility at each representative site was then determined by averaging the 20 estimates collected along the 40 m transect.

Model Development and Testing

Among wildlife researchers, logistic regression has been a popular and effective method for calculating a resource selection function on the basis of a species' presence or absence within sampling units (Walker 1990, Manly et al. 1993, Mace et al. 1998). From a set of values for specified habitat variables at a given sampling unit, the resource selection function then calculates the probability of the species of interest using that sampling

Table 3. Eight land-cover type categories identified in a USGS classification of Thematic Mapper satellite imagery for Glacier National Park, Montana. Associated horizontal visibility percentages, determined through field sampling and averaged to nearest 10%, are also shown.

I.D. #	Land-Cover Type Category	Horizontal Visibility
1	Dry Herbaceous	90
2	Mesic Herbaceous	70
3	Deciduous Tree/Shrub	50
4	Dense, Mesic Coniferous Forest	30
5	Water (Lakes and Rivers)	90
6	Barren Rock/Soil	90
7	Snow (Glaciers and Permanent Snowfields)	90
8	Open, Dry Coniferous Forest	50

unit (Hosmer and Lemeshow 1989, Manly et al. 1993). In this study, the binary response (or dependent) variable is the presence or absence of bighorn sheep within a given 900 m^2 grid-cell as determined through systematic ground surveys. The 12 explanatory (or independent) variables (see Table 2) were selected on the basis of a bighorn sheep habitat model literature review and consultation with colleagues involved in habitat modeling. The logistic regression method is analogous to linear regression, except that instead of constraining the fit of the regression through a least squares method, a maximum likelihood function is employed, and the relationship between the response variable and explanatory variables is non-linear (Hosmer and Lemeshow 1989).

Logistic regression generates a set of coefficients for the explanatory variables, and the regression equation results in an expected probability for each set of explanatory variable values. The probability of an event occurring, in this case the probability that bighorn sheep were present in a given grid-cell, can be expressed as

$$\text{Prob(sheep present)} = e^Z/(1 + e^Z)$$

where $Z = B_O + B_1*X_1 + B_2*X_2 + B_3*X_3 + \ldots + B_K*X_K$. Here, *e* is the base of the natural logarithm, B_O through B_K are the estimated coefficients, and X_1 through X_K are values of the K explanatory variables for that given grid-cell. The standard measure of a logistic regression model's fit is the likelihood – the probability of the observed results given the set of explanatory variable coefficients. Because the likelihood is a small value (between 0 and 1), most statistical software programs express the measure of a model's goodness-of-fit as –2LL, or –2 times the log of the likelihood. The smaller the value of –2LL, the better the fit of the model.

The interpretation of coefficients in logistic regression is less straightforward than in linear regression. In logistic regression, the coefficient for a given explanatory variable indicates the change in the odds ratio for a 1-unit change in that explanatory variable. The odds ratio is the ratio of the probability that an event will occur to the probability that the event will not occur. The log of the odds ratio (the logit) is equal to Z, the equation containing the coefficients and explanatory variables. Analogous to linear regression, a positive coefficient indicates that as the value of that explanatory variable increases, the odds ratio increases; and a negative coefficient indicates a decrease in the odds ratio as the value of that explanatory variable increases. Coefficients of explanatory variables are assessed with test statistics, which constitute hypothesis tests of the null hypothesis that a coefficient is equal to zero. In logistic regression, the preferred test statistic is the likelihood-ratio (LR) test (Hosmer and Lemeshow 1989).

I used SPSS (Statistical Package for the Social Sciences) software to construct and evaluate the fit of logistic regression models. I began by conducting univariate tests for each explanatory variable using the LR test to assess its significance in explaining the observed values of the response variable. This was accomplished by entering all explanatory variables into a backward-stepwise logistic regression analysis, the first step of which results in an LR test value for each variable. The inclusion of variables into candidate models was based on LR test values using a liberal upper significance limit ($p<0.20$) so that all potentially useful explanatory variables would be included in 1 or more models (Hosmer and Lemeshow 1989). These regression analyses were conducted separately for the data from each study area. Using my knowledge of existing habitat models and my professional judgement, I grouped these potentially useful explanatory variables into a set of candidate models for each study area.

Following model construction, each candidate model was examined for the presence of nonlinear relationships between the explanatory variables and the response variable logit (i.e., the log of the odds ratio). This was accomplished by plotting each continuous explanatory variable against the deviance residuals generated by that model. If no pattern is seen in such a scatterplot, the relationship between that explanatory variable and the response variable logit is approximately linear. A curved pattern suggests the relationship is nonlinear, and that a transformation of the explanatory variable should be considered.

Interactions between variables were considered for each candidate model. Sensible interaction terms were added to the model, and their LR test statistics were examined for significance. Each candidate model was further examined for the presence of explanatory variable values with unusually high influence on the model's coefficients. Predicted probabilities were plotted against leverage and Cook's distance values, both measures of how much the coefficients change when that particular set of explanatory variables is omitted from the regression. To optimize model fit, cases with large leverage or Cook's distance values (>0.2 and >0.6, respectively) were omitted, and the logistic regression model was re-computed (Hosmer and Lemeshow 1989). In addition, each model was examined for the presence of colinearity among explanatory variables. The most obvious sign of colinearity is when coefficients have unusually large values and large standard errors (Hosmer and Lemeshow 1989). Another way to look for colinearity is to enter the response and explanatory variables into a linear regression analysis, and look at standard linear regression statistical measures of colinearity such as tolerance and condition index values (Menard 1995).

Candidate model goodness-of-fit was assessed using the Hosmer and Lemeshow Chi-square statistic and Akaike's information-theory criteria (AIC) statistic (Boyce et al. 2001). A small Hosmer and Lemeshow Chi-square test statistic value resulting in a large significance value (e.g., $p > 0.5$) indicates a well-fit model. The AIC statistic is calculated simply as –2LL + 2*K, where K is the number of explanatory variables in the model (Boyce et al. 2001). A lower AIC value indicates a better model fit. In essence, the AIC statistic penalizes a model that adds variables without gaining a better fit as measured by –2LL (i.e., -2*log-likelihood).

The best way to test the performance of a candidate model, however, is to validate the model with data that were not used in constructing the model. Each of my candidate models was constructed with data from a single study area. This meant that I could validate each candidate model with data from the other study area. The performance of different models was compared through cross tabulations showing the rates of commission and omission. Finally, I compared the predictive accuracy of my best-performing models to the accuracy of the winter range component of the NPS-modified Smith model GIS application.

RESULTS

Ground Surveys

I observed bighorn sheep during 480 observation sessions conducted over the course of 2 winters. Observation sessions occurred at vantage points along 10 survey routes, averaged 39 minutes in duration (range of 20-330 minutes), and amounted to 316.7 hours of total observation time, during which 1,061 sheep group locations were mapped. The average group size was 7 sheep (range of 1-42).

Focal observations involved tracking the movements of a recognizable individual over the course of at least 1 full day and sometimes up to 3 consecutive days. These focal observations typically occurred from survey route vantage points; such that sheep were observed from a distance of 800 m to 2 km, and care was taken to not disrupt normal sheep behavior. A total of 20 focal observation sessions were completed during winter months (Jan-Apr) and in all cases the recognizable individual was in a sheep group (size range of 2-11 sheep). Ten of the focal observations were 1-day sessions, 6 were 2-day sessions, and 4 were 3-day sessions. During all 20 observation sessions, the focal individual remained within the study area and no movements into unexpected habitat types (e.g., dense conifer) were recorded.

To depict bighorn sheep habitat use in a grid-cell layer, I used Arc View GIS software to create a 35 m buffer around sheep group location points, then converted the resulting shape file into a grid layer. Because the GIS software uses a corner of each grid-cell for the reference coordinates, this conversion meant that each sheep group location resulted in a cross-shaped cluster of 12 grid-cells being designated as "sheep present." To assess potential bias against sighting small groups at long distances, I plotted sheep group size against observer-sheep distance. No pattern was discernable, and given the proportional application of survey effort relative to the size, ruggedness and vegetation density of each survey unit, the assumption that all sheep groups had equal probability of detection appeared to have been satisfied.

Candidate Models – Goodness-of-Fit and Colinearity Assessment

On the basis of the Hosmer and Lemeshow Chi-square test and Akaike's information-theory criteria (AIC) statistics, none of my candidate models fit the observed bighorn sheep habitat use data well. All Hosmer and Lemeshow Chi-square test statistic values had very small significance values ($p<0.005$) and all AIC values were quite large. No interaction terms had significant LR test values or offered improvements in model fit, therefore none were included in any of the candidate models.

Although none of the candidate models had large coefficient values or standard errors (signs of colinearity among explanatory variables), I performed a linear regression analysis for each model to examine tolerance and condition index measures of colinearity (Menard 1995). The only explanatory variable displaying a tolerance value (<0.20) or condition index value (>15) indicative of colinearity was horizontal visibility. This is not surprising since horizontal visibility values were assigned to grid-cells by their land-cover type category; therefore, any model that included both these variables would display some colinearity. This colinearity was not problematic, as land-cover type contributed more significantly to model performance than did horizontal visibility.

Model Validation Tests

Validation tests are especially important with models intended for use in prediction (Hosmer and Lemeshow 1989). With each of my candidate models, I performed a validation test using data from the study area not involved in that model's construction. Because the response variable predicted probabilities ranged from 0 to approximately 0.26, my candidate models achieved their best separation of used and unused cell classification using a probability cut-off value of 0.13 – i.e., cases that resulted in a predicted probability of use <0.13 were classified as unused, and cases that resulted in a predicted probability of use >0.13 were classified as used. A common and straightforward means of assessing performance in a validation test is cross tabulation – an assessment of the predicted classification of cells versus the observed classification (Hosmer and Lemeshow 1989). The most common measures obtained from a cross tabulation are the rates of commission and omission. The rate of commission is the percentage of cells correctly classified by the predictive model, including both categories of classification (present/used, and absent/unused). The rate of omission is the percentage of cells incorrectly classified. In addition to recording these measures for each validation test, I calculated the percentage of cells with observed bighorn sheep use that were correctly classified as used (the "rate of positive commission"), and the ratio of all cells classified as used to the number of cells correctly classified as used (the "positive ratio"). I ranked candidate model performance based primarily on the rate of positive commission and the positive ratio.

To derive a single model capable of predicting bighorn sheep winter habitat across all of Glacier National Park (GNP), I pooled the data from both study areas and repeated the logistic regression analysis using the format of my best candidate models. The best candidate models were selected on the basis of validation tests, but model simplicity was also considered. Because there is potential for this final model to be applied at sites outside GNP where the user may not have classified satellite imagery, I examined the effect of replacing the land-cover type variable with 2 satellite reflectance variables in terms of validation test performance. I selected the 2 wavelength-bands (2 and 5) on the basis of LR tests conducted during model construction. This second version of the final model also contained the horizontal visibility variable, which was excluded from the first version because of colinearity with the land-cover type variable.

Finally, I conducted a validation test of the winter range component of the Smith model GIS application. I compared the validation test performance of the Smith model application to that of my 2 final model versions (Table 4). On the basis of positive commission and positive ratio measures from cross tabulations, my final model performed slightly better with the land-cover type variable than with the 2 reflectance variables, and both versions of my final model performed considerably better than the Smith model application.

The values of the constant and coefficients for both versions of my final model are shown in Table 5. Because the land-cover type version of my final model contains a categorical explanatory variable with 8 categories (land-cover type, see Table 3), this equation contains 7 indicator variables. When a categorical explanatory variable is entered into a regression analysis, it is necessary to create indicator variables to identify the category assigned to a particular sampling unit. The number of indicator variables required is 1 less than the number of categories in the explanatory variable because 1 category (either the first or the last) is represented by all zeros.

DISCUSSION

Ground Surveys

Based on observations from ground surveys conducted during winter, bighorn sheep on my 2 study areas appeared to prefer open grassland and rocky habitats to conifer habitats. This generalization was supported by focal observation sessions and opportunistic observation of sheep tracks in snow. During all of my focal observation sessions, the focal individual remained in open habitats and did not venture into forest habitats or into dense, tall shrub habitats adjacent to forest stands. Sheep tracks in snow were infrequently encountered along or near forest edges; these tracks were typically in open grassland and rocky habitats, and occasionally in shrubby and coniferous habitats. Tracks in shrubby sites were generally accompanied by evidence of shrub browsing. On a few occasions, I observed track evidence indicating that bighorn sheep had traveled shrubby, streamside routes through otherwise forested habitat for relatively short distances (50-200 m). These areas typically had only light snow accumulations (<25 cm), and field measurements of horizontal visibility were generally 20-50%. These track observations offer anecdotal evidence that, during winter, most bighorn sheep browsing on shrubs occurred on brushy slopes, in avalanche chutes, and along streams. These sites were characterized by fairly dense shrub canopy cover and were typically located above treeline or immediately adjacent to coniferous forest. During winter, shrubby sites at or above treeline generally had horizontal visibility ≥50%.

Dense and contiguous forest stands tended to have greater snow depths throughout winter than open, wind-swept slopes. Bighorn sheep made very little use of these forest stands until mid- to late-spring and early-summer when the snow cover had either melted or become densely compacted. Observations of tracks, fecal pellets, and occasionally of sheep indicated that during mid- to late-spring and early-summer bighorn sheep sometimes traveled through extensive, contiguous forest as they moved to lambing and/or summer ranges. Most of

Table 4. Validation test performance measures for 2 habitat models developed at Glacier National Park (GNP), Montana, and for the Smith model GIS application. For the 2 GNP models, group classification (sheep present or sheep absent) was based on a 0.13 probability cut-off value. Validation tests were conducted for 2 study areas – Many Glacier and Two Medicine.

Test Area	Commission[a]	Omission[b]	Positive Comm[c]	Positive Ratio[d]
		GNP Model (w/ land-cover type)		
Many Glacier	77.7%	22.3%	75.2%	4.0
Two Medicine	72.0%	28.0%	38.8%	7.0
		GNP Model (w/ bands 2 & 5, and horizontal visibility)		
Many Glacier	77.8%	22.2%	75.3%	4.0
Two Medicine	71.9%	28.1%	37.6%	7.2
		Smith Model GIS Application		
Many Glacier	73.6%	26.4%	10.5%	21.0
Two Medicine	76.6%	23.4%	11.1%	15.1

a – Rate of Commission is the percentage of cells correctly classified as used or unused by the model. For example, if among 100 grid cells observed to be used by sheep, 60 are classified as used and 40 as unused by a predictive model, and among 400 grid cells observed to be unused by sheep, 90 are classified as used and 310 as unused, then the model's rate of commission is (60+310)/500 = 0.74, or 74%.
b – Rate of Omission is the percentage of cells incorrectly classified as used or unused by the model. From the example above, the model's rate of omission is (40+90)/500 = 0.26, or 26%.
c – Rate of Positive Commission is the percentage of cells observed to be used by sheep (i.e., a positive response) that were classified as used by the predictive model. From the example above, the model's rate of positive commission is 60/100 = 0.6, or 60%.
d – Positive Ratio is the ratio of the total number of cells classified (correctly and incorrectly) as used to the number of used cells correctly classified as used. From the example above, the model's positive ratio is (60+90)/60 = 2.5.

this anecdotal evidence of forest travel was seen in lodgepole pine (*Pinus contorta*) forest, where horizontal visibility averaged 30-50%.

Model Goodness-of-Fit and Validation

The goodness-of-fit measures for all candidate models indicated rather poor fit. These poor goodness-of-fit measures were due in part to the very large number of unused sampling units (grid-cells). Even within areas used by bighorn sheep, there were large numbers of "unused" grid-cells with explanatory variable values similar to the "used" cells. This situation makes it difficult for regression techniques to find clear group separation trends in the explanatory variables. It is likely that if sheep habitat use was documented for many consecutive winters so that a high percentage of grid-cells within sheep use areas were labeled as "used," then the regression models' goodness-of-fit measures would improve. At first glance it may appear that model fit might be improved by increasing the size of the sampling unit. However, this would likely exacerbate the dilemma because explanatory variable values would be averaged on a larger scale, which might further diminish any separation trends between "used" and "unused" grid-cells.

Table 5. Explanatory variables and their coefficients, with standard errors, for two models for predicting bighorn sheep winter range in Glacier National Park, Montana.

Model	Variable[a]	Coefficient	Standard Error
	Constant	- 1.9892	0.1092
	Distance to Escape	- 0.0003	0.00006
	Snow Cover (Y/N)	- 1.0738	0.0325
	Solar Radiation Index	+ 0.00017	0.000011
GNP Model	Slope (degrees)	- 0.0002	0.000017
with land-	LCT Category 2	- 0.7698	0.0709
cover type (LCT)	LCT Category 3	- 1.007	0.0781
	LCT Category 4	- 0.3452	0.0567
	LCT Category 5	- 1.9407	0.0958
	LCT Category 6	- 0.0579	0.0079
	LCT Category 7	- 0.4277	0.0701
	LCT Category 8	- 1.4078	0.256
	Constant	- 3.5568	0.2114
	Distance to Escape	- 0.0032	0.0001
GNP Model	Snow Cover (Y/N)	- 1.0327	0.0282
with horizontal	Solar Radiation Index	+ 0.000164	0.000005
visibility	Slope (degrees)	- 0.00025	0.000016
and TM reflectance	Horizontal Visibility (%)	+ 0.0177	0.0008
	Band 2 Reflectance	- 0.000171	0.000013
	Band 5 Reflectance	+ 0.000173	0.000013

a – Explanatory variables: distance to escape terrain; snow cover (binary – yes or no); solar radiation index (computed using slope and aspect); slope (in degrees); land cover type (from a Thematic Mapper satellite image classified into 8 land cover categories, regression analysis defines this variable using 7 binary indicator variables, LCT 2 – LCT 8); horizontal visibility (in percent) was assigned to sampling units through correlation with land cover categories; band 2 and band 5 reflectance values from Thematic Mapper satellite image wavelength bands 2 and 5, adjusting radiance values for the influence of topography.

Although the goodness-of-fit measures for all of the candidate models were rather poor, a measure of greater interest is how well they predict bighorn sheep winter range habitat use. In order to be useful to land managers, the models must do an adequate job of predicting suitable habitat, and this is best assessed through validation tests – i.e., applying the model in an area not used for developing the model and comparing model predictions to known use patterns for that area. The most commonly reported measure of model performance in validation tests is the rate of commission – the percentage of cells correctly classified, which in the case of a logistic regression model involves only 2 classification categories. The rate of commission, however, is sensitive to the relative sizes of the 2 categories and will always favor classification into the larger category, independent of model fit (Hosmer and Lemeshow 1989). For example, in both of my study areas the number of unused cells exceeds the number of used cells by a factor of 10; therefore, a model that correctly classifies a high percentage of unused cells but a very low percentage of used cells still registers a high rate of commission, which as a measure of the model's performance is misleading. To get a more accurate picture of model performance, I examined the rate of positive commission (i.e., the percentage of cells known to be "used" that the model classified as "used") and the positive ratio (i.e., the ratio of the total number of cells classified, correctly and incorrectly, as "used" to the number of cells correctly classified as "used"). Clearly, a model with a high rate of positive commission and a small positive ratio is performing better than a model with a low rate of positive commission and a large positive ratio.

Final Models

While the development and validation of 2 sets of candidate models was critical to the selection of the best models, the overall goal was to derive a final model applicable across all of GNP, and perhaps at sites in other geographic areas. This final model contained the following explanatory variables: distance-to-escape terrain, snow cover, solar radiation index, slope, and land-cover type.

Although resource managers at GNP have ready access to a satellite image classification of land-cover types, land managers elsewhere may have neither vegetation maps nor satellite image classifications. For this reason, and given the wide availability of satellite imagery and its digital radiance values, I also derived a reflectance-value version of my final model using wavelength-band 2 and band 5 reflectance values in place of the land-cover type variable (see Tables 4 and 5).

Explanatory Variables Excluded from Final Models

The 2 final model versions were reached through assessment of model performance in validation tests as well as consideration of model parsimony. The fewer variables in a model, the easier that model is to use and interpret. On the other hand, if these final models were applied to a site outside GNP, it may turn out that they do not contain a parameter important to bighorn sheep winter range habitat suitability at that site.

Horizontal visibility is 1 variable that, although excluded from the land-cover type version of my final model, would quite likely prove to be important at other sites. Horizontal visibility has been identified as a necessary component of bighorn sheep habitat (Risenhoover and Bailey 1980, Krausman 1997). This variable was not included in this version of my final model because of its colinearity with the land-cover type variable, which was used as the basis for assigning horizontal visibility values across the study areas. My second final model version, containing 2 satellite reflectance value variables in place of the land-cover type variable, includes horizontal visibility, which contributed significantly to the model's goodness-of-fit, as evidenced by its large LR test statistic.

Availability of water was identified as an important variable in other habitat models, including the Smith model GIS application (see Table 1). None of the grid-cells in my 2 study areas was >3.2 km from water, which is the maximum distance for habitat suitability established by the Smith model application. The distance-to-water variable was not significant, as measured by the LR test statistic, and was therefore not included in any of my candidate models. Sites with less abundant sources of water than my

GNP study areas would likely find distance-to-water to be an important variable, as might efforts to model bighorn sheep summer range within GNP.

While Smith et al. (1991) identified distance-to-human development as an important factor regarding suitable bighorn sheep habitat, subsequent work has found that it contributes little to habitat suitability assessments (Johnson 1995, Sweanor et al. 1996). Although areas covered by buildings, roads and parking lots clearly offer no essential resources to bighorn sheep, they are generally not detrimental to sheep unless associated with elevated levels of stress and/or mortality (e.g., frequent and sustained human disturbance, unsustainable harvest or roadkill).

Distance-to-livestock is clearly an important parameter of suitable bighorn sheep habitat because of potential competition for forage and space, and especially because domestic sheep are known to pose a significant threat of disease transmission to bighorn sheep (Stelfox 1971, Rowland and Schmidt 1981, Smith et al. 1988). When using the Smith model GIS application to evaluate potential reintroduction sites, the National Park Service has stressed that those reintroduction sites must be at least 16 km from areas used by domestic sheep (Sweanor et al. 1996). While domestic sheep were prevalent along GNP's entire eastern boundary through the first half of the 20th century, grazing allotments along this boundary have been used only for cattle and horses over the last several decades. Although the distance-to-livestock variable did not prove significant in my analysis, cattle and horse trespass into GNP is a management issue of concern regarding spread of exotic plants and competition for forage and space.

Management Implications

One deficiency in the predictive performance of my final models is their limited ability to predict bighorn sheep winter range habitat use on north-facing slopes. The majority of bighorn sheep groups observed during winter were on southerly aspects, and indeed the Smith model GIS application restricts suitable winter range to aspects between 120^o and 245^o (Johnson 1995, Sweanor et al. 1996). However, my ground surveys documented use of snow-free, north-facing slopes. Although use of these slopes, compared to use of southerly slopes, was infrequent, it occurred throughout the winter. Future investigation into additional variables or modified analyses that would allow more sensitivity in predicting suitable north-facing sites for winter range would be valuable.

Probably the most pressing management concern for bighorn sheep in GNP as well as other sites in the Rocky Mountains is the encroachment of conifers into bighorn sheep habitat, especially low- to mid-elevation winter range areas (Schirokauer 1996). My final models should prove useful to GNP natural resource managers interested in identifying those bighorn sheep winter ranges most threatened by conifer encroachment, as well as historically suitable winter range that has already been fragmented by conifer encroachment. Potential management actions for such sites include prescribed fire and tree thinning.

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The Suitability Of GPS Wildlife Collars For Studying Coastal Habitat Use By Mountain Goats

SHAWN D. TAYLOR, Wildlife Research Group, Faculty of Agricultural Sciences, University of British Columbia, 208-2357 Main Mall, Vancouver, B.C., Canada V6T 1Z4

Abstract: During winter, mountain goats (*Oreamnos americanus*) in coastal British Columbia and Alaska are known to use lower elevation forests relative to other seasons. While conventional radiotelemetry is one viable method for studying coastal goats, signal reflection, reliance on clear weather, and harassment of goats during critical winter or kidding periods, all present shortcomings. GPS offers a potential solution to these problems, yet introduces others. Some of the most challenging environments for GPS fix acquisition, namely incised, heavily forested valleys, exist within coastal goat habitat. Even in much less demanding environments, fix likelihood bias is known to exist. While habitat researchers have become aware of this, few have corrected for potential bias within their habitat selection studies. I collared 4 mountain goats within the Stafford River Valley on the mainland coast of B.C. as a test of GPS wildlife collar performance in challenging terrain, and to explore the consequences of GPS fix likelihood bias for habitat selection studies. I also tested the repeated fix success of similar collars placed at other sites, varying in forest canopy and topographical relief. After leaving these stationary collars to attempt fix locations over a 24 hour period, I determined the percentages of 2D, 3D and unsuccessful fixes. I combined digital elevation models with an ArcAvenue GIS script to quantify available windows of satellite "sky" that were accessible from each test location. This measure, combined with surveyed and digitized habitat variables, allowed me to calculate multiple regression equations to successfully predict variability in GPS fix likelihood. Using these ground truthing equations in a GIS, I determined the likelihood of obtaining a GPS fix within any portion of the Stafford River study area, and was therefore able to match each individual animal's locations directly to GPS fix probability. Observed GPS fix rates from collared animals were correlated to that predicted from regression equations ($R^2 = 0.60$). I then applied a simple and conservative correction factor to each fix location and conducted an analysis of mountain goat forest habitat selection with corrected and uncorrected 3D data. My results show that researchers must account for GPS fix likelihood bias in mountain environments or erroneous and sometimes opposite selection interpretations can result.

Evaluation Of Habitat Selection By A Reintroduced Population Of California Bighorn Sheep (*Ovis canadensis californiana*) In South-Central Idaho

GRETCHEN FOWLES, Department of Biological Sciences, Idaho State University, Gail Life Sciences, Box 8007, Pocatello, ID 83209 U.S.A.
JOHN LAUNDRÉ, Instituto de Ecologia, A.C., Chihuahua Regional Center, Aldama Chihuahua, 32900 Mexico and Department of Biological Sciences, Idaho State University, Pocatello, ID 83209 U.S.A.
TIM FERGUSON, Idaho Department of Fish and Game, 868 E. Main, Jerome, ID 83338 U.S.A.
NANCY HUNTLY, Department of Biological Sciences, Idaho State University, Gail Life Sciences, Box 8007, Pocatello, ID 83209 U.S.A.

Abstract: Translocations have proven to be a successful conservation tool for reestablishing populations of bighorn sheep in areas where they have been extirpated. The success rate, however, of these translocations has been variable, with lack of habitat being a common source of failure. Given that translocation efforts are extremely expensive and time consuming, it is vital that we maximize their success rate by gaining a better understanding of what habitat is suitable for bighorns, and also rigorously assess proposed reintroduction areas to assure that enough usable habitat is available. In February of 2000 and 2001, 45 California bighorn sheep (*Ovis canadensis californiana*) were translocated from Oregon to the Jim Sage Range in Idaho in an effort to restore them to their historic habitat. Over a 23-month period after the first release we used radio telemetry to estimate the habitat use of the sheep population. We then used GIS and the logistic regression modeling technique to compare the habitat characteristics of used sheep group locations versus the characteristics of randomly selected locations. The characteristics included vegetative composition, terrain ruggedness, distance to water sources, distance to steep slopes, slope, aspect, and elevation. We developed seasonal predictive habitat selection models based on winter ($n = 55$), lambing ($n = 130$), and summer ($n = 211$) habitat use. The habitat models correctly classified 83 – 87% of used sites. The models predicted that 35% of the Jim Sage Range contained favorable lambing habitat, 34% favorable summer habitat, and 41% favorable winter habitat. Across all seasons, distance to steep slopes significantly contributed to the presence of sheep. Otherwise, the predictive subset of variables that best described sheep habitat selection varied by season. The models can be used to determine which habitat variables are important for sheep, and to predict the amount and distribution of favorable habitat in an area. Consequently, the models can be applied to manage sheep where they currently exist, and also evaluate future reintroduction sites.

Bite Rates In Bighorn Sheep: Effects Of Season, Age, Sex And Reproductive Status

KATHREEN E. RUCKSTUHL, Groupe de recherche en écologie, nutrition et énergétique, Département de biologie, Université de Sherbrooke, Sherbrooke, PQ, J1K 2R1,Canada.
JON T. JORGENSON, Natural Resources Service, Canmore, AB, T1W 1P1, Canada
MARCO FESTA-BIANCHET, Département de biologie, Université de Sherbrooke, Sherbrooke, PQ, J1K 2R1, Canada.

Abstract: We investigated the effects of vegetation biomass, crude protein content of consumed forage, age, sex and reproductive status on bite rates in Rocky Mountain bighorn sheep. We expected higher bite rates and vigilance in lactating females with young and higher bite rates in young growing individuals, than in non-reproducing females or rams. Lactating ewes had higher bite rates than yeld ewes and than subadult or adult rams. Subadult rams had higher bite rates than adult rams or yeld ewes. On recently burned grassland in spring, however, rams had a higher bite rate than adult females, while the contrary was true on control plots and on the burned plots in autumn. Bite rates declined for both ewes and rams from April to September and varied from year to year. While rams of different ages had significantly different bite rates, there was no effect of age on bite rates for ewes. There was no correlation between bite rates and available total biomass or biomass of live vegetation, or the numbers of steps taken while foraging for either ewes or rams. Adult rams had a lower vigilance rate than adult ewes, and vigilance decreased with increasing bite rates for all sheep. Bite rates in bighorn sheep vary greatly according to age, season and vegetation structure. An increase in bite rates during the forage growing season may compensate for higher energy demands during lactation and growth. There is a potential trade-off between foraging and vigilance as vigilance decreased with increasing bite rates.

CAPTURE AND DISEASE TESTING PROTOCOLS

Kevin Hurley - Moderator

Wild Sheep Capture And Disease Testing Protocol

CRAIG FOSTER, Oregon Department of Fish and Wildlife, PO Box 1214, Lakeview, OR, 97630 U.S.A.
KEVIN HURLEY, Wyoming Game and Fish Department, 356 Nostrum Road, Thermopolis, WY 82443, U.S.A.

Summary of discussion on Draft 2 of the wild sheep capture and disease testing protocol.

In 1999 at the 2nd North American Wild Sheep Conference (Thomas and Thomas, 200) a need was identified to develop guidelines for the capture and relocation of bighorn sheep. By May, 2001 draft 1 of this document was developed by members of the Northern Sheep and Goat Council and draft 2 was presented for editorial comments at the 13th biennial symposium in Rapid City. Copies of draft 2 were available at registration with a request that attendees review the document and be prepared to present editorial comments at the work session scheduled for April 25th.

Draft 2 was titled Wild Sheep Capture Protocol. Major sections in the draft were: Requirements for Importation of Bighorn Sheep from Canada to the U.S. Animal Health and Standard Testing. Capture and Handling Procedures. Capture Methods. Transport. Release. Personnel Assignments and Duties.

Many comments and ideas were provided during the work session, Most of these comments were directed toward very specific items presented in the document and most will be incorporated into the next draft. Following are the major topics discussed during the work session and decisions made.

In the title "protocol" infers that the methodology presented is the only appropriate way to capture and handle bighorn sheep. Consensus was reached that this document will be guidelines for the capture and handling of bighorn sheep, primarily for relocation. Therefore, the title should be changed to "Guidelines for the capture and handling of wild sheep", recognizing that every capture operation is different and there are no absolutes.

Animal Health and Standard Testing:

There was considerable discussion regarding standard treatments versus emergency treatments given during the handling process. It was decided that a sub-committee including Helen Schwantje, DVM, Emily Jenkins, DVM, and Susan Kutz, DVM would re-write portions of the animal health section, retaining a list of standard and emergency treatments for consideration but directing the user to select these treatments under direction of a veterinarian.

A paragraph on ectoparsites and their treatment is needed and will be developed and added.

It was recommended that a paragraph be developed regarding appropriate helicopter pursuit times, recognizing the impact of ambient temperature on stress.

Helicopter transport techniques were discussed, relating to slinging sheep by hobbles under the helicopter, versus putting them in specialized bags, versus transporting them inside the ship. All of these techniques have been used successfully but there is the social perception that slinging by hobbles looks bad, but for short distances does not pose a health risk. Transporting inside the helicopter poses a safety risk if an animal slips a restraint. The most important consideration is that animals be transported sternum down whenever possible and that we identify the risks associated with the specific types of helicopter transport.

Capture Methods

Most of the discussion focused on ways to improve the presentation of the various methods. The section on chemical immobilization will require major revision and it was decided that the veterinarian sub-committee rewriting portions of the animal health section also would revise this section. Norman Swanson has an effective trap design for catching individual sheep and will provide the information for inclusion.

There was considerable discussion regarding the length of time it should take to clear captured animals from a drop net. An effort will be made to improve this topic.

When Draft 3 is completed it will be sent to the Desert Bighorn Council technical advisory committee for review. After receiving those comments the final document will be completed and made available.

Bighorn sheep (*Ovis canadensis*) diseases: a brief literature review and risk assessment for translocation

SHELLI DUBAY, Arizona Game and Fish Department, 2221 W. Greenway Rd., Phoenix, AZ 85023, USA
HELEN SCHWANTJE, Ministry of Water, Land and Air Protection, PO Box 9338, 2975 Jutland Road, Victoria, British Columbia, V8W 9M1, Canada
JIM DEVOS, Arizona Game and Fish Department, 2221 W. Greenway Rd., Phoenix, AZ 85023, USA
TED MCKINNEY, Arizona Game and Fish Department, 2221 W. Greenway Rd., Phoenix, AZ 85023, USA

Abstract: Prior to European settlement in western North America, bighorn sheep (*Ovis canadensis*) were more widespread and abundant than they are today (Buechner 1960). The species arrived via the Bering land bridge approximately 70-100,000 years before the present (YBP) (Kurten and Anderson 1980) and slowly spread to occupy most mountainous regions of western North America from southern British Columbia and Alberta, Canada to the Cape of Baja California and northern Sierra Madre in Mexico (Brown 1989). Based on fossil records, it is likely that bighorn sheep arrived in the southwestern United States at the end of the Pleistocene era approximately 9-12,000 YBP (Findley et al. 1975). It is clear that bighorn sheep underwent dramatic declines in both occupied area and numbers throughout their range in North America in the 3 decades prior to 1900. The most probable cause of declines in this era was the introduction of domestic sheep with a suite of diseases to which bighorn sheep were naïve (DeForge et al. 1981, Brown 1989, deVos 1989). Subsequent to 1900, bighorn sheep population declines continued due to several causes including habitat fragmentation and degradation, unregulated harvest for trophies and subsistence, and competition with domestic livestock. One strategy to repatriate bighorn sheep populations is translocation of groups from healthy source populations to repopulate vacant historic habitat. Translocation is also used as a management tool to bolster populations that are below demographic objectives. Managers overseeing translocations need to be cognizant of the potential to introduce diseases when moving animals, and their potential impacts on indigenous wildlife or domestic livestock. To facilitate translocations and minimize disease risk, managers need to develop an understanding of diseases that play roles in bighorn sheep demographics, and develop methods to minimize any risk to bighorn sheep, other wildlife, and livestock. This is particularly important when managers move bighorn sheep between jurisdictions and across international boundaries (typically Canada to the U. S., and bi-directional from U. S. – Mexico). In this paper, we review several diseases of livestock and bighorn sheep and propose recommendations for health screening of bighorns to minimize disease risks to animals in the recipient area and to aid in reestablishing healthy bighorn sheep populations.

Key words: bighorn sheep, diseases, risk, translocation, serology

INTRODUCTION

Translocation of an animal and its associated organisms, including bacteria, viruses, and internal or external parasites, can threaten the health of indigenous wild species or domestic livestock. In addition, the effects of stress on the immune system of animals while captured and held, even in short term captivity before release, may increase this risk. However, the risk can be assessed in advance and substantially reduced if timely veterinary precautions are taken (Woodford 2000). Precautions include a clinical evaluation of the health status of source animals and those at the translocation destination, appropriate health screening procedures, consideration of the legal and veterinary restrictions of wild animals to and from certain geographical areas or populations and, when necessary, pre-release treatment and immunization. The translocated animals as well as the indigenous wildlife in the reception area should undergo health screening. Once a wild animal has been released into the wild it is very rarely possible to recover it or the potential pathogens it may have carried (Woodford 2000).

Several parasites, bacteria, and viruses are reported to cause disease in bighorn sheep (*Ovis canadensis*), and some have been involved in large-scale epizootics in populations in the western United States and Canada (Spraker 1977, deVos et al. 1980, King and Workman 1983, Onderka and Wishart 1988, Schwantje 1988). Singer et al. (2001) used empirical models to predict the effects that disease epizootics and habitat patch size might have on overall viability of bighorn sheep populations. They predicted that populations with 250 or more sheep were able to withstand disease epizootics much better than small populations, but disease could have significant impacts on populations overall. Gross et al. (1997) also investigated the impact of disease on bighorn sheep via population models. They concluded that contiguous patches of habitat were the most important variable when determining the likelihood of extinction for a population. However, diseases influenced extinction rate; large populations occupying large contiguous patches were not insulated from disease-induced extinction. When multiple disease epizootics were added to the model, the likelihood of extinction increased dramatically. Therefore, an important part of bighorn sheep management is to reduce the likelihood of disease epizootics.

Jessup (1985) discussed common livestock diseases that affect bighorn sheep, most of which are commonly present in domestic sheep flocks and some are also found in domestic cattle and goats. There are many reports of single or multiple infectious organisms isolated from bighorn sheep following contact with domestic animals. Numerous accounts document fatal pneumonia epizootics, usually associated with *Pasteurella* (*Mannheimia*) infections after such contact (Monello et al. 2001). Viral and/or bacterial pneumonia and/or scabies mite infestations transmitted to bighorn sheep from domestic sheep have been implicated in epizootics in Colorado, Wyoming, Arizona, New Mexico, Alberta, and British Columbia (Lange et al. 1980, Jessup 1985, Onderka and Wishart 1988, Schwantje 1988, Ward et al. 1997). In addition, bluetongue, contagious ecthyma, and parainfluenza 3 viruses were identified as potential causes of decline in bighorn sheep herds. Clark et al. (1985) found evidence of exposure to parainfluenza-3, *Protostrongylus* sp. lungworm, bluetongue and epizootic hemorrhagic disease viruses, respiratory syncytial virus, bovine viral diarrhea, and contagious ecthyma virus in 18 herds of desert bighorn sheep in California. Evidence for exposure to *Brucella* sp. and *Leptospira* spp. was not found in this study.

Exposure to infectious organisms may not result in obvious mortality, but animals moved from one jurisdiction to another can result in infections of new populations, particularly if these populations are naïve or stressed. The susceptibility of bighorn sheep, which originated in the New World, to disease agents of domestic livestock from the Old World is high. This is likely because bighorn sheep did not co-evolve with diseases common to domestic sheep and cattle that were selectively bred to survive intensive husbandry and infectious diseases that exist with close contact (Technical Staff, Desert Bighorn Council, 1990). Thus, bighorn sheep are exposed to pathogens to which they are not adapted when domestic animals come in contact with them on rangelands. In addition, Foreyt and Evermann (1988) found that bighorn sheep neutrophils were much less capable of killing bacteria *in vitro*. Bighorn sheep and domestic sheep are closely related through behavior and genetics and have been known to seek each other out on ranges. These facts combine to create a high risk of fatal disease exposure for bighorn sheep when in contact with domestic sheep. This review will discuss diseases of bighorn sheep that should be considered by managers prior to and during translocation programs.

SPECIFIC DISEASE ASSESSMENTS

Contagious ecthyma:

Contagious ecthyma (CE), orf, or sore mouth, is a parapoxvirus infection that can potentially affect many ungulate species. It has been seen in domestic sheep and goats for over 200 years and recognized in bighorn sheep since 1954 (Thorne et al. 1982, L'Heureux et al. 1996). Symptoms include scab forming sores and localized swelling, usually around the mouth, but also around the udder and coronet bands in some animals. Sheep may be affected year round, with increased numbers of cases in young animals in spring and summer, or following mixing of animals, such as during breeding season. Generally, virus enters the skin of the mouth through abrasions caused by mechanical insult, such as thorns on plants or abrasive materials, such as salt blocks. Visible signs of infection are seen approximately 4 days post-inoculation when domestic sheep are experimentally infected with virus (Robinson and Balassu 1981). Bighorn sheep in a national park in Canada were diagnosed with CE near salt used for road de-icing (Blood 1971). Bighorn sheep often concentrate at salt blocks or road surfaces during winter. Infected and uninfected animals use salt blocks concurrently, thereby transferring virus material to the substrates and then to naïve bighorn sheep (Blood 1971). Scab material exposed to the environment can hold viable virus for long periods of time, even years. Infection can occur at sites in the absence of salt sources. In the late 1990s, a group of adult rams with severe CE lesions was observed along a highway in British Columbia where bags of livestock grain had been dumped (H. Schwantje, British Columbia Ministry of Water, Land and Air Protection, unpublished data). Other herds in British Columbia have had small epizootics of mild to moderate CE with no obvious potential sources of infection; mortality was not reported in these cases. In addition, severe CE has been reported in British Columbia bighorn sheep herds in adult survivors or lambs born in the first two or three years following pneumonia epizootics (H. Schwantje, unpublished data). It is thought that once bighorn sheep are infected with CE as lambs, they are afforded some immunity against the virus as adults (Blood 1971, Thorne et al. 1982, King and Workman 1983). Bighorn lambs are usually more seriously affected than adults and sores on the muzzle make nursing painful. Lesions usually disappear within 4 weeks of onset, but occasional deaths due to CE are recorded (Thorne et al. 1982). Samuel et al. (1975) reported that 2 bighorn sheep in Waterton Lakes National Park, Alberta and 1 mountain goat (*Oreamnos americanus*) from Kootenay National Park, British Columbia were infected with debilitating CE infections. Several others with lesions were found dead, suggesting that CE infection could be fatal. Affected animals were found near artificial sources of salt. L'Heureux et al. (1996) investigated CE infection in lambs in Alberta, Canada and concluded that infected lambs were lighter in mass than uninfected lambs, but disease did not influence lamb survival. Given that serologic exposure to CE does not indicate current viral infection, only previous exposure, the presence of antibodies against CE should not impede translocations of bighorn sheep. To the contrary, clinically normal bighorn sheep with antibodies against CE may be afforded some protection if the herd in the translocation area has active CE in the population. **STATUS – Widespread and posing little risk.**

Bluetongue and epizootic hemorrhagic diseases:

Bluetongue (BTV) and epizootic hemorrhagic disease (EHD) are closely related viral diseases that can impact many free-ranging and domestic ungulates (Thorne et al. 1982). The viruses are transmitted by biting midges of the genus *Culicoides*. Epizootics usually occur near water in the late summer and fall because the midges require water to reproduce. Affected animals can die acutely or demonstrate increased respiration rates, weakness, diarrhea, and hemorrhages in most organs (Thorne et al. 1982). EHD is generally thought to be less pathogenic in bighorn sheep than BTV, but Noon et al. (2002) identified hemorrhagic disease in 2 bighorn sheep carcasses in Arizona, and BTV virus was isolated from 1 animal while EHD was isolated from the other. Hemorrhages were found in several organs including conjunctiva, heart, and rumen in both cases. Bighorn sheep deaths in California and Wyoming have been attributed to BTV, and antibodies against both EHD and BTV have been documented from bighorn sheep in Arizona (Jessup 1985, Heffelfinger et al. 1995). Robinson et al. (1967) found that severe pneumonia debilitated a bighorn sheep ram in Texas. The ram had hemorrhages in the brain as well. The infected lungs were used as an experimental inoculum for 2 domestic sheep and 1 contracted severe pneumonia and died. Both domestic sheep tested positive for antibodies against BTV confirming the diagnosis. Robinson et al. (1967) suggested that contact with domestic sheep could be responsible for bluetongue in the bighorn sheep. Antibodies against BTV and EHD have been detected in many free-ranging species including bighorn sheep with no clinical signs, suggesting that the viruses are enzootic in much of the western United States (Thorne et al. 1982). Bluetongue and EHD are considered reportable foreign animal diseases in Canada. The vector *Culicoides sonorensis* is resident in western Canada, however only sporadic late summer mortality has been reported in wild deer and occasionally bighorns, with no apparent maintenance of the viruses from year to year. Bluetongue serotype 11 or EHD serotype 2 have caused outbreaks in southern Alberta (1962) and in the Okanagan valley of southern British Columbia (1975, 1987, 1988, 1999) (Dulac et al. 1989, Pasick et al. 2001). To ensure that Canada retains its BTV-free international status, the Okanagan valley has special zoning for livestock with a federal surveillance program in place. BTV and EHD are reported commonly in deer mortality events in the Western and Southwestern United States and can be considered widespread on a seasonal basis (Gaydos et al. 2002). It is likely that exposure to the North American serotypes of BTV and/or EHD may provide animals some immunity and serological evidence does not indicate current disease status, especially if clinical symptoms are not evident at time of capture (Thorne et al. 1982). **STATUS – Widespread, poses health risk in areas where these diseases are absent or to naïve animals being translocated to enzootic area.**

Parainfluenza 3:

Parainfluenza 3 (PI3) is common to domestic sheep and cattle, and free-ranging animals that come in contact with domestics can be exposed to the virus (Jessup 1985). PI3 can cause pneumonia in domestic animals but it is considered to be of low pathogenicity. The virus can be part of the "shipping fever" syndrome where combined infections of other viruses and bacteria invade respiratory tracts of stressed animals and cause severe lung infections and death. Few cases of mortality due solely to PI3 infection have been cited in free-ranging animals, but antibody titers have been described from several sympatric free-ranging species. Zarnke and Erickson (1990) identified antibodies against PI3 in bison (*Bos bison*) in Alaska, and prevalence increased from 0 % in 1975 to nearly 100 % in 1983 to 1988 without clinical disease in the herd. The virus was likely introduced to the bison from cattle that recently grazed adjacent to the bison herd. Free-ranging fallow deer (*Cervus dama*) in Italy have been shown to harbor antibodies against PI3 as well. Clinical signs of infection were not observed and cattle were grazed on the reserve where fallow deer were sampled, suggesting that cattle introduced the virus to wildlife (Giovannini et al. 1988). Sadi et al. (1991) investigated potential causes of high mortality among white-tailed deer (*Odocoileus virginianus*) on Anticosti Island, Quebec in 1985. Sera from white-tailed deer were tested for antibodies against several pathogens, and antibodies against PI3 were found in between 82 and 84 % of the animals sampled over a 3-yr period. Antibodies against bovine herpesvirus-1 increased in the population while the herd was experiencing high mortality, suggesting that herpesvirus was responsible for increased mortality and that PI3 was enzootic in population and contributed little to population declines. Antibodies against PI3 have been detected in bighorn sheep in the western United States (Sandoval et al. 1987) and British Columbia (H. Schwantje, unpublished data). The virus has been isolated from clinically ill bighorn sheep in California (Jessup 1985) and from mortalities during pneumonia epizootics in British Columbia (H. Schwantje, unpublished data). Isolates from the British Columbia mortalities were obtained from lungs affected by multiple organisms. PI3 was also implicated in the pneumonia death of a captive bighorn sheep in Wyoming (Parks et al. 1972). No serologic evidence of exposure to PI3 was found in 20 desert bighorn sheep (*O. c. mexicana*) in Arizona during 2000-2002 (T. McKinney, Arizona Game and Fish Department, unpublished data). In general, PI3 infection alone is considered a minor disease of free-ranging wildlife, with many species being exposed and little evidence of mortality without other pathogens being involved (Zarnke and Erickson 1990). **STATUS – Widespread and believed to pose little risk to bighorn sheep. Alone, PI3 may not be important but in combination**

with other pathogens and/or stressors infection may be fatal.

Respiratory syncytial virus:

Respiratory syncytial virus (RSV) is a common organism in domestic cattle populations and is responsible for lung infections and mortality, especially in naïve animals (Lehmkuhl and Cutlip 1979). It is also recognized in domestic sheep, and RSV was isolated from a domestic sheep with rhinitis (Evermann et al. 1985). When RSV virus was re-inoculated into naïve lambs alone or with *Pasteurella haemolytica* bacterial isolates, lambs developed mild conjunctivitis and mild histological inflammatory changes in the lung. The virus has also been identified as a potential pathogen in free-ranging wildlife. Johnson et al. (1986) tested blood samples from hunter-harvested mule deer (*O. hemionus*) and white-tailed deer in Nebraska for antibodies against RSV. Twenty-nine percent of mule deer samples showed exposure, whereas 37 % of white-tailed deer samples had antibodies against RSV. Seroprevalence for RSV antibodies in these deer mimicked those of cattle in Nebraska. Dunbar et al. (1985) identified antibodies against RSV in 187 of 447 (42 %) bighorn sheep sera from 9 western states from 1977 through 1985. Bighorn sheep from several states sampled had severe pneumonia infections and some individuals died from pneumonia. An RSV isolate was cultured from a clinically ill bighorn lamb in Colorado as well (Spraker and Collins 1986). This virus was also isolated from several mortalities during pneumonia epizootics in bighorn herds in British Columbia. All of these isolates were made from lungs affected by multiple pathogens (H. Schwantje, unpublished data). Foreyt and Evermann (1988) inoculated 5 bighorn sheep lambs (3 vaccinated against RSV and 2 unvaccinated) with an RSV isolate from a domestic lamb with rhinitis. Clinical signs of pneumonia were not observed in either vaccinated or unvaccinated lambs, but antibody titers against RSV were identified from all animals. It seems that RSV alone is not an obligate pathogen in bighorn but further research is needed. **STATUS – Widespread and believed to pose a low risk to bighorn sheep, but information is lacking. Alone, RSV may not be important but in combination with other pathogens and stressors may be fatal.**

Infectious bovine rhinotracheitis:

Infectious bovine rhinotracheitis virus (IBR) belongs to the herpesvirus group and causes respiratory disease in cattle (Richards 1981). The virus is ubiquitous in cattle and vaccines have been developed to combat clinical illness. Virus is found in secretions from the respiratory, ocular, and reproductive tracts, but experimentally infected deer showed limited ability to shed virus. Infected deer show depression, anorexia, excessive salivation, and increased respiration. Ingebrigtsen et al. (1986) investigated IBR exposure of white-tailed deer in Minnesota. They tested 504 sera from 1976-1980 and 15 % had antibodies against IBR, with exposure being statewide. Few studies have investigated IBR in bighorn sheep, but serologic evaluation of 20 desert bighorn sheep in Arizona showed no evidence of exposure to IBR (T. McKinney, unpublished data). Hampy et al. (1979) tested 6 Barbary sheep (*Ammotragus lervia*) for antibodies against IBR and 1 had a titer of 1:4, 1 had a titer of 1:8, and another had a titer of 1:16. Similar titers have been documented in bighorn sheep herds in British Columbia as well (H. Schwantje, unpublished data). Titers lower than 1:16 are often considered negative. Therefore, these levels are of doubtful significance. IBR has not been implicated in bighorn sheep epizootics in the literature, and likely is not a significant cause of mortality. **STATUS – Widespread and appears to pose little health risk to bighorn sheep.**

Bovine viral diarrhea:

Bovine viral diarrhea (BVD) is caused by a *Pestivirus* and was first described in cattle in 1946 (Richards 1981). The virus is quite resistant to sunlight, freezing, and desiccation, and is spread several ways: 1) through food and water contaminated with feces, urine, or nasal discharge from infected animals, 2) through inhalation of aerosols containing virus, 3) from pregnant animal to fetus. Clinical signs in cattle include fever, depression, alimentary tract erosions, dehydration, diarrhea, weak neonates, and abortion. BVD virus is immunosuppressive and can predispose herds to epizootics of concurrent infections. An epizootic in mule deer and white-tailed deer in North Dakota in 1955 was associated with infected cattle (Richards 1981). Dead and clinically ill deer were located within a 0.3-km radius of clinically ill cattle. Symptoms in deer include weakness, lack of fear of humans, dehydration, diarrhea, impaired vision and hearing, and convulsions, but animals appeared to recover as the epizootic progressed. Serologic surveys in New York showed that approximately 3-6 % of the deer tested had antibodies against BVD, but mule deer herds in New Mexico and Colorado had higher exposure rates, 34 % and 85 % respectively (Richards 1981). McKinney (Arizona Game and Fish Department, unpublished data) determined viral exposure via antibody levels in desert bighorn sheep in Arizona. A total of 20 animals were tested during 5 captures and none had antibodies against BVD. Elliott et al. (1994) measured antibody levels against BVD in 998 serum samples from bighorn sheep captured in California from 1978 to 1990. The highest seroprevalence for BVD was 18 %, and the lowest was 4.9 %. In Texas, Hampy et al. (1979) tested 6 Barbary sheep for antibodies against BVD, and none showed evidence of exposure. To our knowledge, BVD has not been implicated in disease epizootics in bighorn sheep, and the significance of antibody evidence of exposure to bighorn sheep health is unknown. However, since exposure is widespread, serologic evidence should not impede translocation of bighorn sheep. **STATUS – Widespread exposure. Uncertain significance and requires more research.**

Scabies:

Scabies is a parasitic mite infection of the skin and is commonly seen in certain populations of desert and Rocky Mountain bighorn sheep (*O. c. canadensis*), elk (*Cervus elaphus*), and white-tailed deer in the western United States (Thorne et al. 1982). Several mite species of the genus *Psoroptes* cause clinical disease in free-ranging wildlife. Clinical signs of disease are caused by mechanical insult from mouthparts of mites. The mites feed on serum that oozes from abrasions on the skin, and excrement and other proteins emitted from the mites cause an immune response by the host. As inflammation progresses, the host sloughs portions of the epidermis and secondary bacterial infections often occur at the site of sloughing. Ear and body scabs are seen on bighorn sheep infected with *Psoroptes* mites and large plaques of loosely attached scabs are easily lifted off the body in extreme infestations. Welsh and Bunch (1982) investigated the causes of decline in bighorn sheep from Arizona and identified psoroptic scabies as a potential contributor to decreased population levels. Increased prevalence of scabies occurred concurrent with decreased body condition of animals in the herd. deVos et al. (1980) also identified scabies infection from bighorn sheep in Arizona. Ear lesions were seen in 2 rams and 1 ewe and serologic evidence was detected in another 5 animals in the herd. Foreyt et al. (1985) identified scabies lesions from animals transplanted to Oregon from Idaho. Transplanted animals were treated with 0.2 mg/kg body weight ivermectin to eliminate mites prior to release. Kinzer et al. (1983) used 0.5 to 1.0 mg/kg ivermectin to treat scabies in desert bighorn sheep in New Mexico. Sandoval (1980) discussed another epizootic of scabies in New Mexico, and all 5 bighorn rams harvested from San Andreas National Wildlife Refuge in 1978 had clinical symptoms of scabies infection. The population had declined significantly prior to the hunt, and only 70 of 200 animals remained in 1979. The remaining animals were captured and given emergency medical treatment including dipping in toxaphene solution. Several bighorn sheep had scabies lesions over their entire body, suggesting that scabies contributed to the population decline in New Mexico. Scabies infections are not known to occur in wild sheep in Canada and sampling of bighorn sheep translocated to the United States has confirmed these findings (H. Schwantje, unpublished data). Naïve Canadian bighorn sheep have become severely infected with scabies once translocated into infected populations. Given the severity of scabies infection and the ease of diagnosis in most cases, all translocated bighorn sheep should be examined for scabies lesions and treated with an effective medication prior to release into a new area. Animals from populations without evidence of the mite should not be relocated to endemic areas. **STATUS – Localized with potential for substantial morbidity and mortality, especially in naïve animals.**

Anaplasmosis:

Anaplasmosis is a vector-borne rickettsial infection of cattle and free-ranging ruminants (Thorne et al. 1982). The causative agent in cattle is *Anaplasma marginale*, but *A. ovis* infects domestic sheep and goats, and wildlife species. Anaplasmosis is transmitted by a number of tick species and biting flies and is most prevalent in the Southeast, intermountain West, and California in the United States. Infected animals develop anemia when rickettsia destroy red blood cells, but animals usually recover and remain carriers of the parasite for several months or years. *Anaplama ovis* may be more pathogenic than *A. marginale*, particularly during periods of stress. Clinical signs of infection are usually mild in wildlife, but lack of appetite and weakness are identified as signs in black-tailed deer (*O. hemionus columbianus*). Wild ruminants can act as reservoirs for domestic livestock. *Anaplasma marginale* was inoculated into 2 bighorn sheep and red blood cells in 1 animal became infected with the organism, but clinical disease was not seen in either animal (Goff et al. 1993). Tibbitts et al. (1992) inoculated 2 bighorn sheep with an *Anaplasma ovis* isolate from clinically ill domestic sheep. Both inoculated animals developed severe anemia and became lethargic. Given that the animals were given a very high dose of infected cells ($2 \text{ X } 10^9$), that the isolate may have been relatively virulent, and that the bighorn sheep were stressed due to confinement and frequent handling, clinical disease may have been accentuated. Goff et al. (1993) isolated *A. ovis* from bighorn sheep in California and then inoculated infected blood into 1 splenectomized domestic sheep, 1 splenectomized calf, and 1 intact bighorn sheep. The bighorn sheep and domestic sheep developed anemia and were treated with antibiotics. The calf showed no evidence of infection. It is likely that *Dermacentor* spp. ticks transmit *Anaplasma* spp. to bighorn sheep in California. Jessup et al. (1993) investigated the presence of antibodies against *Anaplasma* spp. in bighorn sheep herds in California. All 20 Rocky Mountain bighorn sheep tested had antibodies against *Anaplasma* spp., 11 of 18 peninsular bighorn sheep (*O. c. cremnobates*) had antibodies, and 0 of 20 California bighorn sheep (*O. c. californiana*) had antibodies. *Anaplama ovis* was thought to be responsible for antibody responses in these bighorn sheep, and differences in vector and host abundances were likely responsible for differing prevalence rates with geographic region and bighorn sheep subspecies. Jessup et al. (1993) believed that naïve bighorn sheep may become infected with anaplasmosis from carrier animals after a translocation event, if vector populations exist in the translocation area. Anaplasmosis is considered to be a foreign animal disease in Canada, and there have been no isolations of either *Anaplasma* sp. in wild ruminants, including bighorn sheep (H. Schwantje, unpublished data). Although bighorn sheep have been experimentally infected with *Anaplasma* sp., it is unlikely that they are important carriers of disease (Thorne et al. 1982), and Kuttler (1981) stated "the greatest importance of wild animals with regard to anaplasmosis is their potential as secondary or reservoir hosts." Given that, evidence of exposure to *A. ovis* or *A. marginale* should not influence bighorn sheep transplants. **STATUS – Widespread but appears to pose little direct health risk for bighorn sheep.**

Johne's Disease or Paratuberculosis:

Paratuberculosis is a bacterial infection caused by *Mycobacterium avium* subsp. *paratuberculosis* and causes chronic enteritis in cattle, sheep, goats, llamas, camels and some free-ranging ruminants (Timoney et al. 1988, Williams 2001). The primary lesions are observed in the digestive tract and infected individuals show deterioration of body condition and diarrhea (Williams 2001). Bacteria are shed in feces and naïve animals are exposed by ingesting contaminated feed or water. Individual carriers can shed the bacterium in feces for years after infection. Paratuberculosis has been documented in farmed deer and in free-ranging Tule elk in California, but free-ranging wildlife populations are rarely impacted by the disease (Williams 2001). Williams et al. (1979) documented 6 cases of paratuberculosis in bighorn sheep in Colorado. Affected individuals were emaciated, had rough hair coats, and had dried feces from the perineum to the lower rear legs. Five of the 6 cases were clinical, but 1 case was subclinical suggesting that carriers could expose herdmates to infection in free-ranging wildlife. These bighorn sheep were thought to acquire infection naturally, perhaps from infected domestic livestock in the area. Williams et al. (1983) orally inoculated Rocky Mountain elk, mule deer, white-tailed deer, bighorn sheep X mouflon (*O. musimon*), and domestic lambs with a *M. avium paratuberculosis* isolate from the bighorn cases documented in 1979. All animals exposed became infected but clinical disease with diarrhea occurred only in mule deer. It was hypothesized that some free-ranging species could become infected with paratuberculosis by sharing ranges with infected domestic livestock or wild ruminants. In addition, bighorn sheep were thought to maintain the disease in the population without a re-introduction of the disease into that population. **STATUS – Causes isolated problems in bighorn sheep. Managers and veterinarians need to monitor animals for clinical signs of paratuberculosis if the disease has been documented in that herd in the past and not use these herds for translocations.**

Leptospirosis:

Leptospirosis is a contagious bacterial disease of animals including humans, and is due to infections of members of the genus *Leptospira* (Thorne et al. 1982). Several serovars, or serologic strains, can cause clinical disease. The severity of disease ranges from asymptomatic to fatal, depending upon the host and serovar involved. Clinical signs of disease may include fever, jaundice, loss of appetite, abnormally colored urine, and abortion. Bacteria are primarily transmitted from animal to animal in water contaminated with infected urine, but bacteria also invade broken skin and mucous membranes including those of the eyes, intestinal tract, genital tract, and nose. Animals usually recover from disease but can carry and shed bacteria after clinical signs cease. Leptospires are found worldwide in numerous domestic and wild species. Serologic surveys are commonly used to determine the presence of *Leptospira* spp. in free-ranging animals (Thorne et al. 1982). Fournier et al. (1986) measured antibody levels in 258 sera from white-tailed deer in Ohio. Eighteen animals (7 %) had antibody titers against at least 1 of 5 serovars identified. Given that white-tailed deer shed bacteria for approximately 30 days post-experimental infection, a much shorter interval than carnivores, deer are less likely to transmit disease to other wildlife. New et al. (1993) evaluated 590 blood samples from white-tailed deer in Tennessee for antibodies against *Leptospira* spp., and 21 % had antibody reactions to at least 1 serovar. They concluded that most infections are probably clinically mild and unlikely to influence populations in Tennessee. Hampy et al. (1979) investigated the presence of antibodies against *Leptospira* in 12 Barbary sheep and 11 mule deer and no antibodies against leptospirosis were detected. Chilelli et al. (1982) measured antibody titers against *Leptospira* spp. from 77 bighorn sheep in Arizona and only 1 animal had a titer higher than 1:64. deVos (1989) compiled serologic data for desert bighorn sheep captured from Arizona in 1985 and 1986. Three herds were tested for antibodies against *Leptospira* spp. in 1985, and antibodies were present in 1 herd (23 % of samples). In 1986, 2 herds were evaluated and antibodies against at least 1 serovar of leptospirosis were detected in animals from both herds, but clinical illness was not detected. Evidence of exposure to leptospirosis is present in several free-ranging ungulate species, but clinical illness appears to be rare. **STATUS – Widespread in many wildlife species, uncertain from bighorn sheep, but seems to pose minor health risk.**

Brucellosis:

Brucella spp. bacteria are the causative agents of brucellosis in free-ranging wildlife and domestic livestock. At least six species and more than 19 biovars of *Brucella* affect animals: 1) *B. abortus* is found primarily in cattle, elk, and bison, 2)

B. melitensis is found in domestic sheep and goats, 3) *B. suis* is found in swine, caribou (*Rangifer tarandus*), and moose (*Alces alces*), 4) *B. neotomae* is found in woodrats (*Neotoma lepida*), 5) *B. ovis* is found in domestic and wild sheep, and 6) *B. canis* is found in dogs (Thorne 2001). *Brucella* spp. are maintained in primary hosts through horizontal or vertical transmission, but accidental transmission can occur into secondary hosts through ingestion or contact with contaminated materials. These diseases are of economic importance worldwide due to their effect on the livestock industry and their zoonotic potential. Infection is most often linked to reproductive problems, particularly abortion or birth of nonviable offspring, but infertility can also result from brucellosis infections. *Brucella abortus* is the primary species involved in free-ranging wildlife in the Greater Yellowstone Area, but *B. suis* biovar 4 has been isolated from clinically ill caribou and reindeer and occasionally from moose (Thorne 2001). Zarnke and Yuill (1981) used the rapid slide agglutination and the complement fixation techniques to test 9 bighorn sheep sera for antibodies against *B. abortus*, and none were detected. Davis (1990) reported that 9 bighorn sheep from Canada and 43 bighorns from Arizona were negative for antibodies against *Brucella* spp. Foreyt et al. (1983) tested 73 Dall's sheep (*O. dalli*) for antibodies against *Brucella* sp. using the plate agglutination test. Three animals had antibodies but the authors did not discuss potential exposure routes. Seropositive tests for *Brucella ovis* have resulted from bighorn sheep captured in Idaho and California (M. Drew, Idaho Department of Fish and Game, unpublished data), and at this time, it is unclear what positive results mean. Serological tests used for bighorn sheep were developed for livestock species and have never been validated for wild sheep, making results difficult to interpret. Brucellosis caused by *B. abortus* is a reportable disease in Canada. It was eradicated in Canadian livestock in 1985, however is present in wood bison in and around Wood Buffalo National Park. *B. suis* biovar 4 and *B. ovis* are not reportable. *B. suis* biovar 4 is restricted to certain caribou and reindeer herds and occasional secondary hosts. There appears to be no risk of transmission to livestock (S. Tessaro, Canadian Food Inspection Agency, personal communication). *B. ovis* is rare in domestic sheep with no isolations in western Canada in the past decade. Since 1990, a large number of bighorn sheep from British Columbia and Alberta have been examined serologically for *B. abortus, B. suis* and *B. ovis* by a range of serological tests performed by accredited laboratories in the United States and Canada (H. Schwantje, unpublished data). The vast majority of these tests have been negative for any *Brucella* exposure, however, some results have been considered to be "incomplete", false positive or equivocal and have resulted in live animal shipments being held for extended periods of time or the removal of animals from shipments. All sera, when retested with more specific testing methodology have been confirmed as negative. Unfortunately, all serological tests used to test for *Brucella* in bighorn sheep were developed for livestock species and have never been validated for wild sheep. Brucellosis has never been reported in wild sheep in Canada and none of the bighorn populations are in contact with species known to be infected with any *Brucella* species. Despite a small number of reactions on serologic tests in certain individuals, brucellosis has never been reported in wild sheep in Canada (H. Schwantje, unpublished data). **STATUS –**

Uncertain for bighorn sheep. Additional research needs to be conducted with bighorn sheep that are sympatric with infected elk and bison populations in endemic areas. Testing bighorn sheep from endemic areas should be considered.

Pasteurellosis:

Pasteurella spp. (*Mannheimia* spp.) are reported to be normal bacterial flora of the nasal mucosa and tonsillar crypts of both domestic and bighorn sheep (Ward et al. 1990) and are equally common in domestic cattle (Friend et al. 1977, Yates 1982, Cutlip and Lehmkuhl 1983). Some species and biotypes can cause serious pneumonia or septicemic disease outbreaks in livestock, often following environmental stress or concurrent infections (e.g., PI3). A similar pneumonic outbreak syndrome is well documented in bighorn sheep and is responsible for many population declines, and is therefore one of the most important diseases of wild sheep in general. Queen et al. (1994) examined nasal and tonsillar samples from apparently healthy bighorn sheep and domestic sheep and successfully isolated *P. haemolytica* from 5 of 5 domestic and 7 of 8 bighorn sheep tonsil samples. Although some biotypes of *Pasteurella* are considered to be normal flora, others are frequently reported in pneumonia die-offs of bighorn sheep (Foreyt and Jessup 1982, and Foreyt 1992). Cassirer et al. (1998) chronicled an epizootic that was attributed to *Pasteurella* associated pneumonia. In this epizootic, 4 of 10 herds associated with Hells Canyon in Washington and Oregon were adversely affected and approximately 325 bighorn sheep died. Prior to onset of the die-off, bighorn sheep were reported to be in excellent physical condition and some environmental stressors such as poor range conditions, adverse winter conditions, and high population levels were absent. Hibler et al. (1980) suggested that under most situations, bacteria cannot cause disease because of the lack of damaged or compromised tissues. One factor that may predispose bighorn sheep to bacterial pneumonia are heavy loads of an endemic wild sheep lungworm (*Protostrongylus stilesi*), which causes damage to lung tissue, and allows bacteria such as *Pasteurella* to invade the lower respiratory tract and cause clinical disease (Hibler et al. 1980, Spraker et al. 1984). Concurrent infections with upper respiratory viruses such as RSV and PI3 have also been implicated as predisposing factors for *Pasteurella* spp. infection (Miller 2001). A common factor seen in many bighorn sheep pasteurellosis outbreaks is close contact with domestic sheep or goats (Callan et al. 1991, Ward et al. 1997, Cassirer et al. 1998). Different biotypes of *P. haemolytica* are more pathogenic, especially to bighorn sheep. Foreyt (1989) found that *P. haemolytica* biotype T was more pathogenic for desert bighorn, and suggested that it was transferred from domestic sheep and caused clinical disease. Cassirer et al. (1998) identified a genetic similarity between isolates from at least 4 bighorn sheep and 3 feral domestic goats in the Hells Canyon epizootic. There is much to learn about pasteurellosis in bighorn sheep, yet it is clear that this disease is a major mortality factor. Bighorn sheep managers across jurisdictions consider the prevention of pasteurellosis in bighorn sheep to be a management priority and believe that the primary way to accomplish this is to ensure the separation of wild and domestic sheep. **STATUS - Many *Pasteurella* spp. and biotypes are widespread and present in most bighorn sheep and domestic livestock herds. Many**

***Pasteurella* spp. of domestic sheep origin are considered to be fatal to bighorn sheep. Those of bighorn sheep origin may present a health risk to naïve animals, but are difficult to predictably identify. The capacity to predict the effects of *Pasteurella* on either the source or recipient bighorn sheep populations is not yet available. Therefore, pre-movement culturing of bighorns in the source and recipient herds can be considered, however consideration of the disease history of the herds is more important. Of paramount importance is the prevention of contact between all domestic and wild sheep.**

CONCLUSIONS AND RECOMMENDATIONS

In general, many diseases are considered to be widespread in livestock and certain species of wild ruminants in the western United States and Canada. Others are restricted to specific geographic areas or their effects are most significant in specific species. Translocation of animals with similar health profiles between areas with similar disease risk appears to present the lowest risk to translocated animals, or to livestock and wild animals in recipient areas. We believe that movement of bighorn sheep across most jurisdictional lines poses minimal risk to wildlife and livestock in the receiving area. However, managers must be aware of potential risks that recipient area herds may pose to relocated individuals (e.g., if scabies is endemic in the recipient areas). Prior knowledge of the health status of bighorn sheep populations, consultation between wildlife and livestock management agencies, and proactive management, such as vaccination (if available, practical, and effective) or reassessment of the suitability of recipient sites are necessary to prevent certain disease epizootics. Many epizootics are much more likely to occur in bighorn sheep than in other wild or domestic species.

Although many diseases reviewed are generally of low pathogenicity to bighorn sheep, there is no way to predict when other factors can combine to predispose apparently healthy animals to disease, especially when multiple pathogens and adverse or unpredicted environmental conditions are involved. Therefore, we have compiled recommendations to minimize the possibility of disease transmission during translocation efforts. The success of any translocation depends on releasing healthy animals into areas with conditions that will promote continued health. General veterinary management protocols often recommend animal isolation or quarantine to ensure health of animals prior to or following movements. However, this technique is impossible, impractical, or dangerous with most free-ranging species. This is particularly true with bighorn sheep, because confinement increases stress, increasing the likelihood of development of pneumonia (Spraker and Hibler 1977; Spraker et al. 1984).

Specifically, we recommend:

- Due to the time required to obtain test results for many diseases, instead of relying on testing of translocated animals alone, we recommend background testing of source herds in order to increase data sets and to obtain general health profiles of the populations. Data obtained should be shared with agencies involved and a general or detailed risk assessment produced and evaluated prior to the translocation event.
- Biologists should choose standard test protocols and procedures most

appropriate for the pathogen and animal species to be tested. If necessary, encourage research for test validation in bighorn sheep.

- Wherever possible, all translocated and resident animals should have serum archived for disease profiles and retrospective analyses. This could be particularly useful in the event of post-translocation disease outbreaks.
- All captured animals should be examined by a veterinarian experienced with that species at capture locations and only healthy animals should be shipped.
- Specific examinations should be conducted for signs associated with infestation of *Psoroptes* mites.
- Due to livestock risk, difficulty of diagnosis, and lack of knowledge of the disease in bighorn sheep, bighorn sheep taken from an area where brucellosis exists in other wildlife species should be tested for *Brucella* spp.

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MANAGING DOMESTIC SHEEP/WILD SHEEP INTERACTIONS

Kevin Hurley - Moderator

Bighorn Pneumonia Die-Offs: An Outsider's Synoptic History, Synthesis, And Suggestions

WAYNE E. HEIMER, Secretary, Foundation for North American Wild Sheep, 1098 Chena Pump Road, Fairbanks, AK 99709 U.S.A.

[**Author's Note:** I'm not a veterinarian, a bacteriologist, or a molecular biologist. What I am is an inter-disciplinary-trained observer and occasional participant in our quest to solve the problem of bighorn die-offs. I am committed to inter-disciplinary or reviews in science. Without the cross-fertilization of "outside thinking" many of the breakthroughs of science, ranging from the structure of DNA to the integration of sheep behavior with harvest management, would have been longer in coming. I think an additional benefit of "outside review" is that it may encourage us to examine our present positions from differing perspectives. It may even help us to take our selves and our opinions a little less seriously and broaden our thinking in the process. I appreciate the editors of this proceeding allowing the use of an informal essay format to share these ideas. I am grateful to Dr. Karen Rudolph for details in the history of *Pasteurella* taxonomy. WH]

Abstract: The presence of pneumonia die-offs in bighorn sheep prior to European settlement of North American is unknown. With European settlement of the American West, pneumonia die-offs became the dominant factor in management and restoration of Rocky Mountain and California bighorn sheep. Early work suggested lungworm parasites were *the causal factor*, and the "lungworm-pneumonia complex" was taught as causative in wildlife and ecology curricula for decades. As bighorn sheep recovery associated with predator extirpations and prohibitions on human harvests progressed, managers realized the potential for human benefits from bighorn sheep harvests, and began to approach management of pneumonia die-offs in bighorns. Presuming parasites were causal, antihelminthic drugs were seen as the treatment. The drugs purged bighorns of parasites in laboratory conditions, but pneumonia die-offs persisted in the wild. Eventually, enough die-offs were statistically and pathologically associated with domestic sheep presence that domestic sheep replaced the "lungworm-pneumonia complex" as *the causal factor*. Managers then generally presumed that bighorn pneumonia die-offs would end if domestic sheep were excluded from bighorn ranges. Still, bighorn pneumonia die-offs were reported in bighorn populations with no documented exposure to domestics. This finding caused some tension between the "domestic-caused" (Pasteur's germ theory descendants) and "stress-caused" (Bechamp's internal environment descendants) camps of pneumonia die-off researchers. This tension has been politically exacerbated as it has involved domestic sheep grazing on public lands. Current work suggests that differing *Pasteurella*-like bacteria may account for these observations. Still, *Pasteurella* taxonomy is, at best, complicated; and recent innovative approaches to bacterial taxonomy have resulted in identifying three presumably different "*Pasteurellas*" reportedly responsible for bighorn die-offs. The highly virulent domestic sheep "*Pasteurella*" (formerly *Pasteurella haemolyticia*, is now called *Mannheimia haemolytica*) will almost certainly cause fatal pneumonia in any wild bighorn exposed to it. The other *Pasteurellas, trehalose* and *multocida* may or may not cause pneumonia die-offs depending on circumstances. Efforts to define a (or the) "hot bug" have recently turned away from traditional bacterial identification techniques toward identification based on genomic structural similarities. The appropriateness of either approach is determined by perspective. These perspectives are discussed with respect to bighorn management relevance, putting "all one's eggs in one basket" and "seeing the forest for the trees."

We don't know whether bighorn sheep populations experienced major population fluctuations before the advent of European settlers and their domestic animals. However, with European settlement of the American West, bighorn die-offs became the dominant factor in management and restoration of Rocky Mountain bighorn sheep. Wildlife biologists and wildlife-driven veterinarians have done their best to solve this problem, but the problem persists. The history of our experience with bighorn die-offs should point us to progress with this problem because we've been confidently wrong so often in the past. This history should prompt us to a cautionary and reserved commitment to our current understanding of the problem. It is not a simple one.

THE INITIAL (OBVIOUS) SOLUTION

Although the problem has become complex in concept with the passage of time, and its solution has evolved toward even greater convolution, the issue was initially perceived quite simplistically. It seemed intuitively clear to early sheep biologists that introduced domestic animals were getting the better of the remnant native bighorn populations in the competition for food. In retrospect, this is readily understandable because density-dependent forage limitation was the basic mantra of early wildlife management. For early bighorn biologists, it was basically an article of faith that "food was everything." Even today, this idea persists as the central dogma in the traditional wildlife management curriculum.

The earliest notable advocate of removing domestic livestock from bighorn ranges was the visionary biologist (or 'wing-nut' depending on one's point of view), James K. Morgan. Morgan argued stridently that, "domestic livestock had to go." More than a quarter of a century later, we can appreciate the validity of Morgan's argument as it relates specifically to domestic sheep, but for reasons, which dramatically eclipse the competition for food. In retrospect, we can also appreciate Morgan's finding that getting into barroom fights with ranchers and cowboys is not a particularly productive approach to the problem. Partly because of Morgan's confrontational approach, and partly because a more sophisticated model always seems more attractive to wildlife managers, Morgan's forage competition model was eventually supplanted by a parasitic disease explanation.

THE "LUNGWORM-PNEUMONIA COMPLEX"

When North American wildlife management emerged in the second quarter of the 20th Century, wild sheep were virtually absent from the scene. They had been long-since decimated throughout their ranges by what were then uncertain but rationally speculative factors including over hunting, competition with domestic livestock, and diseases associated with domestic livestock. As the unprecedented restoration of other North American wildlife species began with the invention of wildlife management (and its funding source), proto-bighorn biologists began to monitor bighorn population trends. They soon observed that bighorn populations appeared to be cyclic in nature with expansion phases followed by major die-offs that did not appear to be completely food-related. Veterinarians and pathologists were summoned to help.

These veterinary pathologists reported bighorn deaths in die-offs were typically due to bacterial pneumonia coincident with a huge infestations of lungworms in the affected populations. Eventually, a

Colorado parasitologist, Ron Pillmore, described the life cycle of the most common bighorn sheep lungworm, *Protostrongylis stylisi*, complete with its alternate host, a lowly snail. In the minds of the wildlife biologists of the day, the presence of an apparent abundance of lungworm parasites in sheep dying from pneumonia suggested parasites were *the causal factor*. The role of the bacteria involved in the pneumonia was simply not appreciated at this time.

[Author's Note: We now understand the pneumonias are caused by bacteria identified as "Pasteurellas," and that wild sheep apparently carry benign forms of these bacteria as a normal compliment of their pharyngeal flora. However, through the 1980s, the prevailing thinking was that ONLY domestic livestock harbored Pasteurella bacteria. The few attempts to isolate Pasteurella from bighorn sheep prior to1990 failed. Nevertheless, Alton Ward and Dave Hunter (from Idaho) persevered in the search for Pasteurella bacteria in bighorn sheep, and in about 1990 they showed bighorns normally carry benign (to them) Pasteurellas. Subsequently, some friends and I found several varieties of Pasteurella in remote Arctic populations of thinhorn, Dall, sheep (which had never been know to have a disease-related die-off); but this is getting a little ahead of our story. Up until the Pasteurella research 'bloom' in the 1990s, the presence of bacteria was considered secondary to the dramatically apparent lungworm involvement. WH]

Striking lungworm infestations were linked with die-offs, and integrated to produce an explanatory hypothesis, the "lungworm-pneumonia complex." This model held that as bighorn populations grew, parasite loads increased because of greater bighorn sheep population density, and the burgeoning lungworm populations in sheep weakened them to the point they developed an opportunistic bacterial pneumonia. This seemingly robust model was taught as an illustration of density-dependent population regulation in the wildlife and ecology curricula for decades. However, there was more to the story than lungworms and high bighorn concentrations. The bacteria involved would eventually prove to be the "wild card" in the system, but more on this later.

As limited bighorn sheep population recoveries associated with predator extirpations and the prohibition of human harvests in pristine habitats progressed, forward-thinking managers began to realize the potential for human benefits from bighorn sheep harvests. As a result, the presumably parasite-driven die-offs related to the "lungworm-pneumonia complex" in bighorn sheep began to draw the attention of sheep biologists and wildlife veterinarians. Colorado scientists, Chuck Hibler, Terry Spraker, and Bob Schmidt were pioneers in this area. Among other things they demonstrated transplacental transmission of lungworm larvae to bighorn fetuses in bighorn ewes with unusually high lungworm infections. This seemed supportive of the "lungworm/pneumonia complex" model as it seemingly explained why lamb survival was poor during and following population collapses.

Managers turn to drugs

From these data, managers inferred the obvious way to sustain higher-density bighorn populations (and increase sheep-related human benefits) was to get rid of the parasites. Subsequently, antihelminthic drugs, those that would kill the lungworms but not the sheep were seen as the way to stable sheep abundance. These drugs, in the "diazole" family, are chemical cousins of some very nasty molecules. That's probably why they work. However, they were approved for use, and worked in domestic livestock. Soon, our Colorado friends tested these drugs on captive bighorns with lungworm infections.

The drugs clearly purged bighorns of parasites in controlled laboratory conditions, and were eventually shown to reduce transplacental transmission of lungworm larvae to fetal bighorn lambs. However, in some cases, most notably a Colorado herd where wild, free-ranging sheep were given heroic doses of antihelminthic drugs in apple pulp (and salt blocks) and lungworm infestations dramatically decreased, lamb survival did not increase. The "lungworm-pneumonia model" was not working out as well as expected.

Managers renounce drugs for bacteria

Eventually, controlled laboratory tests by our Alberta friends, Detlef Onderka and Bill Wishart, showed lungworm-free sheep would still die of pneumonia if infected with bacteria from healthy domestic sheep. The now classic "lungworm-pneumonia complex" explanation had proven, by itself, to be an inadequate explanation. Clearly other factors were involved, most probably infection with bacteria from apparently healthy domestic sheep. Nevertheless, the idea of lungworms predisposing sheep to bacterial pneumonia persists, particularly in what I shall call "lungworm/pneumonia complex" county.

About this time, Jim Bailey (then at Colorado State University, the heart of "lungworm/pneumonia complex country") steered Nike Goodson (now Stevens) toward a systematic compilation of factors related to bighorn die-offs. Nike's synthesis showed bighorn die-offs were tightly linked to the presence of domestic sheep on bighorn ranges. This finding, along with the bacterial evidence implicating bacteria from healthy domestic sheep in bighorn pneumonia, resulted in the inference that "domestic sheep bacteria" were *the causative factor*. Parasites were "out," but not forgotten. Measurement of lungworm burdens in wild sheep continues on many ranges, and interest in parasites enjoyed a recent resurgence in Dall sheep from Canada's Northwest Territories.

Compelling evidence that parasites, in the absence of domestic sheep (and their bacteria), cause major population declines in wild sheep is still lacking. Viewed in the contemporary framework of adaptive response, a parasite which kills its host is not considered very good at its job. Hence, parasitic studies seem likely to remain more an academic pursuit than one of high management relevance. Domestic sheep presence/bacteria replaced the "lungworm-pneumonia complex" as the favored factor limiting bighorn management success in the minds of many active bighorn managers, particularly those from the Northwestern U.S.

"THE GREAT BUG HUNT"
A natural intuitive reaction

Once biologists were, again convinced they knew *the cause* of the die-offs (this would be the third time-first it was parasites, then parasites predisposing bighorns to bacterial infections), the first order of business became identification of the bacterial species presumed responsible for bighorn pneumonias. It appeared normal, healthy domestic sheep carried bacteria that were deadly to the bighorns. Thus began "the great bug hunt."

At the outset, we should note that the rationale for "the great bug hunt" has never been clearly stated, nor achieved a broad consensus. It just 'kind-of happened.' The great bug hunt has been, as was density-dependent limitation before it, more of an intuitive reaction than a rational decision. I define this as a forgivable failing; it should have been expected. After all, identifying the pathogen has been the traditional, and largely successful, approach to disease management for livestock and humans for the almost 150 years since Louis Pasteur. Naturally, it was the most obvious path to pursue.

In humans and livestock, disease control prescribes identification of disease agents so they can be cultured, a vaccine produced (we hope), and the disease managed or eliminated through immunological manipulation. While the prospect of a vaccine has always been inferred from the great bug hunt, the bighorn management community has never actually faced the issue of whether this is feasible from the vaccine development side, the vaccine administration side, or the ethical perspective. Nevertheless, we're in the great bug hunt.

Perhaps ironically, the object of the great bug hunt, *Pasteurella* is Louis Pasteur's namesake. The irony, it is that the "great bug hunt" is not only for Pasteur's taxonomic namesake, but is driven by his intellectual legacy, the germ theory of disease. Understanding this connection and our present situation requires some historical review I consider relevant. It seems to have passed from common knowledge

An old argument not yet settled

When first proffered, Pasteur's germ theory of disease was one of two major contending explanations for the disease state. Pasteur's major competitor was a fellow named Bechamp. Pasteur championed the germ theory of disease; Bechamp argued the disease state resulted from an imbalance in an organism's "interior environment." Pasteur won. Demonstration of the germ theory was straightforward and simple in the 1860s. We still struggle with the influence of stress and physiological or immunological compromise in relation to the disease state. Bechamp is all but forgotten, but his idea is slowly gaining credibility after 150 years.

Regional 'side choosing' in the old argument

Despite the empirical triumphs of Pasteur's germ theory of disease, the niggling observation that not every bighorn sheep herd exposed to a domestic sheep perishes (plus the fact that some bighorn populations experience pneumonia die-offs in the apparent absence of domestic sheep) has divided modern students of bighorn die-offs into the same basic camps championed by Pasteur and Bechamp. The divergence appears to be regional, and corresponds roughly with what I'm willing to call "lungworm/pneumonia complex country."

The "Pasteurites" (strict germ theory types) are primarily located in the Pacific Northwest while the intellectual descendants of Bechamp (those who advocate predisposing stressors) are further toward the east, primarily in Colorado and Wyoming, the region where the work on the lungworm/pneumonia complex dominated research for almost 40 years. The 'germ theory biologists' rely most heavily on the definitive killing assays done by Bill Foreyt at Washington State. Bill has repeatedly demonstrated, and published, accounts of penned bighorns dying of *Pasteurella* pneumonia following domestic sheep introduction to their pens. The 'predisposing stress' biologists don't deny these results, but are somewhat skeptical of their universal application. The 'stress camp' points to its more inferential studies of stressors interpreted to cause compromised immunocompetence as well as the fact that some bighorn populations in their region have coexisted with domestic sheep for decades. Still, the 'germ theory' school maintains the upper hand, probably for the same reasons Pasteur prevailed almost 150 years ago. Gathering supportive data for the germ theory remains direct (either the bighorns die or they don't); 'stress research' is more difficult and inferential. Part of this disagreement could result from the differing camps working with differing pathogens.

These two schools of thought don't seem communicate productively. I'm certain the researchers read and relate to their colleagues results, but they don't seem to be greatly influenced by them. The more serious part of this separation results from the involvement of field managers and their propensity to take sides in a diversity of approach and opinion they may not fully understand. The 'germ theory' folks, having a well-defined loyalty to Pasteur's legacy, adhere to the rational management dictum that "domestic sheep must be excluded from bighorn ranges." This amounts to a philosophically simple but culturally complex philosophy of quarantine to favor bighorn sheep. In apparent contrast to the 'germ theory school,' the 'stress school' is less willing to postulate a simple quarantine will solve the problem. This school argues stressors in addition to domestic sheep presence probably won't be adequately managed by simply separating bighorns from domestic sheep.

The quarantine issue becomes complex and politically relevant because of the former economic, and remaining cultural, importance of the domestic sheep industry in the American West. The domestic sheep industry, fighting for its existence because of its inability to compete on the world domestic sheep products market, is looking for all the help it can get. Typically, the industry opposes any limitations on its ability to compete in a difficult economic situation. As a result, the industry seizes on this divergence of scientific perspective with the argument that that the scientists don't seem to be able to agree, so their interest, domestic sheep, should not be considered harmful to bighorns.

Unfortunately, the issue of whether or not to quarantine bighorns (particularly by excluding domestic sheep grazing on the public lands) leads to some resentment in the bighorn management community as well. The political power of the domestic sheep industry in the 'germ' and 'stress' regions is variable, and the differences over the necessity of eliminating domestic grazing (the radical quarantine) lead the 'germ' folks to consider the 'stress' folks less as colleagues with a differing approach, and more as 'domestic sheep sellouts.' This is not helpful.

As indicated above, the confusion is enhanced by the fact that these differing schools appear to be looking at differing bacterial species. The 'germ theory school' work focuses on the most deadly bacterium it can isolate, the present fruits of 'the great bug hunt.' This 'bad bug' has come to be known as *Mannheimia haemolytica*, a separate genus and species from the traditionally-studied '*Pasterurellas*.' Research in the 'stress school' has focused on the more traditionally classified '*Pasteurellas*,' particularly the species, *trehalosi* and *multocida*.'

[Author's note: I realize I'm generalizing a bit here. The most highly publicized bighorn die-off in recent history, the Hells Canyon die-off, is presently thought (by the involved biologists to have been *Pasteurella* (not *Mannheimia*)-driven. Nevertheless, the Hells Canyon program clearly focuses on the alleged non-Mannheimia bacterium within the context of Pasteur's germ theory of disease. WH]

Adventures in bacterial taxonomy

The first step in identifying bacteria is to obtain a presumably pure culture of the bacteria and look at it under a microscope to see if it rod-shaped, round, filamentous, has flagella etc. Once this is known, a cell-wall stain, called Gram's stain is applied. The bacterium responds by developing either a blue or a red color depending on the structure of the cell wall. Then the fun really begins because the microscopic examination and Gram's staining separate bacteria only into very broad categories.

The classic approach to bacterial identification is to take the presumed pure culture, and see what it eats. On the basis of the foods (metabolites) the bacterium can process, it is further sorted to genus and species. There are at least two inherent assumptions in this approach to identification. The first is that the culture is pure. Empirically, this assumption seems justified provided adequate micro technique was practiced in the separation procedures. The second assumption is that the bacterial culture is genetically and phenotypically stable with respect to the metabolites it can process.

The assumption of genetic or metabolic stability is apparently open to question. About 105 years after Pasteur, three other French microbiologists won the Nobel prize for description of the "enzyme activation" phenomenon in *E. coli*. These Frenchmen (Jacob, Lwoff, and Monod) found that some cultures of *E. coli* could process lactic acid when they encountered it in their culture media, and some could not. Classically, this would have been adequate grounds for separating the two cultures as different species. However, the Frenchmen found that after being exposed to lactic acid for a generation or two, the cultures, which formerly couldn't metabolize it, developed the same ability to use lactic acid as the other cultures. This meant that either the culture had always had the latent (genetic) ability to metabolize lactic acid, or it had somehow acquired the ability. Jacob, Lwoff, and Monod eventually concluded the latent ability was there all along, and was just expressed when the metabolite stimulated their cultures to express the gene required to produce the enzyme to use lactic acid. I've never heard this work referenced in wildlife bacteriology, but since it won the Nobel Prize, I figure it must have been good science. For me, this raises some questions about the confidence we should have in classic bacterial identification.

With respect to domestic sheep bacteria that can kill bighorn sheep via pneumonia, the classic identification originally came down to genus, *Pasteurella*, and species *haemolytica*. Unfortunately, this wasn't an adequate functional description because some *Pasteurella haemolytica* cultures could kill bighorns and some couldn't. 'Bug hunters' figured this meant our system of what foods a bacteria could eat wasn't detailed enough to allow us to sort the benign *Pasteurellas* from the killers. Alternately, we have to face the possibility that the bacteria, as we had identified them to genus and species, didn't "breed true" like species of more complex organisms. That is, they may have been practicing enzyme induction or have acquired the ability to kill bighorns using some other trick our sorting system couldn't identify.

The first presumption was that there were differing strains, including the 'hot bug,' we could identify through more complex testing. One of these tests (called serotyping-because it is based on immune serum protein reactions) was used to identify very specific proteins on the surface of the bacteria as a means of sorting for the killer. This work was done with bacteria cultured from domestic sheep, and offered some promise. Eventually, Alton Ward a bacteriologist working in a domestic-sheep driven research facility, expanded on serotyping, melding it with more-detailed classic metabolic identification to produce an elaborate, second-order metabolic sorting system called biotyping. Al's lab was just down the street from Idaho's wildlife health lab, and a collaboration between the domestic-driven research unit and the wildlife folks began. Using his system, Al made the first attempts to identify the bacteria from bighorn die-offs. His work seemed to indicate there were, indeed, differing *Pasteurella* strains. It seemed Ward had been able to sort some "bad" strains of *Pasteurella haemolytica* from the benign ones. However, clear identification of 'the killer strain' proved yet-elusive. The bighorn-derived killers didn't sort as accurately as the strains from domestic sheep because they had differing (often more, as I understand it) specific surface proteins identified by the serotyping procedures. That is, instead of being identifiable as simply "A2," the common bighorn strain, they might type out as "A1, A2, or A7."

Here we should note that most of the work done on *Pasteurella* has been done by the domestic industry for which the bacteria represents problems. The domestic sheep issues with 'bad *Pasteurellas*' relate to decreased profits for ranchers and farmers. They are not basic life or death issues as in bighorn sheep. Consequently, the domestic industry has been involved in a decades-long quest to develop a vaccine to use against *Pasteurella* for economic reasons. This may be important to us because the agricultural researchers, who developed serotyping, re-used their *domestic* sheep cultures in an attempt to further identify their problem species. They did this by looking at the genetics of these domestic sheep bacterial cultures. Their method of sorting beyond sero- and bio- typing was to look at the DNA of differing cultures. When they did, they found some significant DNA differences between what had been called *Pasteurella haemolytica* and the other *Pasteurella* species, *trehalosi* and *multocida*. Consequently, they proposed a change in name from *Pasteurella haemolytica* to *Mannheimia haemolytica* based on basic DNA differences between the 'new' *Mannheimia*, and the 'old' *Pasteurella trehalosi*, and *Pasteurella multocida*.

[Author's Note: I don't know if all the wildlife managers involved in this issue have been able to keep up with these complex, 'out-of-discipline' changes. On the chance they haven't, we should note that, while we broadly labeled the bighorn killer bacteria as *Pasteurella haemolytica*, and while domestic sheep strains formerly called by this rather broad name are now called *Mannheimia*; it may be questionable to presume the 'great bug hunt' has come to a definitive and successful conclusion because of the DNA-driven name change. We can concur with the domestic sheep reclassification, and call all previously bighorn-derived *Pasteurella haemolytica* cultures "*Mannheimia*," if we so choose. However, we should realize no bighorn-derived strains have been retyped using the DNA system the domestic industry researchers used in their re-designation. WH]

Keying on the successful reclassification of the old *Pasteurella* *haemolytica* to *Mannheimia haemolytica*, bighorn 'bug hunters' have turned to the more modern and trendy DNA analysis. Here it is important to note that the assumption of metabolic (i.e. genetic) stability is still driving this portion of the great bug hunt.

I find this a bit unsettling because, plainly put, bacteria (like *Pasteurella/Mannheimia*) don't do sex the same way we do. That is bacterial DNA is of less certain origin than in life forms (like humans) that reproduce sexually. Relatively recent bacterial research shows some bacteria routinely transfer DNA by mechanisms called "plasmid transfer" (a kind of wholesale DNA swapping), "conjugation" (which is roughly the same way we do sexual reproduction), "transduction" (a form of viral DNA introduction), and a catchall called "transformation" (which means bacteria may incorporate any DNA they find lying around their environment). Additionally there is a phenomenon called "genetic splicing" wherein it seems as though proteins may "back code" for DNA. This is, of course, backwards to the prevailing model of gene action where DNA serves as a template for RNA, which serves as a template for protein synthesis. There's a whole 'brave new world' out there which I think should compel caution in "putting all our eggs in the DNA basket."

[Author's Note: I realize few, if any, of us were taught about this in school. It's new. If you want to catch up, two relatively understandable references are Barry Commoner's article "Unraveling the DNA Myth" in the February, 2002 *Harper's Magazine*, and a technical paper by John Maynard and Noel Smith called "The Genetic Population Structure of Pathogenic Bacteria." It's on pages 183-215 in the Oxford University Press Publication (1999) called <u>Evolution in Health and Disease</u>, edited by Stephen C. Stearns. WH].

SO WHAT?

I think this is important for two reasons. First, the assumption of genetic stability, when married to DNA analysis, intuitively leads us to look for genetic markers to identify the "bad bugs." This means we are likely to look for (presumably stable) genetic markers in what may, in all likelihood, be an unstable bacterial genome. It seems certain the genes basic to life and function (called 'houskeeping genes') must be present in living cells, and are likely to be quite similar, if not identical for all living things. This means that if we want to 'catch the bad bug,' we'll have to find where it does its nefarious work at the genetic level. It also seems certain the bacterial strains that cause fatal pneumonia in bighorns will have DNA that serves that purpose. Obviously, these cultures will prove to have differing DNA than those similar bacteria that don't kill bighorns…IF we can find the 'bighorn killing gene." Unless, of course, the enzymes required for toxin production are products of the enzyme induction phenomenon. So, I wonder, what will be the breakthrough of demonstrating the obvious in DNA banding patterns?

Second, I suggest the DNA business, though cutting edge and quite sexy, is actually retrograde in terms of progressive taxonomy. Classic taxonomy was based on physical morphology (structure). That is, we designated species on the basis of what they "were." This system was fine for making orderly lists of plants and animals, but did not serve us well when we needed to sort at a finer level of resolution. I presume we have defined our interest in a more meticulous sorting mechanism because we must presume evolutionary selection acts at a more subtle level than gross anatomy. The emerging approach to solving to identifying differences, which are not detectable through gross physical structure, has been use of DNA analysis. This is still a basically structural approach, which does not take phenotypic adaptation to environment as seriously as I would prefer.

Paradoxically (to me) the particular fascination of the DNA-level species sorters has focused on DNA that has no known function. This approach is considered quite useful for calculating what is known as "genetic distance" (which allows us to guess how closely differing critters may be related). However, the selective significance of variations in structural DNA is unknown. This interfaces with our interest in bacterial taxonomy because the relationship between structural DNA (and analogous, necessary to basic survival 'housekeeping genes,') and functional, i.e. for our argument, 'bighorn killing DNA' has not been defined. If we would identify the 'bad bugs' on a genetic level, doesn't certainty demand that we identify the gene that produces the toxin that kills bighorn sheep. If we could sort on the basis of that gene, AND IF bacterial DNA were as stable as mammalian DNA, we might be getting somewhere in genetically identifying the 'bad bug.' I'm uncertain of the rationality of 'the great bug hunt.'

SUMMARY

As stated above, I think it unfortunate the wild sheep community has never clearly faced the rationale for finding the "bad bug." Also, I'm uncertain there is an identifiable, genetically stable 'bad bug' because of the broad spectrum of DNA swapping possibilities among bacteria. Still, if there is a management relevant rationale (please recall our original goal was to make more, stable wild sheep populations), it must be production of a bighorn vaccine against *Pasteurella* pneumonia. The wildlife community has done what it could in our intuition or emotionally-driven effort to produce such a vaccine, but our efforts pale to insignificance when compared with those of the domestic sheep industry. It has failed to solve its "*Pasteurella* problem" despite the work of many great scientists over many decades and with the expenditure of many millions of dollars. I fear production of a bighorn *Pasteurella* vaccine is a highly unlikely event.

Furthermore, if there were a vaccine, managers would have to decide whether a "vaccine protected" sheep is desirable. For a vaccine to work, it would have to be universally administered. Would "universally vaccinated bighorns" be wild? Is having "wild sheep" important? If so, how important? These questions must be faced. If our only consideration is providing sheep for harvest or transplant, and if we could protect these sheep via vaccination, the questions would be fewer. However, if management of wild sheep in wild environments is our goal, the questions about "how much management is desirable" must be faced.

Finally, the 'germ theory' vs. 'stress theory' issue has not been solved. It has persisted at least since Pasteur and Beauchamp, and while the 'germ' folks have always had the upper hand, it appears the 'stress' camp may be gaining. Given "Murphy's Law" (that whatever can go wrong will), one would logically predict that the entire bighorn die-off syndrome is probably more complex than the presence of a simple "bad bug." The evidence supports Murphy's Law. For me, investing in the idea of a single, stable "bad bug" that could be managed through vaccination is inconsistent with what we now think we know of bacterial reproduction. Also, I must confess to having greater confidence in Murphy's Law than in the present approaches to bacterial taxonomy and management.

MANAGEMENT IMPLICATIONS

What we do know is that bighorn sheep will certainly do better if they aren't exposed to diseases that are "new" to them. It seems practically certain that separating bighorn sheep from domestic sheep would go a long way to limiting the pneumonia outbreaks that currently dominate bighorn management. Hence, my recommendation for wildlife biologists would be to leave the bacterial adventures and vaccine development to specialists in those fields, and to concentrate on doing the best we can to humanely separate bighorns from domestics. It's not sexy, and it's not new; but it will probably do more for bighorns than the excursions into DNA, diseases, and parasites that have occupied us for the last 50 years. Wild sheep habitats must, as a first step, be secure from the introduction of modern, exotic diseases and parasites. When we have achieved this, we may rationally move on to other management concerns. The 'stress camp' probably has much to tell us, and we should probably take it seriously. For now, I think the best we can do is to secure bighorn habitats from encroachment by domestic sheep and to keep bighorn populations at relatively low densities. These are, after all, the most basic of management requirements. They may be difficult, but they aren't new.

Rocky Mountain Bighorn Sheep/Domestic Sheep And Domestic Goat Interactions: A Management Prospective

VICTOR L. COGGINS, Oregon Dept of Fish and Wildlife, 65495 Alder Slope Road, Enterprise, OR 97828 U.S.A.

Rocky Mountain bighorn sheep (*Ovis canadensis canadensis*)/domestic sheep (*Ovis aries*) and goat (*Capra hircus*) interactions in Hells Canyon are reported on. Case histories of domestic sheep and goats co-mingling with bighorns are presented. Some short-term encounters did not result in disease outbreaks. Two cases of pneumonia outbreaks in bighorn herds following apparent contact with domestic goats are discussed. The timing of the onset of disease following known contact with domestic sheep is presented. Management actions discussed include:

1. Buffer zones between domestic sheep, domestic goats and bighorns.
2. What constitutes contact with domestic sheep and domestic goats.
3. When bighorn sheep should be removed.

Recommendations involving contact are summarized.

Managing Domestic Sheep Allotments In Bighorn Sheep Habitat: Seeking Solutions

KEVIN P. HURLEY, Wyoming Game and Fish Department, 356 Nostrum Road, Thermopolis, WY 82443, U.S.A.

Throughout the Western U.S. and Canada, separation of domestic and bighorn sheep has been a high management priority in recent years. Solutions to prevent or minimize contact and potential disease transmission range from simple to complex, and are often politically charged. The Foundation for North American Wild Sheep (FNAWS) and several of its chapters and affiliates have participated in discussions, negotiated solutions, and provided financial incentives to help resolve at least 17 overlap situations in 7 western states. Case histories, primarily from Wyoming but also from 6 other western states, are discussed. Resolution of future domestic/bighorn sheep overlap situations may be expedited or enhanced by this information.

POSTERS

Presented in Alphabetical Order by Author

Sightability Model For California Bighorn Sheep In Canyonlands Using FLIR Mounted On An Airplane.

SUSAN BERNATAS[1], Vision Air Research, Inc., 904 East Washington St., Boise, ID 83712 U.S.A.; Email – Wildlife@Visionairresearch.Com

LOU NELSON, Idaho Department of Fish and Game, P.O. Box 25, Boise, ID 83707

Abstract: The purpose of this study was to determine if a forward-looking infrared radiometer (FLIR) mounted in a fixed-wing airplane could detect and verify California bighorn sheep (*Ovis canadensis californiana*). The study area included the highly dissected rhyolite canyons of southwestern Idaho. All age and sex classes could be detected with the FLIR. Flying at 2,000 ft above ground level (AGL) the FLIR could distinguish bighorn sheep from other ungulates (i.e., pronghorn antelope, mule deer, livestock) on most occasions. Flying directly over the animal group and/or using the daylight video camera with full zoom provided confirmation. The survey was conducted after sunrise allowing for verification using a natural color video camera housed within the FLIR gimbal. Image clarity and the ability to circle the animal without disturbance allowed determination of male age classes for use in setting harvest of available rams. Bighorn sheep could be detected in all habitats used within the study area. Data were collected over three years with probability of detection of 89%. A set search pattern allowed consistent detection rates between sensor operators, airplane type, or between years. This study identified variables that influence sighting probability using FLIR. The use of a FLIR mounted on an airplane flying at 2,000 ft AGL has advantages over visual surveys using human observers in airplanes or helicopters: reduced stress to the animals, reduced violations of assumptions of sightability models, and reduced hazard to observers.

Key Words: sightability, population estimates, aerial surveys; Idaho; USA; infrared surveys; forward-looking infrared; FLIR, California bighorn sheep; (*Ovis canadensis californiana*)

A major problem in studying mammals in the field is finding them (Boonstra et al. 1994). Because ground-based observation of mountain sheep (*Ovis canadensis*) is often limited by access and topography, aerial census is often the only practical way to estimate mountain sheep numbers (Remington and Welsh 1989). This technique has limitations because biases may occur as a result of observers (Simmons and Hansen 1980), technical problems (Caughley 1974), or more commonly, sightability (Remington and Welsh 1989, Bodie et al. 1995). Visibility is the most important factor affecting population estimates (Pollock and Kendall 1987, Samuel et al. 1992, Bodie et al. 1995). This parameter is influenced by weather and lighting conditions, season, heterogeneity of terrain, vegetative cover, observer fatigue, search speed altitude, and distribution pattern of bighorn sheep (Simmons and Hansen 1980, Remington and Welsh 1989, Bodie et al. 1995).

Idaho Department of Fish and Game (IDFG) uses helicopters to survey for California bighorn sheep (*Ovis canadensis californiana)* (Neal et al 1993, Bodie et al. 1995). These surveys are conducted within the canyon at or below 30 m above

[1] Formerly with Odgen Environmental and Energy Services.

ground level (AGL) (Simmons and Hansen 1980, Remington and Welsh 1989). Helicopters are highly stressful to bighorn sheep and other ungulates (Bodie et al. 1995, Stockwell et al. 1991, Bleich et al. 1990). Bighorn sheep respond to helicopter disturbance in a variety of forms (Bleich et al. 1990, Bleich et al. 1994), including grouping up and running which cause them to alter both their distribution and movements. This disturbance is prolonged since mountain sheep reportedly moved 2.5 times further the day following the survey than on the day before the survey. Stockwell et al. (1991) found that helicopter overflights reduced the foraging efficiency of mountain sheep. Potential consequences such as altering habitat use, increasing susceptibility to predation, or increasing nutritional stress, are unknown (Bleich et al 1994).

The repeated disturbance from the helicopter surveys has resulted in questioning the results therefore, the utility of these surveys. A 1998 helicopter survey for California bighorn sheep in the South Fork Owyhee River, Idaho highlight the reliability problems with this survey technique (IDFG 1998, unpublished data). Over 40 animals were not found during the helicopter surveys that were subsequently located two weeks later during ground surveys. In addition, bighorn sheep were observed to change behavior including grouping and running when the helicopter is six or more km away. Movements during helicopter surveys violate several assumptions required for population estimation: individuals maybe counted more than once so the probability of "recapturing" an animal is not constant; and surveys are not independent. Violation of these assumptions affects accuracy and precision of the population estimates (Bleich et al 1990).

Helicopter surveys have other limitations because biases may occur as a result of technical problems or more commonly the observer's ability to detect the subject animals (Caughley 1974, Caughley et al. 1976). Visibility, the most important factor affecting population estimates (Pollock and Kendall 1987, Samuel et al. 1992), is influenced by weather and lighting conditions, season, heterogeneity of terrain, vegetative cover, observer fatigue, search speed, altitude, and distribution pattern of animals (Samuel et al. 1987). In addition, these surveys pose high-risks for the biologists collecting the data. The helicopter must fly low to search for animals in rough terrain where wind turbulence is unpredictable. Alternatives to helicopter surveys that provide reliable information are needed.

Tests conducted in 1997 under the first phase of this study indicated that a forward-looking infrared (FLIR) mounted on an airplane could detect bighorn sheep (Bernatas, 1997, unpublished data). The use of a color video camera housed within the FLIR gimbal provided the ability to determine age class of rams. These test flights were conducted in May when the bighorn sheep were more likely to be in smaller groups within lambing areas. Maximum likelihood of disturbance was anticipated during this period however, the animals did not respond to the airplane flying at 2,000 ft AGL. Late winter was selected for future surveys for three reasons: animals would more likely be located in the upland facilitating sighting potential; cool temperatures allow a longer period to perform the survey before the ground temperature reached the temperature of the animals; and, potential for good weather for aerial surveys. Flight parameters (e.g., scan pattern, airspeed and altitude) were tested and reconfigured to optimize their effect on detection rates. A list of variables was developed to provide input into sightability model development such as environmental variables (i.e., cover type, sun/shade, and position in canyon) and animal behavior (i.e., running, standing, bedding, walking) and group size. This goal of the second phase was to develop a sightability model to determine population estimate.

STUDY AREA

The study area was located in Owyhee County in southwestern Idaho. It included the East and South Forks of the Owyhee River and Dickshooter Creek. Elevations ranged from 1,380 to 1,660 m. The terrain includes gentle rolling uplands and steep rhyolite canyons that range from 30 to 300 m deep. Canyon width ranges from approximately 300 to 1,500 m. These canyons are highly dissected with areas of cliffs, talus slopes and mid-elevational benches with shallow soils. Soils in the uplands are relatively deep soils and the vegetation is sagebrush-steppe dominated by Wyoming big sagebrush (*Artemisia tridentata wyomingensis*) that averages 1.0 m tall. Thin, stony soils are dominated by low sagebrush (*A. arbuscula*) in the uplands. The western portion of the study area includes scattered Western juniper (*Juniperus occidientalis*). Mountain mahogany (*Cercocarpus ledifoius*) and hackberry (*Celtis retuculata*) are found rarely in the riparian or lower benches in the canyon. Rabbitbrush (*Chrysothamus* spp) is found in disturbed areas and on north facing slopes. Common grasses include: bluebunch wheatgrass (*Pseudoroegneari spicata*), Sandberg's bluegrass (*Poa sandbergii),* and bottlebrush squirreltail (*Sitanion hystrix*).

Along with bighorn sheep, mule deer and pronghorn antelope inhabit the study area. Cattle and horses were infrequently found during the study period.

METHODS

Paired observations were obtained using 30 radio-collared bighorn sheep available from a previous Bureau of Land Management (BLM) study. Canyon habitat was divided into segments to form survey plots. Survey orbits of 1,500 m in diameter and spaced 450 m apart, were plotted on a 7.5-minute topographic map of the survey area. Each orbit was assigned a unique number to facilitate communication between the two aircraft. The center of the orbit was noted on the 1:24,000 and 1:100,000 maps. Latitude and longitude coordinates of the center point of the orbit were programmed into the aircraft GPS navigational system to locate and maintain the correct flight path.

Two airplanes and crews were required for data collection. A crew including a pilot and a biologist using telemetry, hereafter telemetry crew, located collared bighorn and identified them within the predefined plots. The bighorn group was identified as the sample. A second airplane and crew included a pilot, sensor operator and biologist, hereafter FLIR crew. The biologist with the FLIR crew coordinated the two aircrews and recorded data. Only those plots where bighorn sheep located by the telemetry crew were selected to avoid expenditure of resources by sampling in canyon reaches with no bighorn sheep. The telemetry crew located bighorn sheep groups and radioed the plot number, location information, group size and habitat to the biologist with the FLIR crew. The sensor operator was not provided any information on the group. The operator scanned the selected plot in a predefined search pattern. The IR sensor operator could not see out the windows because the windows were blacked out to reduce screen glare.

The search pattern included two revolutions around the selected orbit. The orbit was flown with a 1.1 km radius providing a 0.8 km search radius to avoid having to search directly under the airplane. The sensor operator searched the orbit using a radial search pattern and located animals by their level of emitted heat versus the background using the IR sensor. Each orbit was flown with two revolutions. All surveys were flown at 2,000 ft. AGL. If the subject group was not located, the crew offset with another orbit located upstream of the selected orbit provided overlap. An additional overlap was provided downstream of the selected orbit. These offset points of the selected orbit providing 50 % overlap. If the group was not located after completing this search pattern it was considered a miss. The number of revolutions and overlap of adjacent orbits was established for an operational survey. As such, selecting the center orbit and the adjacent upstream and downstream orbits provides a measure of efficacy of an operational survey when known groups were available. Once detected, positive species identification was confirmed using specific body features using the color camera.

The sample was defined as the collared animal and their respective group. The group was counted as one sample even if more than one collar was located within the group. Although there was concern about the ability to recognize and define a single sample group or the sample group(s) from other unmarked groups, this did not prove problematic because the animals did not move in response these two airplanes used for these surveys. Weekly telemetry flights have been conducted over this East Fork Owyhee herd to support a BLM research project reduced any response to the lower flying telemetry airplane.

The fixed wing airplane type changed between years however, this did not affect data collection since flight speeds, navigation equipment, crew size, and FLIR remained the same. The gimbal, which houses the FLIR and color TV camera, was mounted to provide a 360-degree view. The gimbal was mounted in the fuselage of the Cessna 303 in 1998 and 1999 and under the left wing of the Cessna 337 in 2000. Both aircraft had a LORAN and a Northstar global positioning system (GPS). The FLIR was a commercially available Westinghouse WesCam DS16 FLIR (WesCam, Burlington, Ontario, Canada) which operates in the 8-12 micron spectral band. At 2,000 ft AGL looking straight down, the footprint or field of view (FOV) is 110 m in the wide or 10^{o} FOV and 30 m in the narrow or 3^{o} FOV. (All altitudes are provided in English units since all aircraft use this system.) The FLIR can detect differences in temperature of 0.25^{o} C. The latitude, longitude, date, and time were overlaid on the screen as well as the simultaneous recording of the voices of the sensor operator, pilot, and observer to provide reference for subsequent review upon return. The operator sat in the rear seat and manually aimed and focused the sensor or TV camera. The operator scans using the FLIR in wide FOV and switched to narrow FOV for object identification. The natural color TV was used for species identification and to determine ram age class. Either the color TV picture or IR image was recorded with screen overlay for future reference and analysis.

Flight speeds ranged between 70-100 knots. Surveys commenced approximately 30 to 60 minutes prior to sunrise and continued until temperature of the background was hotter than the animals.

The survey period was typically three hours. Night surveys were not considered because of the goal of determining ram age class requires using the natural color camera to verify horn curl size. Latitude and longitude coordinates of the center point of the orbit were programmed into the aircraft GPS navigational system to locate and maintain the correct flight path. Upon completion of the surveys, the sensor operator and observer/biologist reviewed each tape and recorded the number of animals and groups detected.

A hit or miss, along with the variables associated with the group, were recorded. If a group was missed the two airplane crews worked together to identify the attributes of the missed group and attempt to locate them with the sensor. The two aircraft did not fly in the same orbit during the IR search for safety and to avoid disturbance to the search pattern. They did work together to locate the group after the IR search pattern resulted in a missed group. They also worked together to verify that any groups found were the same as the sample. This clarification was important because group size or location occasionally changed between the time the telemetry airplane flew over the group to when the IR airplane flew over the group.

Data Analysis

Logistic regression has been used to build sightability models (Samuel et al 1987, Ackenson 1988, Unsworth et al 1990, Bodie et al 1995) because predictor variables are not normally distributed and some variables are discrete or categorized (Johnson 1998). Chi-squared test was used to test for differences between estimators among survey flights. SYSTAT 9.0 (SPSS Inc. 1998) was used for the analysis.

RESULTS

A total of 92 samples were collected in March between 1998 and 2000. The sightability or percent seen was 85.2 %, 89.4 %, and 88.9%, for 1998, 1999, and 2000, respectively, with no significant difference between years for sightability ($p = 0.861$). Chi-square value for all covariates (i.e., group size, cover, slope position, activity type, and sky) was 22.456 (11 df) ($p = 0.021$) indicating these variables were significant predictors of sightability. The univariate chi-squared comparisons of variables were not significant except for cover type (Table 1). Backward logistic regression revealed that cover type and sky remained in the model.

DISCUSSION

FLIR capabilities

Results show that the IR sensor and natural color camera mounted on an airplane perform well to locate and verify bighorn sheep with a detection rate of nearly 90%. The current technology is far improved over initial uses of IR sensors, which showed promise but had limited success (Croon et al. 1968, McCullough et al. 1969, Graves et al. 1972, Parker and Driscoll 1972, Wride and Baker 1977). Those problems included inability to differentiate species, inability to distinguish animals from background objects, bias in sampling techniques, and canopy cover limited the widespread use of this technology. Early surveys relied on computer analysis of survey tapes to identify target species. This procedure involved measuring the emitted temperature, via the IR sensor, of an animal and the temperature of the environmental background prior to a survey.

Advances include increases in thermal detection resolution, improvements in optics, real-time data acquisition, and

Table 1. Univariate comparisons of independent variables tested during the IR surveys in the East Fork of the Owyhee River during 1998, 1999, and 2000.

Variable		n	% seen	Chi^2
Year				0.861
	1998	27	85.2	
	1999	47	89.4	
	2000	18	88.9	
Group Size				0.359
	1-6	35	82.9	
	7-13	35	88.6	
	14+	22	95.5	
Sky				0.151
	Bright	67	85.1	
	Dull	25	96.0	
Slope Position				0.10
	Upland	63	93.6	
	Upper slope	22	77.3	
	Mid-slope	4	75.0	
	Lower slope	3	66.7	
Cover Type				0.0
	Rock	21	61.9	
	Sagebrush	60	96.7	
	Grass	8	87.5	
	Juniper	3	100.0	
Activity Type				0.911
	Bed	19	89.6	
	Stand	60	88.3	
	Walk	13	84.6	

miniaturization of equipment (Garner et al. 1995). The current IR technology allows the sensor operator to identify animals in flight using morphology or specific body features during surveys. Finer resolution through an increase in the number of pixels represents the most important advancement in thermal-IR technology for wildlife survey applications. Increase thermal sensitivity combined with increase in pixels provides the ability to determine the animal through morphology. A natural color camera housed in the gimbal can facilitate species verification. The sensor operator can switch between the FLIR and the color camera to detect and verify the animal. Infrared sensors have been used to detect small mammals (Boonstra et al. 1994), waterfowl (Best et al. 1982, Sidle et al. 1993), turkeys (*Meleagris gallopavo*) (Garner et al. 1995), birds and their nests (Boonstra et al. 1995, Benshemesh and Emison 1996), marine mammals (Barber et al. 1991, Cuyler et al. 1992, Ryg et al 1988), fox (*Vulpes* sp. and *Alopex lagpus*) (Klir and Heath 1992), bats (Sabol and

Hudson 1995), moose (*Alces alces*) (Adams 1995, Garner et al. 1995), white-tailed deer (*Odocoileus virginianus*) (Wiggers and Beckerman 1993, Garner et al. 1995, Naugle et al. 1996, Haroldson 1999), wild horses and burros (Bernatas 1999), and other animals (Havens and Sharp 1998).

Wiggers and Beckerman (1993) used FLIR to survey captive white-tailed deer of known sex and age classes, and Garner et al. (1995) surveyed free ranging white-tailed deer and found that age and sex discrimination was possible. Both studies found that canopy cover reduced the probability of detection. Best times were when the thermal contrast between the target animals and the environmental background was the highest, generally during the early morning hours, on overcast days, or in the cooler seasons of the year. Adams (1995) found that overall sightability of moose was 88%, in comparison to salt lick surveys and that FLIR surveys were more cost effective relative to traditional aerial surveys and had greater survey area. Naugle et al. (1996) compared aerial IR surveys with spotlight surveys of white-tailed deer and found IR surveys a more reliable density estimator. A wild horse and burro survey conducted in July near Yuma, AZ, found that these animals could be detected while bedded under salt cedar (*Tamarix pentandra*) (Bernatas 1999) suggesting that ambient temperature may not be the best indicator of thermal contrast. Temperatures during flights were in the high 80^{o}s F to low 90^{o}s F.

A major goal for the improvement of aerial survey estimates is to determine the number of animals missed during surveys (Samuel et al. 1987). The degree of visibility bias depends on many factors, including animal behavior and dispersion, observers, weather, vegetation cover, and equipment (Ackerman 1988). Visibility also may confound the estimation of age and sex ratios when males, females, or young have different visibility factors. Unsworth et al. (1990) found that to assure the most accurate and precise estimates when using the elk sightability technique, surveys should be conducted when group sizes are at a maximum and elk are using the most open habitats. In addition, double counting can be reduced by surveying elk when mobility is restricted by snow and using unit boundaries that restrict elk movements. Double counting can be avoided further during helicopter surveys by flying adjacent units consecutively and paying particular attention to the size and composition of groups near unit boundaries.

Our study finds that aerial IR provides a higher detection rate than the current helicopter survey being used to develop the population estimate in this area. Using the increased detection capabilities of an IR sensor over human vision and flight altitudes above 1,000 ft eliminates the problems associated with helicopter. The animals don't run or otherwise change behaviors therefore the probability of double counting or under counting can be sharply reduced. This study identified variables that influence sighting probability using an infrared sensor. These data indicate that all members of the population have a greater than zero probability of being detected using this survey technique. This study finds that IR provides for higher detection rate than the helicopter survey (i.e., 89 % vs 50 %). All age and sex classes may be detected, and it is possible to detect these animals in all habitats used. Although there does appear to be in increase in the detection rates with increased group size, it is not statistically significant ($p = 0.359$). Even small group sizes have a high detection rate (82 %).

The two greatest influences in detection rate are season of survey and search pattern as evidenced by the increase from 25 % to nearly 90 % when these parameters were tested in 1997 in Little Jacks Creek. A radial search pattern appears optimal for the highly dissected canyons allowing all possible look angles. Circling each orbit twice and having a 50 % overlap has increased the sightability from about 20 % in 1997 to 89 % in 1999. Airspeed of 80-90 knots appears optimal to allow the IR sensor operator to search the area. In 1998, the orbit radius was 1.6 km, however plotting the observed and missed groups indicated that the actual search radius was 0.8 km. Therefore, those sample groups classified within the orbit (i.e., being located within 1.6 km from the orbit center point), but were determined to be located greater than 0.8 km from the orbit center were missed. Orbit centers were plotted 0.8 km apart in 1999 to provide a better representation of the actual coverage of each orbit.

Trained observers are imperative to reliability traditional aerial surveys (Unsworth et al. 1990, Haroldson 1999). This is also true of aerial IR survey. Wiggers and Beckerman (1993) found that sensor operator bias was high resulting in a wide range (e.g., 25-80%) in detection rates. However, there was no cross training between the IR firm conducting the surveys and the wildlife biologist requesting the survey. Standard and tested search protocols were not established for subject species and habitat. Our initial tests found that the trained military sensor operator with over 2,000 hrs had a 25% detection rate for bighorn sheep in this study area. However, cross training where the biologist learned to operate the system and the sensor operator learned more about wildlife proved fruitful. Subsequently, survey search and scan protocols were established and detection rates increased. Using standard protocols there was little difference between sensor operators as evidenced by the between years ($p = 0.861$) comparisons. Wiggers and Beckerman (1993) also found that a biologist could review the IR tapes with reasonable accuracy after an eight-hour training period. This has limited application if the sensor operator collecting the data incurs survey bias or is ill trained to operate the system. (Basic training time for a sensor military operator is over 200 hours.)

Also influencing detection rate was the difference in surfacing temperature. Bighorn sheep on rock or talus slopes are more difficult to detect, although the detection rate is still fairly high (61 %). The study goal included determining when to stop the surveys because of increased temperature gain. As such, flights were conducted into periods that were not optimal for locating animals. Most "misses" occurred later in the survey period where background temperature occluded group detection. This is particularly true for groups located on rocky or gravelly terrain. Operationally, the sensor operator would suspend the survey prior to degraded detection.

Cost comparison

The helicopter survey for bighorn sheep in this area requires search both sides of the canyon and all mid-elevational benches within the canyon. A hypothetical, 10 miles long canyon reach with a lower, mid and upper elevational bench and the uplands were used to compare costs. The helicopter flight would require 4 passes on each side or 80 miles for a minimum time flight time at 40 knots of 2 hours. The cost is estimated at $1,200 for the flight time. Salaries for two biologists, plus fuel truck transport and other helicopter support requirements and ferry time costs are additional costs. This same segment would require 20 orbits for a minimum flight time of 2 hrs with the cost estimated at $1,100. Additional biologists as observers are not required. Ferry time is typically less for a fixed wing and the hourly rate is much less.

Direct costs for a fixed wing airplane and FLIR are less as indicated above. Perhaps as important are the risk and stress issues. The detection rate is much higher, the risk to the observers and stress to the animals are sharply reduced. The IR survey costs could be reduced by modifications of the flight patterns based on knowledge of detection rates. A very high proportion of the collared animals were located in the uplands (63 %) or upper third of the canyon (24 %). The bighorn sheep in the sagebrush uplands were typically located during the first revolution of the orbit since there is very little to confound the detection. If the scanner passed over the group it was detected. As such, transects would be effective in the uplands reducing the survey time by for this segment of the habitat by 50 %. In addition, those groups located in the upper third of the canyon can be located using two revolutions of the orbits without using overlap a high proportion of the time. The survey time would be reduced by reducing the overlap of the orbits, hence reducing the number of orbits to be flown in a given canyon reach. The survey time and cost would be reduced through the use of transects in the uplands and modifying the sampling approach in the canyon.

Benefits of surveying for California bighorn sheep with IR sensors over traditional aerial surveys include: 1) IR sensors can detect animals at greater distances than human eyesight, especially animals that are not moving; 2) the aircraft can fly at higher altitude 1,500 – 2,000 ft vs. 30 ft, allowing for increased ground coverage in less time and decreased disturbance to study animals; 3) reduced costs; 4) increased detection rates; and 5) increased human safety.

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Spatial And Temporal Synchrony In Horn Growth Of Dall Sheep Rams In The Yukon

DAVID S. HIK, Department of Biological Sciences, University of Alberta, Edmonton, AB, Canada, T6G 2E9
JEAN CAREY, Department of Environment, Government of Yukon, Box 2703, Whitehorse, YT, Canada, Y1A 2C6

Abstract: Horn growth of Dall sheep (*Ovis dalli*) rams was estimated as the volume of annual increments for 8491 individuals harvested throughout the Yukon between 1974 and 2001. We observed broad synchronization, with an approximate 10-year periodicity, in patterns of horn growth throughout the Yukon. The greatest variability and coherence in horn growth among different cohorts was observed in the southwest Yukon. In the northern Yukon, less interannual variability was observed. The largest horns were from the central Yukon. These patterns of variability between different ecological and climatic regions of the Yukon are consistent with our earlier hypothesis that horn growth of Dall sheep rams is a sensitive index of climatic variability. Periodic variation in climate, which influences availability of forage productivity in alpine environments, provides a means of predicting patterns of horn growth and has implications for management of these populations.

Rocky Mountain Bighorn Sheep Management In Badlands National Park

EDDIE L. CHILDERS, Badlands National Park, P.O. Box 6, Interior, SD 57750

Abstract: Rocky Mountain bighorn sheep were extirpated from most of their historical range in the western United States by the turn of the century. Since 1967, 3 bighorn subpopulations have been established at Badlands National Park through translocation efforts by the South Dakota Department of Game, Fish and Parks (SDGF&P), Colorado Division of Wildlife (CDW) and the National Park Service (NPS). Fourteen bighorn sheep (2 ewes, 2 rams, 4 yearling ewes and 6 lambs) were released to the wild on August 31, 1967. The population size has fluctuated during the last 35 years with total numbers estimated at 163 in 1994 to our present population in 2002 of 58 individuals found in three separate subpopulations. Future long-range goals for Badlands National Park include continue to gain an understanding of bighorn sheep dynamics by inventory and monitoring populations, habitat relationships as well as detecting both natural and human caused changes in abundance and distribution. Our current major objective for the Badlands National Park Bighorn Sheep population is to secure animals for translocation into the park to minimize the danger of extirpation in the next 1-200 years.

Key words: Rocky Mountain Bighorn Sheep, *Ovis canadensis canadensis,* South Dakota, Badlands National Park, Management.

Badlands National Monument (BNM) was authorized by Congress in 1929 and was established to preserve the scenery, protect fossils and wildlife, and to conserve the mixed-grass prairie. The monument boundary was laid out to primarily protect the Badlands scenery and their constituent fossil material. Prairie areas in and around the Badlands were excised throughout the first two decades of the existence of the BNM to support cattle grazing. The monument boundary stabilized over time with the growing realization that BNM was the only major representation of mixed prairie in all of the National Park Service (NPS) system.

In 1976, an agreement between the Oglala Sioux Tribe (OST) and the NPS added 133,000 acres of the Pine Ridge Reservation to BNM. This stunning landscape of high grassy tableland and spectacular buttes is the scene of much of Sioux history. In 1978, Congress elevated the status of BNP to Badlands National Park (BADL), emphasizing the value of the landscape to present and future generations.

Widespread population declines and local extinction during the past century eliminated bighorn sheep (*Ovis canadensis)* from most of their historical range in the western United States (Buechner 1960). Reductions in numbers and distribution of bighorn sheep have been largely attributable to habitat alteration caused by human activities and land management practices (Bear and Jones 1973, Wishart 1978, Wakelyn 1987). The Audubon's bighorn sheep (O. c. *auduboni*) once occupied suitable habitat throughout the Black Hills and badlands of South Dakota (Buechner 1960). By 1925 this subspecies was considered extinct throughout its range (Buechner 1960) as a result of over-hunting combined with urban, mining and agrarian development.

BACKGROUND

Bighorn Sheep Population Origin and History

In 1964, the National Park Service (NPS) cooperated with the South Dakota Department of Game, Fish and Parks (SDGF&P) and the Colorado Division of Wildlife (CDW) to reintroduce 22 Rocky Mountain bighorn sheep (*Ovis canadensis canadensis)* from the Pikes Peak, Colorado source herd, into Badlands National Park (Bessken and Plumb 1997). The area of restoration was a 150-hectare enclosure located approximately 1 km west of the Conata Road Picnic Area. The goal of the agreement between the NPS and SDGF&P was to establish a herd at Badlands National Park. After establishing the herd, animals could then be translocated to other areas of South Dakota initiating additional populations within suitable habitat within Badlands National Park as well as two locations in the northwest part of the state (Hjort and Hodgins 1964).

Following an approximate 50% loss to the enclosed population attributed to *Pasteurella* infection during late-summer 1967 (Hazeltine 1967, Powell 1967, Weide 1967), the remaining 14 bighorn sheep (2 ewes, 2 rams, 4 yearling ewes and 6 lambs) were released to the wild on August 31, 1967 (Badlands National Park Bighorn Sheep Restoration Program 1969). For two years, periodic, opportunistic observations suggested that a band of 10-12 animals remained within 2 km of the release site (Badlands National Park Bighorn Sheep Restoration Program 1969).

The first post release population survey was conducted in June 1980. During a one-man, one-week ground survey, 27 bighorn sheep (9 ewes, 8 rams, 2 yearlings and 8 lambs) were observed within a 13.5 km^2 area adjacent to the release enclosure (McCutchen 1980). McCutchen (1980) considered the population to be stable but not increasing based on a 100:22 ewe:lamb ratio he derived from his survey. No definite factors limiting population growth were identified at this time although water, forage and genetic factors were considered.

During the early 1980's, the population continued to inhabit an area of about 40 km^2 in the Pinnacles area of the Park. From 1987-1990, SDGF&P conducted winter ground counts in the North Unit and estimated a population of 133-200 bighorn sheep with a ewe: lamb ratio of 100:53 during the winter of 1989-90 (Benzon 1992). During an aerial survey in September 1991, 30 bighorn sheep were observed in the South Unit of Badlands National Park, approximately 20 km south of the Pinnacles population. Qualitative accounts from local ranchers suggest that a small band had been established in the South Unit as early as 1981 (Badlands National Park Resource Management Plan and Environmental Assessment 1984).

During 1992-94, Badlands National Park conducted aerial surveys of the North and South Units. The estimated population size at this time was 163 +/-55 (90% C.I.) using the sightability model developed by Unsworth et al. (1994). Air surveys in October 1994 indicated a ewe: lamb ratio of 100:39.

A period of heavy decline and poor recruitment from 1995 to 1997 was attributed to an outbreak of Epizootic Hemorrhagic Disease (EHD). A November 2000 survey found the BADL population with a minimum number of 58 individuals occupying three separate habitat patches. However, one documented case of the often fatal Bluetongue disease was found from the carcass of a radio-collared ewe in the Cedar Pass Area in October 2000, and three other collared ewes were found dead in the South Unit during the November 2000. Cause of death for these three ewes, all at least 6 years of age, was unknown. A pronghorn antelope found dead in the North Unit of the Park in September was also found to have Blue tongue. So, while the Cedar Pass and Stronghold subpopulations appear stable, disease is a very real concern.

MANAGEMENT DIRECTION

Philosophy

Ecologists with the USGS-BRD believe that restoration efforts at BADL to date have not been sufficient, since only 14 individuals comprised the founder population in 1967; optimal size for success of a translocation has been documented at greater than 40 individuals. Several unoccupied suitable habitat patches in the greater badlands ecosystem also remain. Recent research (Singer et al 1999, Gross et al 1999) indicates that colonization into new habitat are most likely to occur: from populations stemming from larger founder groups; when the new population is migratory or partially migratory; when there are few barriers to movements to the new patches; and, when the population is growing at a rate greater than 21% per year. Recent analysis of over 100 translocations also indicates that restoration is more successful when at least three translocations or founder groups (of 25 or more animals each) are placed into clusters of suitable habitat separated by 16 to 50 km. This potential metapopulation structure has been shown to increase dispersal, population growth rates, range expansions, contacts between subpopulations, and the probability of long-term persistence. Conservation biologists recommend restorations only into very large blocks of suitable habitat likely to support a minimum of 300 animals. The greater Badlands National Park area should be able to support more than 300 Bighorn Sheep based on GIS modeling efforts by Sweanor et al (1995). Only populations of this size retain genetic diversity, are more likely to recover and persist following a catastrophe such as an epizootic, and are predicted to persist with minimal management for 100 to 200 years.

The greater badlands ecosystem comprises lands administered by several different state and federal agencies. The core bighorn sheep habitat is on public lands administered by the NPS as Badlands National Park. This includes the federally owned North Unit as well as the South Unit, tribal lands of the Pine Ridge Indian Reservation managed under an agreement with the Oglala Sioux Tribe (OST). Additional adjacent grasslands are administered by the USDA, Forest Service (USFS) as the Buffalo Gap National Grasslands. The SDGF&P has an interest in the establishment and perpetuation of a healthy, stable metapopulation of bighorn sheep in the greater badlands ecosystem and will be a key partner in the translocation.

Goals

- BADL will continue to support a bighorn sheep population.
- BADL will continue to gain an understanding of bighorn sheep dynamics by inventory and monitoring populations, habitat relationships as well as detecting both natural and human caused changes in abundance and distribution.
- BADL staff will ensure that the parks' activities do not adversely

impact bighorn sheep using NEPA and NPS-77 as guidance.

Objectives

- Identify habitat areas that are critical to the bighorn sheep population and protect these areas.
- Work cooperatively with BADL personnel by providing assistance on bighorn sheep issues.
- Work cooperatively with other agencies and landowners to resolve human/ bighorn related conflicts.
- Maintain the bighorn sheep population at a level that does not exceed the carrying capacity of the park.
- Maintain the bighorn sheep population at a level to minimize the danger of extirpation in the next 1-200 years.
- Seek funding from cooperative sources.
- Seek to build partnerships.
- Educate BADL personnel and park visitors concerning their potential impact to the parks' bighorn population.

Badlands National Park Resource Management staff are responsible for the inventory and monitoring the Bighorn Sheep population within the boundaries of Badlands National Park. The population is presently found in 3 areas of the park (Pinnacles, Cedar Pass and Stronghold, Figure 1).

Carrying Capacity

The greater Badlands National Park area should be able to support more than 300 Bighorn Sheep based on Geographic Information System (GIS) modeling efforts by Sweanor et al (1995). In fact, only populations of this size retain genetic diversity and are more likely to recover and persist following a catastrophe such as an epizootic, and are predicted to persist with minimal management for 100 to 200 years. Consequently, the minimum size of the Badlands Bighorn Sheep Population should be approximately 300 animals to maintain population stability.

Some biologists believe that Badlands National Park cannot support numbers as high as those projected by the model by Sweanor et al (1995). This is based on observations of the population decline observed at Badlands National Park after 1990 when total numbers plummeted from greater than 160 animals in 1992-94 to less 100 presently. This population crash could have been the result of the documented epizootic outbreak or some unknown behavioral/nutritional deficit not yet discovered. Ted Benzon, Big Game Biologist for the South Dakota Department of Game, Fish and Parks, believes that the maximum ecological carrying capacity for the Pinnacles area is approximately 165 bighorn sheep, for the Cedar Pass area is approximately 75, and, the Stronghold area, approximately 150 sheep (Figure 1). These estimates correspond closely to those projected by Sweanor et al (1995) in those focus areas analyzed. Consequently, maximum ecological carrying capacity for the three areas that presently have Bighorn Sheep within Badlands National Park is probably between 300 and 400 animals.

Maintenance

Bighorn sheep are a high maintenance species and to manage them properly requires time, effort and expense. Negative factors that effect populations include habitat changes, disturbance, disease, competition for space and forage and other human caused disturbance. All of these factors are known to exist at Badlands National Park and has probably at one time or another during the last 35

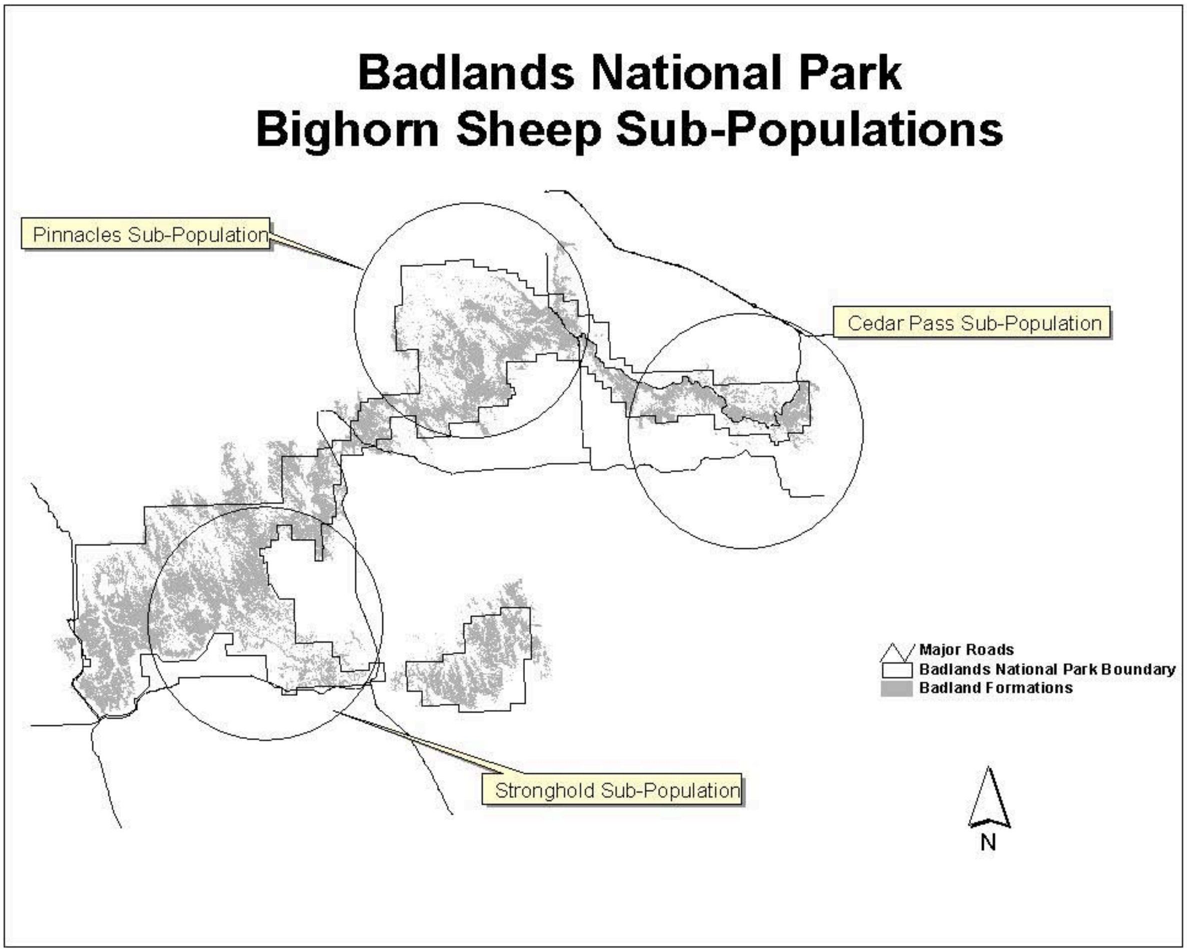

Figure 1. Map of Badlands National Park Bighorn Sheep Sub-Populations.

years contributed to the Bighorn Sheep population increases or decreases to varying degrees. The park now has monitoring strategies are in place to consider these factors and their impact on the Badlands Bighorn Sheep population.

Prescribed fire is the most prevalent habitat change that resource managers utilize at Badlands National Park. Prescribed fire has been found to provide positive benefits to bighorn sheep populations in mountain areas as it removes woody vegetation that provides cover for predators to hide in as they prey upon young bighorn sheep (Bleich 1999). Moses et al 1997 found few significant differences in forage quality as a result of prescribed burns at Badlands National Park with the only advantages being short term increases in nitrogen levels of *A. smithii* and increased digestability of *Stipa spp*. Careful, consistent monitoring of the Bighorn sheep population will be continued as the Park prepares to burn approximately15, 000 acres during the next 15 years.

While disturbance and or urbanization is not a major concern for Badlands National Park, development in the form of new road construction in the north unit of the park and visitor Center Construction in the South Unit is under consideration as part of the alternatives for the Park's General Management Plan. Monitoring of the Bighorn sheep population during this road construction period during the 2001 lambing season revealed a slight decline in the number of lambs found; however, there were 4 fewer adult breeding ewes in the population in 2001 as a result of an epizootic outbreak the previous year. Again, careful, consistent monitoring of the population will continue to determine the impacts of any future construction activities that occur within the Park, especially during the critical lambing period from April 1 to Jun 30.

Disease continues to be a factor for the Bighorn sheep population at Badlands National Park. Badlands appears to provide environmental conditions for outbreaks of EHD in the fall when dry conditions produce "mud-flats" throughout the Park that are favorable to outbreaks of the midge *culioides* that pass the virus to sheep by biting them. Sheep can then spread the virus by orally. It is believed that there could also be some holdover of the virus in the park's bison population because domestic cattle are known to harbor the disease and bison (*Bison bison*) could be serving as a reservoir for the disease (Dr. Margaret Wild, pers. comm.). In any event, disease monitoring will continue at Badlands National Park will continue and any animals translocated into the population or found dead will be sampled and analyzed for cause of death or possible disease transmission.

Human disturbance is common at the park as visitors frequently encounter bighorn sheep while hiking or traveling throughout the park. Human recreation has been implicated in the decline of several populations of bighorn sheep and recreational activity, especially hikers has been shown to disturb sheep, with recreational hikers causing the greatest behavioral response measured in terms of total distance fled when encountering a hiker (Papouchis 2000). Other behavioral responses to sheep include those of causing sheep to vacate suitable habitat enough to reduce the population's carrying capacity or rate of growth; frequent vehicle activity that may cause sheep to reduce or abandon their use of water sources; energetic losses due to disturbances that might effect the physiology, amount of fat reserves and reproductive success or human habituation (Geist 1975, Wehausen et al. 1977, Kovach 1979, Horesji 1976, Hicks and Elder 1979). Consequently, continued monitoring of the population will document any negative responses from human disturbance to the bighorn sheep population. Known lambing areas will be closed to off trail hiking during the lambing season, if necessary. The impacts of visitor use on bighorn sheep movement and habitat use and bighorn sheep use of man-made versus natural watering sources throughout the badlands are important research considerations for the future.

Population Size

The population of bighorn at Badlands National Park has fluctuated since its early beginnings of 14 animals in 1967 to approximately 160 in 1992 to the present minimum size of approximately 50 animals in 2002. Table 1 is a summary of the average population size for the last five years throughout the park.

Census Protocols

Bighorn Sheep surveys at Badlands National Park have been performed in the past using both ground and air surveys. On the ground surveys were performed in 1980 by McCutchen and in the late 80's

Table 1. Bighorn Sheep November population estimates, 1996-2001, Badlands National Park, South Dakota.

Area		1996	1997	1998	1999	2000	2001
Pinnacles	Rams	28	28	28	25	25	11
	Ewes	6	6	2	1	2	6
	Yearlings	0	2	0	1	0	0
	Lambs	2	0	1	0	1	2
	Totals	36	36	31	27	28	19
Stronghold	Rams	No data	2	5	6	3	5
	Ewes		10	9	12	9	6
	Yearlings		2	3	7	1	2
	Lambs		5	8	1	4	1
	Totals		19	25	26	17	14
Cedar Pass	Rams	3	1	0	1	1	4
	Ewes	11	5	5	9	10	10
	Yearlings	1	1	5	1	4	0
	Lambs	1	5	1	4	5	4
	Totals	16	12	11	15	20	18
North Unit	Rams	31	29	28	26	26	15
	Ewes	17	11	7	10	12	16
	Yearlings	1	3	5	2	4	0
	Lambs	3	5	2	4	6	6
	Totals	52	48	42	42	48	37
Badlands National Park Total	**Rams**	**31**	**31**	**32**	**32**	**29**	**20**
	Ewes	**17**	**21**	**16**	**22**	**22**	**22**
	Yearlings	**1**	**5**	**8**	**9**	**5**	**2**
	Lambs	**3**	**10**	**10**	**5**	**10**	**7**
	Totals	**52**	**67**	**66**	**70**	**61**	**51**

and early 90's by Benzon (1992). Air surveys were performed in the late 90's as part of a sightability development model (Singer et al 1999). This model is still under development and should be completed for use by National Park Staff by 2002 (Dr. F. Singer, pers. comm.). Projections from this model documented the crash in the population that occurred in 1992 (Singer and Moses 1997).

Since 1996 ground counts have been performed consistently using protocols developed by Bourrassa (1999). These counts involve surveying the Pinnacles, Cedar Pass and Stronghold areas for sheep three consecutive days during the bighorn sheep rut, which usually peaks November

1. Consecutive counts in the same sub-population area during multiple days allow observers to get a good estimate of total numbers. These types of surveys will continue to be performed each year in perpetuity at Badlands National Park. The air sightability model under development by Singer will also be used after this work is completed if park staff determines that the ground counts are not providing reliable data. Park staff will continue to monitor the results using both methods and decide which method is best to use for Badlands National Park.

Translocation of Animals into and between sub-populations

It is critical to take management actions before sub-populations of sheep within Badlands National Park reach predicted carrying capacity; otherwise, populations are susceptible to rapid declines. Biologists in other areas have focused on removing ewes from their bighorn sheep population to alleviate over-crowding caused by too many sheep. We plan on using this same strategy at Badlands National Park. It may be necessary to move areas from one sub-population area within the park to another if the sub-population is approaching the projected carrying capacity. For example, if Park population model estimates show that Pinnacles subpopulation will reach 150 total sheep within the next 2 years and ewe:lamb ratios have been consistently greater than 100:50 during previous fall population surveys, immediate plans for a translocation will be initiated (Sweanor et al 1995). This same translocation strategy would apply given the same scenario for the Cedar Pass (Maximum ecological carrying capacity =75) or Stronghold sub-populations (maximum ecological carrying capacity = 190).

Priorities for translocation areas will be based on need. The priorities, in order of preference, are: other sub populations within the park in need of more ewes; previously identified areas of suitable habitat (Sweanor et al 1995) within the park that presently do not have sheep; other areas in South Dakota that need sheep as determined by the South Dakota Department of Game, Fish and Parks (Benzon 2000), or other National Parks. Badlands National Park staff will work closely with SDGF&P staff in determining the best sites for proposed translocations based on their long range Management Plan for Bighorn Sheep in the state of South Dakota (Benzon 2000).

GENETICS

Genetic bottlenecking has been observed in many ungulate species that have been restored to potential habitats. When a population crashes, a reduction in genetic diversity coupled with a loss of rare alleles may be expected (Allendorf 1986). The decline is dependent on effective population size (Ne), defined as the size of an ideal population that loses the same amount of genetic variability as an actual population under consideration (Crow and Kimura, 1970). Effective population size is one of the most important parameters that population ecologists can measure because it estimates the amount of inbreeding and loss of genetic variation in populations (Ramey et al 2000). Census size does not indicate the actual genetic variation of a population.

Another parameter that population ecologists measure is neutral heterozygosity. The rate of loss of selectively neutral heterozygosity (F) is estimated as $F = (1-1/(2*Ne))$.

Consequently, larger population sizes will retain a higher proportion of F (e.g. a population where Ne = 500 would retain greater than 99 % of its heterozygosity each generation). This is why population ecologists recommend population sizes greater than 300 to avoid extirpation of populations.

Most methods of estimating Ne require information on the genotypes of individuals from one generation to the next. Although the original founder population was 14 animals in 1967, the estimated Ne for the Badlands National Park Bighorn Sheep Population was 6 individuals counting only adults and yearlings. Assuming all of these individuals survived and reproduced, the maximum effective population size is only 12.9 (Singer 2000). This represents a significant bottleneck for the founding population and is probably one of the reasons why the population floundered for almost 20 years with relatively little increase in total population size, until through the process of genetic drift, the population was freed up to increase in size.

As mentioned, the population went through another disease-induced bottleneck during the outbreak of EHD 1992 and 1996 when total numbers of plummeted from 160 to less than 100 animals. Fortunately, blood samples were taken from the bighorn sheep in the Pinnacles area and were translocated to Cedar Pass in 1996. This valuable genetic information will be used by Dr. Francis Singer and R.R. Ramey to look past and recent bottlenecks in the Bighorn Sheep population to determine the effects this has had on the genetic health of the population.

Effective population (Ne) and rate of loss of neutral heterozygosity (F) have been calculated for the Badlands National Park population using the formula $Ne = 4 Nm*Nf/(Nm+Nf)$, where Nm = total number of breeding males in the population and Nf = total number of breeding females. Ne was calculated for the North Unit only because there has been very little documented genetic flow between the North and South Unit sub-populations between 1997-2000. As Table 2 indicates the effective population size for the North unit has been less than 35 for the last 4 years, and the South Unit Population is less than 20. Loss of neutral heterozygosity follows a similar trend. Consequently, extirpation of the population is highly probable within the next 50 years, especially in the South Unit that appears to be a separate population.

One way to mitigate these effects has been suggested by Singer (2000). He recommends “prudent intervention” to the Badlands National Park population at this time and suggests a mixed sex augmentation of greater than 30 individuals from an out-bred native source population of Rocky Mountain bighorn sheep. However, he also recognizes that there may not be enough surplus animals available from other states or Provinces to complete such a restoration effort and recommends smaller augmentations be carried out over several years. Singer also recognizes that augmenting the present population with ewes is the most direct means of increasing population numbers even though it may take longer to have an effect on the population than introducing rams too. Augmenting the population with ewes also poses a smaller risk to the rest of the population in terms of diseases from other domestic animals that may be in the area because rams have been documented to wander great distances and are more likely to come into contact with domestic sheep. We currently have a verbal agreement with the SDGF&P to translocate ewes in the coming years, if they are available. Hopefully this will be

Table 2. Bighorn Sheep effective population size (Ne) and neutral heterozygosity loss (F) for the North Unit and South, Badlands National park, South Dakota 1996-2001.

Area	Parameter	1996	1997	1998	1999	2000	2001
North Unit (Pinnacles and Cedar Pass sub-populations)	Ne = Effective Population	45.7	33	22.9	30.2	34.6	30.96
	F = Neutral Hetero-zygosity loss (%)	1.1% loss	2% loss	2.2% loss	1.7% loss	1.5% loss	1.4% loss
South Unit (Stronghold sub-population)	Ne = Effective Population	No data	9.75	15.9	15.9	20.7	10.9
	F = Neutral Hetero-zygosity	No data	5% loss	3% loss	3% loss	2% loss	4% loss
Badlands National Park Total	Ne = Effective Population	No data	57.6	50.6	55.2	55.7	40
	F = Neutral Hetero-zygosity	No data	<1% loss	<1% loss	<1% loss	<1% loss	1.25% loss
Ne = 4 Nm*Nf/(Nm+Nf), where Nm = total number of breeding males in the population and Nf = total number of breeding females (not including yearlings). Neutral heterozygosity (F) is estimated as F = (1-1/(2*Ne)) for each generation.							

the beginning of increase genetic and population health for the sheep population at Badlands National Park.

Continued opportunistic blood and genetic sample will be collected from the Badlands bighorn sheep population and any translocated individuals to document its genetic health and provide data for current Ne estimates. Genetic studies will be funded when possible to document the on-going progress in genetic health augmentation.

POPULATION HEALTH

Disease Management

Various infectious and parasitic diseases are believed to have caused significant obstacles in restoring and managing populations of bighorn sheep. Bighorn numbers throughout western North America declined dramatically during the late 1800's and early 1900's and disease is believed to have played a key role in the historic decline along with unregulated market hunting, habitat loss, overgrazing and human development.

As mentioned previously, disease is a very real concern at Badlands National Park. Lower recruitment rates throughout the 90's (100:32 ewe:lamb ratios) as compared to those in during the mid 80's (100:70) indicated that some type of mortality was beginning to occur in the Badlands. While predation could have been a factor, disease was probably the more probable cause. Outbreaks of EHD were documented in the 90's and as recently as 2000. Immunization has proven ineffective in other populations of Bighorn Sheep because of the many different strains of EHD that presently exist (Dr. M Wild, DVM, pers. comm). Consequently, management for disease outbreaks will continue on a case by case basis that will include continued monitoring of the bighorn sheep population and necropsy of any dead individuals. Necropsies of other ungulates that are suspected of carrying disease or found dead will also be performed using the protocols developed below.

Necropsy Protocols

All bighorn sheep necropsies will be performed by a professional veterinary pathologist, if possible. If it is impossible to collect the carcass and transport it to a professional biologist, the wildlife biologist or the field technicians will perform the necropsy. Necropsy protocols will follow those outlined by Wobeser and Spraker (1980:89-98). All specimens will be collected and general condition will be noted. Outer skin, under the skin, Cardiovascular, Lymph, Digestive, Respiratory, Musculoskeletal, Urogenital, Endocrine, Brain, Spinal Cord and Eye tissues will be examined and placed in formalin. If lesions or abnormalities are observed, a sample of the lesion will also be collected and kept in a separate container. Sample will then be shipped to the laboratory for analysis of the suspected disease vector.

THE FUTURE

Badlands National Park will continue to support and gain an understanding of bighorn sheep dynamics by inventory and monitoring populations, habitat relationships as well as detecting both natural and human caused changes in abundance and distribution. The Park will ensure that the parks' activities do not adversely impact bighorn sheep using NEPA and NPS-77 as guidance.

Badlands National Park Staff will continue to identify habitat areas that are critical to the bighorn sheep population and protect these areas and work cooperatively with other agencies and landowners to resolve human/ bighorn related conflicts. The bighorn sheep population will be maintained at a level that does not exceed the carrying capacity of the park to minimize the danger of extirpation in the next 1-200 years.

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Population Status of Transcaspian Urial (*Ovis orientalis* [*vignei*] *arkal*) at Aktau Buzachinsky Nature Reserve, Kazakhstan.

MICHAEL R. FRISINA, Montana Fish, Wildlife & Parks, 1330 West Gold Street, Butte, MT. 59701

Abstract: A ground survey of Transcaspian urial (*Ovis orientalis* [*vignei*] *arkal*) was conducted over a 7-day period in March 2000 on a 113-km^2 portion of the Aktau Buzachinsky Nature Reserve in southwest Kazakhstan. The purpose of the survey was to determine the population status of urial, especially males. A total of 491 urial (183 ewes, 97 rams, 15 lambs, 196 unclassified) were observed. About 70 urial were observed per day afield. The observed urial density was ~4 per km^2. Approximately 35% of urial habitat on the reserve was surveyed. During the survey 71 adult rams were observed of which 45% were older than 6 years. One ram was observed for every 2 females and 1 mature ram for every 2.6 females. Rams 5 years or older were considered mature. The data indicate urial are abundant on the reserve and adequate mature rams are present in the population for breeding. Indications are that historic grazing has impacted the land's ability to produce forage which, in combination with the relatively high density of urial, may be negatively affecting ram horn growth rate.

Key words: habitat, hunting, Kazakhstan, population, *Ovis orientalis*, urial

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Urial (*Ovis orientalis [vignei]*) are small to medium size wild sheep inhabiting temperate mountainous, steppe, and desert regions of Central Asia and the Middle East, including Kazakhstan (Clark 1964, Valdez 1982). The taxonomic status of urial is unclear, especially designation of the various subspecies, varying with author (Clark 1964, Ellerman and Morrison-Scott 1966, Valdez 1982, Shackleton and Lovari 1997). One subspecies, the Transcaspian urial (*Ovis orientalis [vignei] arka*l), occurs in Kazakhstan (Valdez 1982). The total number of Transcaspian urial in CIS (former USSR) countries at the beginning of the 1990s was estimated at ~ 6,000 animals (Weinberg et al. 1997).

In 2000, all urial except for the subspecies Ladakh urial (*Ovis orientalis [vignei] vignei*), which was already listed in the Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES) Appendix I, were listed in Appendix II (FWS 2001). During 1999 and 2000 several international organizations became concerned that "over hunting" of urial across their range was putting populations in peril. This issue was a major topic at the April 2000 CITES meeting in Africa. The Aktau Buzachinksy Reserve urial was one of the populations in question (Fedosenko 1998, Fedosenko and Weinberg 1999). I was asked by GSC/OVIS, an affiliate of the Foundation for North American Wild Sheep, to visit the reserve during March 2000 to conduct an independent survey of urial population status. This paper reports the findings of that survey.

STUDY AREA

The 170,000-ha Aktau Buzachinsky Nature Reserve is located in the Central Asian country of Kazakhstan on the shores of the Caspian Sea (Figure 1).

Figure 1. The Aktau Buzachinsky Nature Reserve is located in southwest Kazakhstan.

The landform of mountains separated by broad valleys was created over thousands of years as a receding Caspian Sea exposed steep chalky cliffs composed of marine deposits (Figure 2). The climate is temperate and plant communities are typical of shrub/steppe vegetation in the inner part of the Eurasian Continent (Coupeland 1993, Lavrenko and Karamysheva 1993). The landscape has been highly impacted by human activity, especially by domestic livestock grazing (Fedosenko 1998).

Situated about 65 km north of Aktau City, the reserve is government owned and is a popular urial trophy hunting area. It is home to a population of 1,600 to 2,000 Transcaspian urial (Berdaliev, personal communication, 2000). Managed trophy hunting is allowed (average about 10 licenses per year) and revenues from hunting play an important role in managing the reserve (Berdaliev, personal communication, 2000). On an annual basis the number of hunting licenses issued has varied from 5 to 20 (Fedosenko 1998, Fedosenko and Weinberg 1999). After a few successive years of trophy hunting on the same portion of the reserve, that portion may be closed for a few years to provide rest from hunting (Berdaliev, personal communication, 2000).

Other large ungulates on the reserve include Asiatic wild ass (*Equus hemionus*), and goitred gazelle (*Gazella subgutturosa*). The only large predators are wolves (*Canis lupus*) and golden eagle (*Aquila chrysaetos*).

Figure 2. The Aktau Buzachinsky Nature Reserve is a landform of mountains separated by broad valleys that was created over thousands of years as a receding Caspian Sea exposed steep chalky bluffs composed of marine deposits.

METHODS

Wild sheep were systematically surveyed within a 113-km^2 portion of the study area over a 7-day period from 25 March through 31 March 2000. Surveys were conducted on foot and from a jeep on travel routes and from observation points. Drop off points, base camp locations, and observation points were documented using GPS technology. Animals were observed with aid of 8X and 10X binoculars and 10X-60X spotting scopes. One or 2 observation groups consisting of 3 or 4 experienced observers went into the field together each day to observe sheep. Censuses were conducted over a 7-day period because it allowed sufficient time to adequately cover the area and to minimize counting the same animals twice. When the possibility existed that the same animals were observed more than once, only the first observation was recorded to minimize error. Location and altitude of sheep observation sites were recorded using GPS technology.

Observed urial densities were determined by dividing the number of animals observed by the size of the survey area. Each sheep observed was classified into one of the following categories: adult ewe, lamb, or ram. Rams were grouped by size class based on horn length (Geist 1971, Valdez 1982) as follows: Class I (1-2 years old), Class II (3-4 years old), Class III (5-6 years old) and Class IV (> 6 years old). Ages of 3 hunter harvested rams and 1 picked up head were determined by counting annual growth rings (Geist 1966). Horn measurements are in English units, the standard used by the most well known trophy record books (SCI 2000, RW 1998)

RESULTS AND DISCUSSION

A total of 491 urial were observed, of which 183, 15, and 97 were classified as adult females, lambs, and rams respectively. There were 179 that, due to field observation difficulties, were determined to be ewes and lambs but the age of individuals could not be determined. There were 17 unclassified urial observed. The 17 unclassified individuals were included in population density calculations, but were excluded when calculating population structure. All of the 97 rams classified were grouped into age classes. The observed ram age structure was 6 Class I, 20 Class II, 39 Class III, and 32 Class IV.

Population Density & Size

About 70 urial per day were observed during the 7-day survey. The observed urial density within the 113-km^2 portion of the reserve surveyed was ~4 urial per km^2. Approximately 35% of the reserve's urial habitat was surveyed. Fedosenko and Weinberg (1999) estimated a population density of 2.5 urial per km^2 for the north Aktau Mountains in 1997. In 1997, the area included the plain between separate mountains. In the 2000 survey, only the mountains and small lower elevation valleys frequently used by urial were included. Large, low elevation plains that are infrequently used by urial, sometimes when they cross from one mountain to the next, were excluded. This may be the reason for the lower observed density in 1997 compared to this survey.

A total urial population for the north Aktau Mountains was estimated at 1,000 by Fedosenko and Weinberg (1999) following their April 1997 survey. Berdaliev (personal communication, 2000) estimated the urial population to be 1,600-2,000 in 2000. March and April may not be the best months of the year to conduct a population census as it coincides with lambing when ewes may be more reclusive than other times of the year. March and April are also a time when winter is giving way to spring and animals are beginning to disperse to higher elevations on the reserve. A more suitable time to conduct a population census may be in November during the breeding season when males are more visible and ewes may be in larger groups as winter approaches. However, for comparative purposes, if one extrapolates the 491 urial I observed on the 35% of the reserve's urial habitat surveyed to the remaining 70% not surveyed, a population of ~1,400 urial is estimated for late March 2000. This estimate is higher than the 1,000 estimated for April 1997 by Fedosenko and Weinberg (1999), but smaller than the 1,600-2,000 estimated by Berdaliev (personal communication, 2000). Fedosenko and Weinberg (1999) believed the urial population to be slightly increasing since 1990.

Population Structure

About 80% of urial classified were ewes and lambs, and about 20% rams. An April 1997 urial survey on the reserve resulted in 27% males observed (Fedosenko 1998). Of 198 urial for which sex and age were determined, 15 were lambs. This proportion of lambs is low and is not suitable to use as an index of lamb production since lambs were being born during the survey. All 15 lambs observed were just recently born (within a few days) and the survey may have coincided with the peak of lambing.

The proportion of rams observed by size class was 6% Class I, 21% Class II, 40% Class III, and 33% Class IV. The relatively low proportion of Class I rams observed may reflect poor survival of lambs born the previous year.

One ram was observed for every 2 females and 1 mature ram for every 2.6 females. Rams 5 years or older were considered mature. These figures are conservative, as my classification of females combines nonproductive yearling females (lambs born the previous March) with adults. Savinov (1983) and Benikov (1983) determined females are sexually mature at 2.5 years of age (in Fedosenko 1998). During my survey, 71 mature rams were observed, of which 45% were older than 6 years.

CONCLUSIONS

Urial are abundant on the Aktau Buzachinsky Nature Reserve.

The observed ratio of 1 ram $\geq$ 5 years of age for every 2.6 females is adequate for successful breeding. Had we conducted the survey during the fall rut, when males are more observable, the ratio of males to females would likely have been higher than reported here.

To maintain high-quality trophies for the hunting program, and for long-term evolutionary processes, it is important to maintain a diversity of ram age classes representing the entire spectrum from young to old animals. However, it is interesting that Woodgerd (1964) determined Rocky Mountain bighorn (*Ovis canadensis canadensis*) rams to be sexually mature and capable of breeding at 18 months. For a population of Rocky Mountain bighorn sheep, Coltman et al. (2001) found that, although a few large-horned rams (age 8+ years) had very high reproductive success, younger rams sired about 50% of the lambs. Mating success was not restricted to a few top ranking rams each year (Coltman et al. 2001).

Horn development may be negatively affected by inadequate diet (Browning and Monson 1980). Environment and habitats may play a greater role in horn growth then genetics (Hook 1998). Even though livestock grazing on the reserve was significantly reduced during the early 1990s (Fedosenko 1998), habitat conditions are still less than ideal due to historic intensive, poorly managed livestock grazing. Although reduction in livestock grazing was needed to allow the land to heal, recovery is a long, slow process. The reserve is still in the initial stages of recovery (Figure 3). This

Figure 3. Intensive, historic livestock grazing on the Aktau Buzachinsky Nature Reserve has impacted the reserve's ability to produce forage.

historically intensive livestock grazing has impacted the land's ability to produce forage, and may be negatively affecting available nutrition and thus the rate of horn growth of rams. As a result, it appears that rams at the Aktau Buzachinsky Reserve take longer to achieve trophy size then they would under better nutritional circumstances. For example, during the survey 2 rams harvested by hunters were determined to be 7 years old. One of these rams is shown in Figure 4. Due to its relatively small horns, this mature Class IV (>6 years) male could easily be mistaken by a field observer for a younger Class III (5-6 years) or even a Class II (3-4 years) male. When conducting surveys rams are typically placed in size or age classes by estimating horn length. It is possible that during some of the previous surveys, the number of rams in age Classes III and IV were

Figure 4. Many rams like this one, unusually small for a 7-year-old male, were observed during the survey and may be the result of slow growth due to habitat conditions. This Transcaspian urial (*Ovis orientalis* [*vignei*] *arkal*) has horn lengths of 24 5/8 and 25 3/8 in. and basal circumferences of 10 1/4 and 10 3/8 in.

underestimated due to the unusually slow horn growth at the reserve. During the March 2000 survey I observed many rams of the size shown in Figure 4. Trophies taken by hunters during recent years and picked up heads indicate suitable trophies are being produced, but it takes them longer than is typical to achieve trophy size (Figure 5).

The average trophy harvest of about 10 rams per year appears to be having little detrimental effect on the urial population. Fedosenko and Weinberg (1999) indicated a harvest quota of 10 trophy rams per year should be the maximum. Since ram horn growth may be relatively slow at the Aktau Buzachinsky Nature Reserve, a more conservative hunting quota may be necessary than for a similar population with more typical horn growth. Harvest quotas are important as hunting fees provide essential funds for managing the reserve and the salaries of game guards (Berdaliev, personal communication, 2000). Kazakhstan is the only Central Asian country in the CIS where part of the income from trophy hunts is spent on research, population counts, and protection (Fedosenko and Weinberg 1999).

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Figure 5. Klaus Ånerud (left) with his 10-year-old Transcaspian urial (*Ovis orientalis [vignei] arkal*) taken in 1999 (horn lengths = 34 3/4 and 35 3/8; basal circumferences = 11 and 11 1/4 in.). Author (right) with the head of an 11-year-old Transcaspian urial picked up on the Aktau Buzachinsky Nature Reserve (horn lengths = 34 1/2 and 35 3/4 in.; basal circumferences = 10 in.).

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Determining Pregnancy Status Of Rocky Mountain Bighorn Ewes From Fecal P4, A Progesterone Derivative Hormone.

ELISE J. GOLDSTEIN, Department of Wildlife Sciences, University of Washington, Seattle, WA 98195 U.S.A.
JOAN BAUMAN, Research Department, St. Louis Zoo, 1 Government Drive, St Louis, MO 63110 U.S.A.
GARY C. BRUNDIGE, Custer State Park, HC 83 Box 70, Custer, SD 57730 U.S.A.
KENNETH RAEDEKE, Department of Wildlife Sciences, University of Washington, Seattle, WA 98195 U.S.A

Abstract: The pregnancy status of ten Rocky Mountain bighorn ewes (*Ovis canadensis canadensis*) was evaluated using fecal P4, a progesterone derivative hormone. Six fecal samples from each individual were collected during the period of time corresponding to the second trimester of pregnancy and measured for P4. Mean values of each ewe were compared to 95% confidence intervals from P4 values of 23 samples collected during the same time period from known pregnant ewes. Eight of the ten ewes tested were not pregnant during this time period and the pregnancy status of the other two ewes was inconclusive. This non-invasive technique for assessing pregnancy status has a great potential for gathering information without causing any stress to the animal, and a more rigorous study to validate this technique is currently underway.

INTRODUCTION

The use of non-invasive techniques for evaluating pregnancy status of wild ungulates is becoming more common. Evaluation of various fecal metabolites, including estrone conjugates (E_1C), pregnanediol-3-glucuronide (IPdG), and free progesterone (P_4), has been preformed in ungulates such as moose (*Alces alces*) (Monfort et al. 1993), caribou (*Rangifer tarandus*) (Messier et al. 1990), elk (*Cervus elaphus*) (Garrott et al. 1998, White et al. 1995), and bighorn sheep (*Ovis canadensis*) (Borjesson et al. 1996).

Elevated P_4 is observed during the estrous cycle, and can be used to monitor pregnancy status since it increases throughout pregnancy. There is an abrupt decline in P_4 concentration after parturition, and a drop during pregnancy is an indication of fetal loss (Cook et al.2001). Both radio immunoassay (RIA) and enzyme immunoassay (EIA) can be used to detect P_4 levels. EIA is less expensive, but may require a larger number of samples to accurately evaluate pregnancy status (Garrott et al. 1998).

In an effort to explore the validity of using fecal P_4 to assess pregnancy status in Rocky Mountain bighorn sheep (*O. c. canadensis*), P_4 concentrations were analyzed in fecal samples collected from known pregnant and known nonpregnant ewes in Custer State Park, SD. High natality rates are usually observed in bighorn sheep (Goldstein 2001, Merwin 2000, Brundige 1985, Woodgerd 1964,), but low natality was observed in one subherd of bighorn in CSP during 2000. We used fecal P_4 to evaluate the pregnancy status of 10 Rocky Mountain bighorn ewes never observed with a lamb.

STUDY AREA

This study was conducted in Custer State Park in the southeast corner of the

Black Hills, South Dakota. Bighorn sheep in this 29,150 ha park live in four geographically separate subherds. This study focused on two subherds, one in the east end (EE), and one in the west end (WE), of French Creek Canyon. EE and WE bighorns are separate subherds, but have occasional contact where their ranges overlap.

Dominant grasses along this canyon include western wheatgrass (*Pascopyrum smithii*), blue grama (*Bouteloua gracilis*), little bluestem (*Schizachyrium scoparium*), and buffalo grass (*Buchloe dactyloides*) (Morgan 1987, Turner 1974). Canyon rims in EE are characterized by open meadows, and canyon walls have large cliff faces interspersed with ponderosa pine (*Pinus ponderosa*) forests. Attributes of WE are similar, although there are fewer meadows and forests tend to be denser. North and west of French Creek, wildfires burned approximately 8,500 ha in 1988 and 1991. These open hills, rising from approximately 1,250 m to 1,850 m now contain many charred snags and burnt downed woody material.

Other animals living in this study area include mountain lions, coyotes, bison (*Bison bison*), elk (*Cervus elaphus*), white-tailed deer (*Odocoileus virginianus*), mule deer (*O. hemionus*), pronghorn (*Antilocapra americana)*, and a variety of small mammals, herpetiles, songbirds, and raptors.

METHODS

Thirty-two adult bighorn ewes were radiocollared or otherwise uniquely identifiable, and monitored daily for two years between 1999-2000. In 2000, fecal samples from ten marked ewes in the East End subherd in Custer State Park, South Dakota, never observed with a lamb were analyzed for pregnancy status. Six fecal samples from each of these ewes collected between March 1, 2000, and May 14, 2000 were evaluated for P_4, (St. Louis Zoo Endocrinology Laboratory, St. Louis, Missouri, USA). P_4 laboratory extraction methods followed those of Shideler et al. (1993), and radio immunoassay methods followed those of Bauman and Hardin (1998) using reagents from DSL, Webster TX. To evaluate efficacy of P_4 to indicate pregnancy status, these values were compared to P_4 values of 23 samples from known non-pregnant ewes collected from August 1-7, 2000, and to values of 30 samples from known pregnant ewes collected from March 4 – May 3, 2000. Ewes were classified as non-pregnant in August, or as pregnant during spring if they were known to have given birth during the following summer.

ANALYSIS

Mean and 95% confidence intervals (CI) for P_4 values from known pregnant ewes during March and April, and from known non-pregnant ewes during August were calculated. P_4 values for known pregnant ewes were then separated into samples from March, and samples from April, and mean P_4 and 95% CI were calculated for each month. A two-sample t-test was used to compare P_4 values during these two time periods. Mean P_4 values were calculated for each of ten ewes of unknown pregnancy status. These values were not divided by month due to small sample size. These values were compared with 95% CI for P_4 values from known pregnant ewes during March, April, and May combined, and with 95% CI for P_4 values from known non-pregnant ewes, to ascertain pregnancy status

For pregnancy tests evaluating P_4 in only one fecal sample, the lower 95% confidence limit for known pregnant ewes was used as a cutoff value for concluding

Table 1. P_4 values of pregnant versus non-pregnant ewes during different time periods

Pregnancy status	**Mean P_4 (ng/g)**	**95% Confidence interval of the mean (ng/g)**
Non-pregnant Ewes	570.2	354.9-794.5
Pregnant Ewes (March – early May)	1699.1	1316.5-2081.6
Pregnant Ewes, March	1203.8	895.8-1511.8
Pregnant Ewes, April	1990.3	1374.4-2606.2

that a ewe was pregnant. The upper 95% confidence limit for known non-pregnant ewes was used as a cutoff value for concluding that a ewe was not pregnant. Any value falling between these two numbers was regarded as inconclusive.

The number of fecal samples needed to accurately predict pregnancy status was calculated by selecting one random sample from a given known pregnant ewe. If this value predicted pregnancy, then only one sample was needed for the test. If not, a second sample was randomly selected and this value was averaged with the first (samples were chosen without replacement). This process was repeated until the average of the samples exceeded the lower 95% confidence limit for pregnancy.

RESULTS

Mean and 95% CI for pregnant and non-pregnant ewes are reported in Table 1, as are values for pregnant ewes during March and during April. Mean P_4 values from pregnant ewes were higher in March than they were in April (P=0.04). Mean P_4 values for the 10 ewes of unknown pregnancy status are presented in Table 2. Eight of ten ewes tested for pregnancy status were not pregnant during the time period corresponding with the second and the beginning of the third trimesters of pregnancy (March-May 2000). Pregnancy status of two ewes could not be determined with certainty because their average P_4 values fell between the upper 95% confidence limit for non-pregnant ewes, and the 95% confidence limit for pregnant ewes.

Results of using the P_4 value from one fecal sample and comparing it with the upper 95% confidence limit for non-pregnant ewes and with the lower 95% confidence limit for pregnant ewes to predict pregnancy status are presented in Table 3. The numbers of pellets groups needed to accurately predict pregnancy status are presented in Table 4.

DISCUSSION

The use of noninvasive techniques to obtain biological samples is generally less expensive, logistically easier, and less stressful to the animal than the use of invasive techniques. Observing a minimum of eight of 10 ewes tested not being pregnant is quite rare in bighorn sheep. Among marked ewes in the East End subherd, 19 of 20 were observed with lambs in 1999, compared with 4 of 13 in 2000. Two additional marked ewes disappeared during early summer 2002 before the peak of lambing (and thus before they had the opportunity to be observed with a lamb), but only one of these ewes was analyzed for pregnancy status in this study.

In a second subherd in CSP (West End), 8 of 8 marked ewes were observed with a lamb in 1999, and 10 of 11marked ewes were observed with a lamb in 2000.

Table 2. Pregnancy status during the second trimester of pregnancy 2000 (March-April) of marked ewes in East End never observed with a lamb, compared with 95% confidence intervals of mean values form pregnant ewes, and from nonpregnant ewes. Values exceeding 1316.5 ng/g indicate pregnant and values under 794.5 ng/g indicate not pregnant.

ID	P4 averages	Pregnant?
29g	680.6	NO
2y	1067.8	UNKNOWN
34g	161.4	NO
47g	279.8	NO
Black	502.1	NO
EE black red	679.3	NO
Green	449.9	NO
Green red	662.6	NO
Lf horn II	549.4	NO
Orange	800.6	UNKNOWN

Table 3. Predicted pregnancy status when comparing the P_4 value of one fecal sample from a ewe of known pregnancy status with a reference group of a larger number of samples from ewes of known pregnancy status.

	Sample size (number of fecal samples comprising the reference group)	Number of incorrect results using a single fecal sample	Number of ambiguous results using a single fecal sample	Number of correct results using a single fecal sample
Non-pregnant	23	2 (9%)	2 (9%)	19 (82%)
Pregnant (March and April samples)	30	3 (10%)	9 (30%)	18 (60%)
Pregnant (March samples only)	14	3 (22%)	1 (7%)	10 (71%)
Pregnant (April samples only)	17	1 (6%)	5 (30%)	11 (64%)

Whether the 10 ewes never observed with a lamb aborted during the time period corresponding with the first trimester of pregnancy, or were never bred cannot be concluded from this data, but either case is unusual.

Of the two ewes whose pregnancy status could not be ascertained, the average P_4 value of one of these ewes (Orange) was very close to the 95% confidence limit of non-pregnant ewes, and there was no trend in the values to suggest either pregnancy or an abortion. She was likely not pregnant. The other ewe (2y) had low P_4 values in March, corresponding with non-pregnant status, but high levels in April, corresponding with pregnant status. Had this ewe been bred, she would have been a yearling at the time. It is uncommon, but not unheard of, for two-year olds to lamb. In addition, this ewe was never observed with a

Table 4. Number of pellet groups per individual needed to accurately predict pregnancy status. All ewes presented in the table were known pregnant ewes.

	March	April	March-April
Blue black	2	2	1
Black red	1	1	1
Blue green	1	1	1
Brown yellow	1	1	1
Green yellow	2	1	4
red	(only one sample available for comparison)	2	3
Average	1.4	1.3	1.8

swollen udder. It is possible that she was bred late, therefore her P_4 levels did not rise perceptibly until April, and then aborted, but the results remain inconclusive.

Results from this pilot study indicate that radioimmunoassay of fecal P_4 may provide a reliable, noninvasive technique for assessing pregnancy status in bighorn sheep. One potential problem with this study is that samples from known pregnant ewes were collected from March through May, whereas samples from known nonpregnant ewes were collected during August. The most accurate comparison would be among fecal samples collected during the same time period. However, samples were collected from wild bighorns and it is not possible to differentiate between ewes which were not bred and those that lost a lamb prior to observation (either pre- or post-natal). Such samples could only come from a captive herd. Bjoresson et al. (1996) found that IPdG, a metabolite of P_4, concentrations in nonpregnant bighorn did not increase between November and June. P_4 concentrations should follow the same trend as IPdG for non-pregnant ewes, therefore P_4 values of non-pregnant ewes should not be different during March – May than during August.

Bighorn breeding peaks in December in CSP (Brundige et al. 1988). Ewes that are not bred in December may experience a second, and potentially a third estrous in January and February, respectively. Elevated P_4 levels during estrous may be erroneously interpreted as pregnancy, therefore samples were not collected prior to March.

Samples collected from pregnant ewes in March only, April only, and March and April combined, yielded accurate results 71%, 64%, and 60% of the time, respectively, when using a single fecal sample to predict pregnancy status. Small samples sizes and differences in sample sizes for the reference group may have influenced the results, making it difficult to conclude which collection period would yield the most accurate results. However, March and April combined had the largest sample size but the lowest degree of accuracy, therefore choosing a single month should yield more accurate results. There was greater variation in samples collected in April compared with March and with March and April combined. This may be due in part to two outlier values occurring during April, but none occurring during March. Increased variation may be a function of increased P_4 values during this time period. Borjesson et al. (1996) found the standard deviation of IpdG levels for bighorn sheep increased from 0.47 during 0-60 days of pregnancy, to 1.18 during 60-180 days of pregnancy.

Both iPdG and P_4 concentrations were demonstrated to be higher during late gestation than during early gestation in elk (White et al. 1995), and that held true for iPdG (Bjoresson et al. 1996) and P_4 in bighorn sheep during this study. Misdiagnosis of pregnancy happened most often during March, presumably because P_4 values in March are closer to P_4 values of non-pregnant ewes than they are in April. Based on this parameter, it may be more desirable to collect samples as late during pregnancy as possible. Given the small overlap of P_4 values of pregnant and non-pregnant ewes, it may be necessary to use more than one fecal sample to increase accuracy of the results. Four samples always predicted accurate results, regardless of the time period. However, two samples always predicted accurate results when sampling from March only or April only. Therefore, it would be more accurate to restrict sample collection to as narrow a time frame as possible.

Differences in P_4 values between non-pregnant and pregnant ewes, and pregnant ewes during the second and beginning of the third trimesters of pregnancy are large enough with small enough variation to be a useful technique in assessing pregnancy status. A minimum of two samples collected within the same month as late during the pregnancy cycle as possible is recommended to increase accuracy of the results. The small sample size used (n=6 ewes) during this study inhibits a more in depth evaluation of collecting samples during March versus April, and sampling during a shorter time period. A study using a larger sample size is currently underway to validate this technique for bighorn sheep, and assess how many samples per ewe should be analyzed.

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The Behavioural Effects Of Helicopter Logging On Mountain Goats

STEVE GORDON, Sustainable Resource Management, 7077 Duncan Street, Powell River, B.C., V8A 1W1 Canada

Abstract: This two-year study investigates the effects of sustained use of large heavy-lift helicopters on the daily and seasonal behavioural and habitat use patterns of mountain goats (*Oreamnos americanus*) in a remote watershed 60 km NE of the community of Powell River, B.C. Specifically, the study assesses whether the proportion of time goats spend foraging and bedding changes relative to levels of helicopter activity near occupied habitats. Mountain goats are yellow-listed (of Management Concern) in B.C.; the coastal goat ecotype is considered particularly sensitive due to low population densities and reliance on old growth forests for winter shelter and forage. A recent increase in the both industrial and recreational use of helicopters in coastal areas has heightened conservation concerns. Non-invasive observational techniques are used to record behavioural patterns and the effects of helicopter and logging activity on mountain goats. Using 20 – 60X weatherproof spotting scopes, instantaneous scan surveys are performed at 5-minute intervals. Goat behaviour is classified according to 5 non-overlapping behavioural classes. Overt responses to helicopter and falling activity and behaviours of note are also recorded. Results are recorded in field notebooks and the spatial location of goats is recorded on 1:5000 scale maps and air photos. Observation posts have been established in valley bottom and alpine sites. 2 separate herds of mountain goats are observed – a 'treatment' herd occupying habitat immediately adjacent to a stand of forest to be helicopter logged with a Boeing 234 "Chinook" helicopter, and a 'control' herd subject to no helicopter disturbance. Data collection trips are conducted prior to disturbance, during falling activity, during helicopter logging, and post-disturbance. Over 300 hours of behavioural data was obtained in the 2001 field season. A second field season in 2002 to collect additional behavioural data and assess habitat use patterns in both herds will occur. Data analysis will attempt to determine if the proportion of time goats spend in feeding, not feeding and bedded behavioural classes changes as a function of helicopter activity. The study results will be applicable to development of management guidelines for helicopter activities adjacent to mountain goat habitats in jurisdictions throughout North America and will also be applicable to the management of other ungulate species.

Life Cycle, Distribution, And Significance Of *Parelaphostrongylus odocoilei* In Thinhorn Sheep (*Ovis dalli*)

EMILY J. JENKINS, Department of Veterinary Microbiology, Western College of Veterinary Medicine, 52 Campus Drive, Saskatoon, SK, S7N 5B4, Canada

ALASDAIR M. VEITCH, Department of Resources, Wildlife, and Economic Development, Box 130, Norman Wells, NT, X0E 0V0, Canada

ERIC P. HOBERG, Parasite Biology, Epidemiology and Systematics Laboratory, and US National Parasite Collection, BARC East, No. 1180, 10300 Baltimore Avenue, Beltsville, MD, 20715 U.S.A.

SUSAN J. KUTZ, Department of Veterinary Microbiology, Western College of Veterinary Medicine, 52 Campus Drive, Saskatoon, SK, S7N 5B4, Canada

BRETT T. ELKIN, Department of Resources, Wildlife, and Economic Development, #600 5102 50th Ave., Yellowknife, NT, X1A 3S8, Canada

LYDDEN POLLEY, Department of Veterinary Microbiology, Western College of Veterinary Medicine, 52 Campus Drive, Saskatoon, SK, S7N 5B4, Canada

Abstract: In 2000, the muscleworm *Parelaphostrongylus odocoilei* was identified in Dall's sheep (*Ovis dalli dalli*) of the Mackenzie Mountains, Northwest Territories (NWT). As *Parelaphostrongylus odocoilei* had not previously been reported in wild sheep (only in cervids and mountain goats), we began investigating the significance of this parasite in thinhorn sheep. Larvae consistent in appearance with *P. odocoilei* (molecular tests are underway) were present in fecal samples from thinhorn sheep in two "metapopulations": Eastern (the Mackenzie and Selwyn Mountains) and Western (the central Alaska and Wrangel-St. Elias ranges, and northern Rocky Mountains). *Parelaphostrongylus odocoilei* larvae were absent from thinhorn sheep populations north of the positive metapopulations. Larvae that resembled *P. odocoilei* were present at low levels in mountain goat (*Oreamnos americanus*) samples from the central Mackenzie Mountains. In addition to describing the geographic distribution, we examined seasonal patterns of larval shedding in a naturally infected Dall's sheep population in the northern Mackenzie Mountains. The prevalence of infection with *P. odocoilei* was 87-100% throughout 2000 and 2001. The pattern of larval shedding was similar for both years, with the highest levels in March/April/May, a decline through summer until August, followed by an increase in October/November to relatively high levels that were maintained over winter. In 2001, we completed the life cycle of *P. odocoilei* in an experimentally infected captive Stone's sheep (*Ovis dalli stonei*). The life cycle, pre-patent period (72 days), patterns of larval shedding, and effects (weight loss, chronic pulmonary hemorrhage, and granulomatous interstitial pneumonia) were similar to those described in experimentally and naturally infected cervids (the typical hosts). We continue to monitor the effects of *P. odocoilei* in experimentally infected Stone's sheep and a mule deer. Descriptive work on this newly discovered host-parasite relationship complements ongoing studies of population health in Dall's sheep in the Mackenzie Mountains, and will hopefully prompt others to investigate the presence and significance of this "new" parasite of wild sheep, particularly if translocations are contemplated.

Use Of Low Elevation Habitats By Bighorn Sheep In Nebraska

EDWARD KLINKSIEK, Department of Biology, University of Nebraska-Omaha, Omaha, NE 68182 U.S.A.
SUE FAIRBANKS, Department of Biology, University of Nebraska-Omaha, Omaha, NE 68182 U.S.A.

Abstract: The reintroduction of bighorn sheep (*Ovis canadensis*) to historically native ranges has been an ongoing effort throughout the United States. The assessment of suitable habitat for a species is a vital part of successful reintroduction to an area. Nebraska rangelands that could previously support bighorn populations may be inadequate at present because of increased tree density, livestock use, and habitat fragmentation. The Audubon subspecies, *O. c. auduboni*, was once native to western Nebraska but became extinct in the early 1900's. The low elevation terrain it inhabited in Nebraska lacked some of the characteristics of more typical, modern, bighorn sheep ranges. Rocky Mountain bighorn sheep (*O. c. canadensis*) were successfully reintroduced to the Pine Ridge area of northwestern Nebraska in the early 1980's. This population will be studied to determine bighorn sheep use of these unique low elevation habitats. Habitat use by male and female groups will be investigated from January 2002 through August 2002 and again from January 2003 through August 2003. Lambing habitat will be identified and compared with the model parameters developed by Forbes and Merchant (1998). Lamb production and survival will also be documented. Diet analysis and lungworm levels will be determined from fecal samples collected from the study area. This study will provide information that will be key to continued management of Nebraska bighorn sheep and will aid in future reintroduction efforts.

Lamb Production And Survival Of A Bighorn Sheep Population In Central Idaho.

CHRISTOPHER S. MCDANIEL, Conservation Biology, University of Idaho. 330 S. Asbury #2. Moscow ID, 83843 U.S.A.

Abstract: Long-term monitoring allows for the establishment of baseline data over extended time periods and gives biologists the opportunity to quantify data into predictive management strategies. The Rocky Mountain bighorn sheep (*Ovis canadensis*) population in the Big Creek drainage of the Frank Church-River of No Return Wilderness in Central Idaho experienced a sudden population decline from 1988 to 1990 as the result of a *Pasteurella* related die-off. Extensive monitoring of the population during that period provided information on lamb production and survival during the die-off phase of a *Pasteurella* die-off. A replicate survey of lamb production and survival was conducted during the summer of 2001 to assess the recovery stage of the die-off. The average number of lambs:100 ewes was established for three different lambing areas across three different time periods. These were compared to similar data collected during the summers of 1989 and 1990. Chi-square analysis of this data showed significant differences between total 1989-90 ratios and 2001 ratios but not between lambing areas in each of the die-off and 2001 periods. Results show a high survival ratio through the beginning of August 2001(avg. 86:100) compared with a significantly lower ratio in August 1989 (avg. 19:100) and August, 1990 (avg. 12:100). Thirteen years of lamb:ewe ratio data, collected between 1985 and 2000, were regressed against precipitation. Lamb recruitment through the following spring was positively correlated with March precipitation.

Using Gps Telemetry To Study The Seasonal Habitats Of Mountain Goats Within The Sunshine Coast Forest District, British Columbia.

SHAWN D. TAYLOR, Goat Mountain Resources, 2703 W. 11th Ave. Vancouver, B.C., Canada V6K 2L8
WAYNE WALL, International Forest Products Ltd. #311-1180 Ironwood Road, Campbell River, B.C. Canada V9W 5P7

Abstract: Mountain goats have been identified by MWLAP (Ministry of Water, Land and Air Protection) as a species of management concern in the Lower Mainland Region of British Columbia. To improve understanding of coastal goat habitat use and its relation to forestry operations, International Forest Products Limited, with support from FRBC, has started a two-year GPS telemetry project. The objective of the project is to further knowledge of seasonal habitat use by coastal goats. Goals in meeting this objective include determining collared goats' seasonal home ranges, movement patterns and use of broad habitat units, particularly forested habitats. Ground truthing of collars and correction algorithms derived from GIS mapping will allow us to account for GPS fix likelihood bias due to topography and forest canopy. The use of this correction within an RSF model (Resource selection function) will allow us to estimate the probability of use of habitats by goats within our study area. Two types of non-differential GPS collars are being used and have been initialized to collect data from different schedules. ATS collars will remain on animals for a two-year period and will allow us to examine goats' fidelity to seasonal ranges, and to monitor the timing of their seasonal movements. Lotek 2200R GPS collars have been programmed to increase our daily rate of GPS fix attempts and to increase our sample size of independently collared mountain goats. These collars will remain on animals for a one-year period and will then be placed on independent animals. The first group of animals is currently collared, and a total sample of 26 animals will be collared over our two-year study period.

Hierarchical Habitat Selection By Dall's Sheep Within The Tanana-Yukon Uplands, Alaska.

BRAD WENDLING, Alaska Cooperative Fish and Wildlife Research Unit, 209 Irving I, P.O. Box 757020, University of Alaska, Fairbanks AK 99775-7020 U.S.A.
BRAD GRIFFITH, Alaska Cooperative Fish and Wildlife Research Unit, 209 Irving I, P.O. Box 757020, University of Alaska, Fairbanks AK 99775-7020 U.S.A.
JIM LAWLER, National Park Service, 201 1st Ave., Doyon Building, Fairbanks, AK 99701 U.S.A.

Abstract: We investigated temporal and spatial habitat selection by two populations (West Point, Cirque Lakes) of female Dall's sheep (Ovis dalli dalli) within and adjacent to the Yukon Charley Preserve, Alaska. West Point sheep were significantly larger, had a higher body reserve index, had higher pregnancy rates, and had more lambs per 100 ewes than the Cirque Lakes population. Ten sheep were GPS-collared from each study area in 1999, 2000 and 2001 from which we collected a pooled total of 23,112 locations in 1999, and 24,132 in 2000. We used GIS to assess availability of resource units. Each 30 m pixel was described by variables: landcover type (a_1….a_n), slope (b_1…bn), aspect (c_1….c_n), elevation (d_1…d_n), terrain ruggedness (e_1…e_n). We estimated 95% utilization distributions and 50 % concentrated use areas for each sheep and temporal period of analysis with fixed kernel analyses. We assessed habitat selection across a hierarchy of scales with resource selection probability functions (RSPF): 1) season ranges within the landscape, 2) concentrated use area within seasonal ranges, and 3) sheep locations within concentrated use areas. We will employ these results to estimate habitat suitability within Yukon Charley National Preserve.

Population Genetic Structure Of Thinhorn Sheep From The Yukon And Northwest Territories.

KIRSTY WORLEY, Department of Animal and Plant Sciences, University of Sheffield, Sheffield, England
ALASDAIR VEITCH, Dept of Resources, Wildlife, and Economic Development, Government of the Northwest Territories, Canada
DAVE COLTMAN, Department of Animal and Plant Sciences, University of Sheffield, Sheffield, England

Abstract: We examined genetic variation in thinhorn sheep (*Ovis dalli*) from management zones in the Mackenzie Mountains of the Northwest Territories and from two Yukon Territory zones using microsatellite genetic markers. DNA was extracted from 394 horn core samples obtained from trophy hunted rams, from a total of ten zones, and typed at five highly variable microsatellite markers. Levels of genetic variation within each zone were high compared to data from other ungulate species. Heterozygote deficits were observed in all zones, with significant results in half of those sampled. We suspected the presence of null alleles at two loci, but suggest that the major cause of non-Hardy Weinberg allele frequencies is the presence of more than one genetic stock in some zones. There was evidence for significant genetic differentiation between eight of the ten zones sampled, suggesting that most zones as designated may constitute distinct genetic stocks. Genetic differentiation of zones was found to fit the isolation by distance model. This suggests that philopatry limits the dispersal of thinhorn sheep, resulting in genetic differentiation between populations. The gradient of the isolation by distance plot was higher than carnivores, but of a similar magnitude to other mountain ungulate species. We found no significant evidence for genetic differentiation based on colour polymorphism within both Yukon zones sampled.

Keywords: *Ovis dalli*, microsatellites, genetic structure, Yukon, Northwest Territories

Thinhorn sheep of the Yukon and Mackenzie Mountains of the Northwest Territories comprise native populations thought to number 22,000 and up to 26,000 respectively (Barichello et al. 1989; Veitch & Simmons 1999). Both thinhorn subspecies, the all white Dall's (Ovis dalli dalli) and the darker Stone's (O. d. stonei) are present in the Yukon, while only the former inhabit the Northwest Territories. The proportion of each subspecies is not uniform throughout the Yukon, with more Stone's found in the southern range than in the north, although in total there are around six times more Dall's sheep in the territory. In addition, where the colour morphs overlap an intermediate can be found. These Fannin sheep are thought to result from interbreeding between subspecies (Barichello et al. 1989). In this paper we are treating all morphs as one species in all our analyses unless otherwise stated.

Currently, little is known of population genetic structure within the species range. This information could be beneficial when managing sheep populations. If genetic stocks could be identified, managers could use the information to maintain genetic variation within a sheep population. An individual harvest target could be given for each genetic stock, thus preventing biased removal of some stocks over others. Maintaining genetic variation may prove to be valuable, especially if traits such as horn size are later found to have a genetic component. Even if this is not the case, maintaining genetic diversity in a herd is advantageous in that problems associated with inbreeding are avoided. The effects of inbreeding depression on fitness include an increased incidence of mortality due to environmental factors, a decrease in juvenile survival, and increased disease susceptibility (Keller & Waller 2002). A genetic dataset across the species range would also be very useful for forensics cases. With the existence of such a database, cases of suspected illegal hunting and reporting incorrect kill site locations could be investigated immediately.

There are several reasons to suspect genetic differences between animals across the species range. It is known that wild sheep are very philopatric, with individuals utilizing the same home range each year. This lack of dispersal also limits gene flow to within short distances, enabling genetic differences to accumulate between isolated populations. The effects of philopatry on genetic structure in thinhorn sheep have not previously been shown. If there is an effect, the distances needed to allow such population differentiation could be estimated. Previous studies on bighorn sheep (Ovis canadensis) populations have shown the presence of genetic structure. By sequencing a gene from desert bighorn (*O. c. nelsoni*) ewes, Boyce et al. (1999) showed that genetic variation was not randomly distributed, but reflected structure in the population as expected in a philopatric species. Significant genetic distances between Rocky Mountain bighorn (*O. c. canadensis*) populations have also been reported, from both across the species range (Forbes et al. 1995), and between populations transplanted from a common source herd (Fitzsimmons et al. 1997). One previous study on Dall's sheep concluded that little genetic variation was present across locations sampled (Sage & Wolff 1986), although allozymes were used as the genetic markers in this case. If there are high enough levels of genetic variation to allow a population study, then allozyme analysis is not the best way to find it. As translated loci, changes in DNA sequence at these sites may result in an inactive enzyme product, and hence be disadvantageous to the carrier. Mutations will therefore be selected against unless they are beneficial. As a result there are lower levels of variation at allozyme loci than in non-coding regions of the genome, where mutations do not have negative consequences to the individual.

Here, microsatellites were used to study the genetic structure of thinhorn sheep. Microsatellites are regions of the genome composed of one to five base pair tandem repeat units, the dinucleotide repeat CACACA…… being one of the most common found in animals. Such sites are non-coding, and are therefore not under selection. Microsatellites mutate in a stepwise manner, with sequential addition or loss of repeat units. The mutation rate is high due to the absence of selection, allowing a large number of alleles to accumulate at each locus. This leads to substantial levels of genetic variation between individuals, making microsatellites extremely useful tools for population genetic studies (reviewed in Jarne & Lagoda 1996).

Three main issues were addressed in this study: the magnitude of genetic variation present within each game management zone sampled; the extent of the differentiation between zones and; the probability of correctly assigning an individual to the zone from which it was collected based on genotype data alone (the assignment test) (Waser & Strobeck 1998). We also investigated the presence

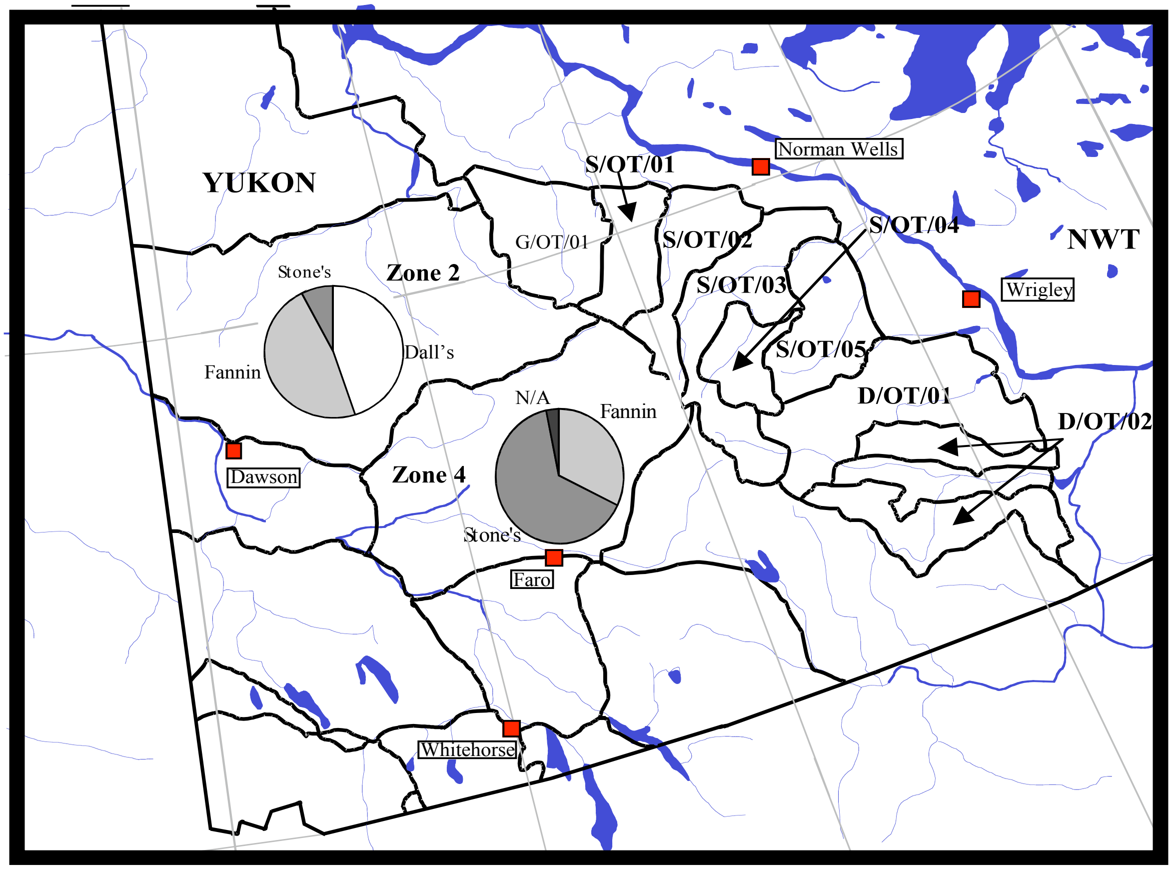

Figure 1. Game management zone locations in the Yukon and Northwest Territories. Pie charts illustrate proportions of each subspecies in samples genotyped from Yukon zones.

of genetic differences between thinhorn subspecies.

METHODS

Sample locations

The 394 thinhorn rams included in this study were sampled from 10 game management zones, all eight zones of the Northwest Territories (NWT) and two from the Yukon (zone 2 representing the Ogilvie range and zone 4 the Anvil range) (figure 1), with between 31 and 42 individuals per zone. All NWT sheep were Dall's sheep, while Yukon zones contained Dall's, Stone's and Fannin, with proportions of each depending on zone. Yukon zone 2 was largely Dall's and Fannin, whereas Stone's sheep occurred frequently among the zone 4 samples. Horn samples used were taken from plugs removed from hunted animals for the insertion of identification tags at registration between 1994 and 2000.

Molecular Techniques

Genomic DNA was extracted from approximately 0.5ml of horn material per sample using a tissue extraction kit (Qiagen, Crawley, West Sussex, UK). DNA was amplified by the polymerase chain reaction (PCR) over five highly variable dinucleotide microsatellite loci (AE16, BM1225, BM848, CP26 & FCB266) developed in domestic sheep and cattle. Each 10□l reaction contained 1.5□l DNA template at an annealing temperature of 54oC. Full details of molecular techniques used can be found in Coltman et al (2002). PCR products were genotyped using an ABI 377 sequencer and analyzed using the software GENESCAN and GENOTYPER (Applied Biosystems, Foster City, California, USA).

Data Analyses

All measurements of genetic variation, both within and among game management zones were made using the computer program GENEPOP 3.1 (Raymond & Rousett 1995). Basic genetic parameters, including allelic diversity (the number of alleles observed at a locus) and allele frequency were calculated. Genetic structure within each zone was examined using exact tests to quantify deviations from Hardy Weinberg expectations (Guo & Thompson 1992), and by the statistic FIS. This is a measure of population wide deviation from random mating, or inbreeding, as calculated via associated reduction in heterozygosity. Significance levels of this measure and all other multiple tests were corrected using Bonferroni methods. Means of observed and expected heterozygosity, and allelic diversity were tested for equality between zones. The presence of linkage disequilibria between loci was tested using the exact test method of GENEPOP.

Genetic differentiation between zones was estimated by exact tests for differences in allele frequency both globally and pairwise between zones. The statistic FST was used to quantify genetic distance between zones. The relationship between genetic and geographic distance was examined to assess isolation by distance, with significance tested via the Mantel methodology employed by GENEPOP. Genetic distance was measured by FST/(1-FST), while geographic distances between zones were calculated by measuring the linear distance between zone central points. For Yukon samples distances were measured from the centre points of all sub-management zones included (only a small area of the total management zone).

Within the two Yukon zones, samples were divided into the groups Dall's, Stone's, or Fannin. Genetic differentiation between these groups was tested by exact tests for differences in allele frequency as well as by the genetic distance measure FST.

Assignment tests calculate the probabilities that a sample originated from all zones in the dataset, before assigning the sample to the zone with the highest likelihood of being the source. Each sample is removed from the dataset in turn and placed in the zone from which it most closely matches the group allele frequency profile. This information can be useful to investigate several aspects of population structure. If individuals have low likelihood of assignment within the source zone, it indicates genetic similarity between zones. Individuals assigning to neighboring zones could represent migrants, and their descendents, so assignment testing is informative for estimating dispersal. Another use of this data is to identify the most likely origin of illegally hunted rams. Genotypic data could for example indicate that a ram was unlikely to originate from where it was reported to have been. The program WHICHRUN (Banks & Eichert, 2000) was used here to assign each sample to the zone that most closely matched its allelic profile.

RESULTS

Variation within zones

Heterozygosity observed in all zones was relatively high, ranging from 0.681 in S/OT/04 and Yukon 2 to 0.783 in S/OT/02

Table 1. Genetic variation at five microsatellite loci in ten thinhorn sheep management zones.

Zone	N	H_e	H_o	H_{diff}	A	F_{IS}
NWT						
D/OT/01	40	0.783	0.735	-0.048	8.4	0.0618
D/OT/02	42	0.711	0.705	-0.006**	10.0	0.0042
G/OT/01	40	0.747	0.714	-0.033	8.2	0.0445
S/OT/01	40	0.790	0.764	-0.026	9.4	0.0313
S/OT/02	40	0.788	0.783	-0.005	9.2	0.0081
S/OT/03	40	0.780	0.698	-0.082*	8.6	0.1056
S/OT/04	40	0.803	0.681	-0.122**	8.8	0.1523
S/OT/05	41	0.779	0.686	-0.093	7.4	0.0714
Yukon						
Zone 2	40	0.758	0.681	-0.077**	8.2	0.1105
Zone 4	31	0.768	0.743	-0.025**	7.8	0.0189
Mean	39.4	0.771	0.719	-0.052	8.59	0.0609

N, sample size, H_e expected heterozygosity, H_o, observed heterozygosity, H_{diff}, H_o-H_e (measure of deviation from HWE), A, allelic diversity, F_{IS}, measure of deviation form random mating. Levels of population deviation from Hardy Weinberg equilibrium (H_{diff}) that are statistically significant are indicated. *P<0.05, **P<0.01.

(Table 1). Mean allelic diversity ranged from 7.4 to 10.0, reflecting the high levels of variation present at microsatellite loci. Measures of heterozygosity and the number of alleles per locus did not differ significantly across zones (paired Wilcoxon signed rank tests, all with P>0.2), indicating similar levels of genetic diversity are present across the sampled range.

Values of expected heterozygosity differed significantly from those observed in five of the ten zones, while all ten zones exhibited some degree of heterozygote deficit, indicating violation of random mating assumed in Hardy Weinberg equilibrium. Deviation from Hardy Weinberg expectations (HWE) was most pronounced in the NWT zones D/OT/02 and S/OT/04 and in both Yukon zones. Global tests of HWE by locus revealed that BM848 and FCB266 deviated significantly (P<0.001 in both cases). The deviation found in zones S/OT/04, Yukon 2 and Yukon 4 appear to have been the result of these two loci, especially BM848, which was not at equilibrium in any of these zones. The locus BM848 was then removed from the data and tests for significant heterozygote deficit repeated. Results showed that Yukon zones and S/OT/04 remained significant for deviation from HWE. In zone D/OT/02 three out of the five loci showed deviation from equilibrium. The marginal significance seen in S/OT/03 was found to be the result of the locus AE16.

Table 1 also shows values of FIS for each zone. All values were positive, ranging from 0.0042 in D/OT/02 to 0.1523 in S/OT/04. Significant positive values of F_{IS} can indicate population substructure and inbreeding. The high value found in S/OT/04 corresponds to the highly significant deviation from HWE. F_{IS} by locus ranged from 0.0157 for CP26 to 0.1232 for BM848. Again all values were positive. There was no evidence of genotypic disequilibria between the loci, with only one from all individual comparisons showing significance at $P<0.05$ after Bonferroni correction.

Population differentiation

Allele frequencies exhibited highly significant differentiation at all five loci ($P<0.001$ in all cases by exact tests), indicating the presence of more than one genetic stock. 141 out of 225 pairwise comparisons of allele frequency differences were significant. Those comparisons with Yukon zones were the most differentiated, the highest was seen as 42 significant differences out of 45 comparisons with Yukon zone 4. All zonal pairwise comparisons for differentiation over all loci were highly significant ($P<0.001$) except for those of G/OT/01 with S/OT/03 and S/OT/01 with S/OT/02 ($0.02<P<0.05$; this is non significant when Bonferroni corrected for multiple comparisons with □ at 0.001). This apparent lack of differentiation between these two zonal pairs is reflected in the corresponding low incidence of individual allele frequency differences (both have no significantly differentiated loci from the five tested). Population specific rare alleles were seen in zones D/OT/02 (AE16), S/OT/02 (FCB266) and Yukon zone 2 (BM1225).

Over all zones F_{ST} was 0.0656. Pairwise values ranged from 0.0055 between G/OT/01 and S/OT/03; reflecting the lack of population differentiation here, to 0.1721 between G/OT/01 and Yukon zone 4 (Table 2). Analyses indicated that Yukon zones were more genetically distant from NWT zones than NWT zones were from other NWT zones. The highest value seen between NWT comparisons was observed between D/OT/02 and G/OT/01, reflecting the largest geographic distance between zones. F_{ST} by locus ranged from 0.0504 for FCB266 to 0.0816 for AE16.

Isolation by distance

Significant correlation was found between measures of genetic and geographic distance (Figure 2, $R^2=0.310$, $F_{1,44}=19.34$, $P<0.0001$), indicating the presence of isolation by distance. This points to limited dispersal being the causative factor for genetic differentiation across the sampling sites. There could have been some indication that comparisons with the zones containing a higher frequency of Stone's sheep (Yukon zone 4) showed greater genetic distance measures than expected, as all points in Figure 2 comparing between subspecies fall above the regression line. At present there is no statistical evidence that this is the case, as distances are not significantly higher than expected. When taken alone, comparisons between subspecies show no statistical evidence of isolation by distance ($P=0.838$), although the associated sample size is low ($n=9$).

Colour polymorphism in thinhorn sheep

Due to genetic differentiation found between the two Yukon zones, data could not be pooled, so zones were considered individually. All exact tests for genetic differentiation within zones 2 and 4 based on colour were non significant ($P>0.189$ in all cases, with the only comparison between Dall's and Stone's with $P=0.479$), and pairwise F_{ST} values were at the lower

Table 2. Genetic distance matrix

Zone	D1	D2	G1	S1	S2	S3	S4	S5	Y2
D2	0.0454								
G1	0.0579	0.1084							
S1	0.0433	0.0871	0.0475						
S2	0.0258	0.0491	0.0445	0.0101					
S3	0.0257	0.0606	0.0055*	0.0322	0.0236				
S4	0.0169	0.0522	0.0491	0.0111	0.0094	0.0243			
S5	0.0390	0.0341	0.1073	0.0600	0.0362	0.0658	0.0318		
Y2	0.0886	0.0902	0.1288	0.0782	0.0645	0.0987	0.0780	0.0941	
Y4	0.1145	0.1141	0.1721#	0.1170	0.1102	0.1485	0.0975	0.1387	0.1227

Pairwise F_{ST} is given to measure genetic distance. The lowest (*) and greatest (#) values are indicated.

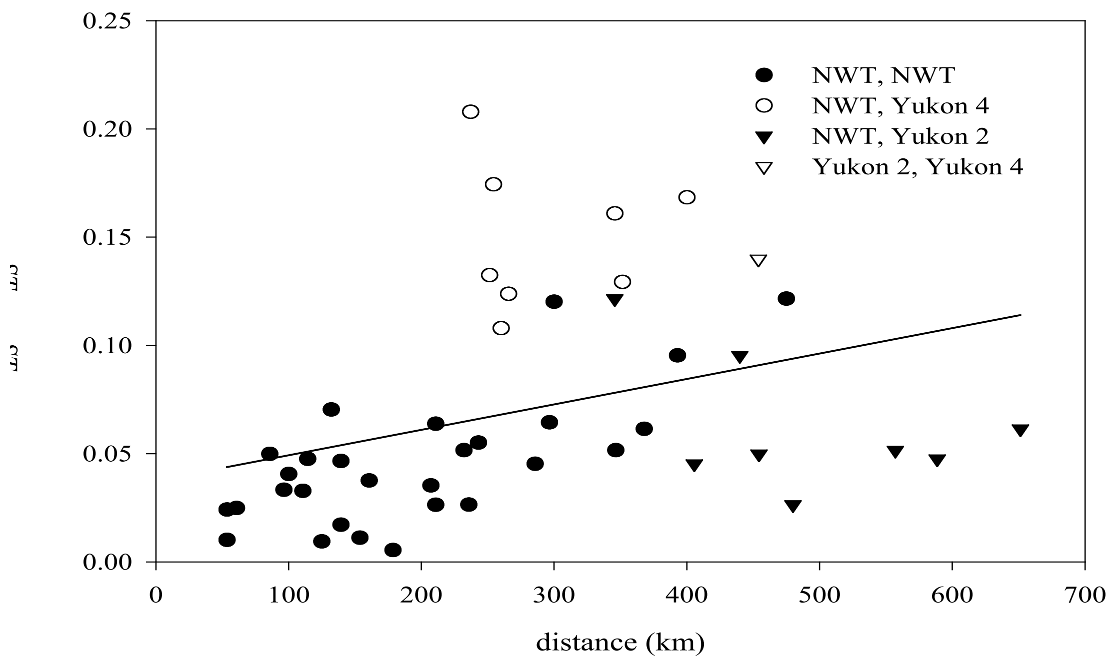

Figure 2. Plot of genetic distance, given by $F_{ST}/(1-F_{ST})$ by geographical distance for all thinhorn sheep zones. The regression line corresponds to all points on the plot. Within Dall's sheep comparisons (filled symbols) show a significant correlation, whereas the regression slope between subspecies comparisons (open symbols) was not significant.

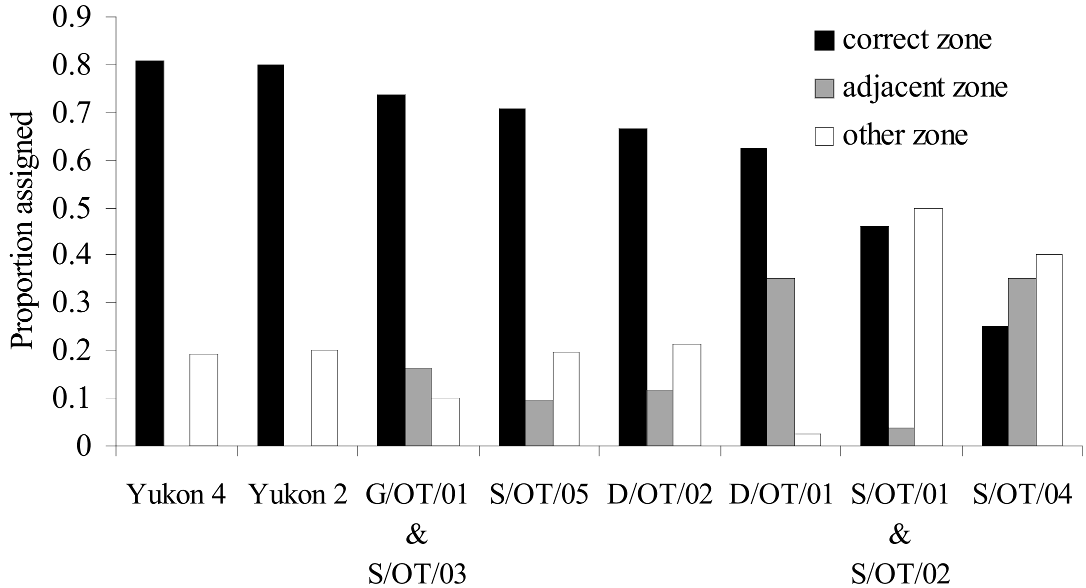

Figure 3. Results of assignment tests with undifferentiated zones combined. Adjacent zone is taken as any zone bordering the zone from which the sample was taken.

levels found in this study, ranging from -0.0012 to 0.0457 (Table 3).

Table 3. Genetic distance between subspecies in Yukon game management zones

Zone 2	Dall's	Fannin
Fannin	-0.0012	
Stone's	0.0203	0.0457

Zone 4	Fannin
Stone's	0.0045

Assignment

We ran our assignment tests with genetically undifferentiated zones combined, and recorded a high mean success rate of 63% (SE 6.7%). Figure 3 showed that Yukon individuals had a very high proportion of correct assignments, at over 80%. The poorest proportion of individuals correctly assigned was found in S/OT/04 at 25%. Those zones separated from others by the smallest genetic distances showed lower success in correct assignment to zones of origin. There was no significant difference in correct assignment between zones (Kruskal-Wallis □2= 7, d.f.=7, P=0.4289). Overall, no difference was seen between the proportions of individuals assigned to neighboring zones to those assigned to other more distant zones (P=0.156, Wilcoxon rank test). When assignments were restricted to those in which the likelihood was ten times that of assignment to any other zone, the proportion of NWT genotypes assigning to a zone fell to low levels (all <20%), and included some samples that assigned to a zone other than the source. However, 43% and 68% of all Yukon genotypes (zones 2 and 4 respectively) still assigned to a zone, and in no case was this zone other than that reported.

DISCUSSION

Genetic variation within management zones

Measures of genetic variation, such as allelic diversity and observed heterozygosity were higher than other mountain ungulate species, including bighorn sheep and Ibex (Capra ibex) (Forbes et al. 1995, Maudet et al. 2002), indicating that a large quantity of genetic variation at microsatellite loci is present within thinhorns. This variation is likely due to the large population size of native thinhorns compared to the smaller fragmented populations of Rocky Mountain bighorns (Valdez & Krausman 1999), many of which have been translocated following extirpations, causing loss of genetic diversity. Low genetic diversity in Alpine Ibex is to be expected as the population decreased to between 90 and 200 individuals at the end of the nineteenth century, most likely due to overhunting (Maudet et al. 2002).

Within all ten zones there were fewer heterozygotes than expected, with significant deviations from Hardy Weinberg equilibrium at five of these. This pattern can be explained in several ways. Firstly, null alleles may be present at some loci (Paetkau & Strobeck 1995). A null allele occurs where a mutation in the primer binding site results in non amplification of a specific allele, therefore leading to assignment of the incorrect genotype. Where this is the case deviation from HWE within a zone would be present only at loci containing null alleles. As two of the loci showed deviation from expectations across zones (BM848 and FCB266), we suspect the presence of null alleles at these sites. This explanation could account for the heterozygote deficit seen in three of the five zones deviating from expectations (S/OT/04, Yukon 2 and Yukon 4), as either or both loci suspected of containing null alleles were not at equilibrium there. In the presence of null alleles, we would also expect non-amplifying genotypes, where homozygotes for the null alleles are present. When we compared frequencies of missing genotypes across all five loci, we observed that the two with suspected null alleles did not contain more missing results than the others. Therefore the high frequency of a null allele that is needed to account for the highly significant HW deviation would seem unlikely. In addition to this, when BM848 was removed from the data and the tests re-run, we still found significant deviation from HWE. This evidence does not rule out the presence of null alleles, it still remains likely that they are present, but it would suggest that frequencies of such alleles are too low to cause all the heterozygote deficits. The deviation from HWE found in S/OT/05 could be the result of a rare null allele at AE16 in this zone.

Secondly, the result could have a biological cause. Heterozygote deficit can result from grouping genetically isolated subpopulations for analyses: the "Wahlund effect". It can be caused when individuals from one genetically isolated population are more likely to breed within than outside this group. The Wahlund effect is therefore a form of inbreeding. Factors limiting gene flow between two divergent populations within a zone include differences in microhabitat. If populations are separated by unfavourable terrain, then differentiated groups are unlikely to meet and breed. In addition to this, the Wahlund effect is also likely to be seen when dispersal ranges are much smaller than the zones of sampling, even without the presence of physical barriers to gene flow. In this case several non-overlapping thinhorn ranges, and therefore isolated populations, can exist within a game management zone. Significant genetic differences have been reported over relatively small distances in desert bighorn ewes using DNA sequence data (Boyce et al. 1999). Here we have reported probable genetic divergence within zones on a similar geographic scale. The highest FIS statistics were recorded in zones S/OT/04, S/OT/05 and Yukon zone 2. Since this value also indicates inbreeding it appears that these zones are likely to be composed of more than one genetically differentiated breeding stock.

Taking all explanations into consideration, we conclude that although null alleles at low frequencies are likely at BM848 and FCB266, the majority of heterozygote deficiency seen in thinhorn sheep in the Yukon and Northwest Territories is due to genetic substructure within zones. Further analyses including kill site location of each sample within a zone is needed to test this conclusion. It would seem probable that this is the case, as sheep population borders never defined those of management game zones.

The Mackenzie Mountains comprise more than one mountain block. If a zone overlaps two blocks, genetic differences are likely to be found between these populations, as sheep will be unlikely to cross from one to the other. One result that is difficult to explain is the apparent lack of differentiation between zones G/OT/01 and S/OT/03. These two are separated by two other zones, which they show differentiation with.

Genetic differentiation between zones

Both tests for allele frequency differentiation and measures of genetic distance showed significant differentiation between zones. Six zones were genetically distinct from each other, with the remaining four zones containing two isolated stocks, indicating that there were at least eight (more if subpopulations are later found) genetically distinct stocks present. NWT zones showed a greater degree of differentiation from Yukon zones than from other NWT zones, indicating that geographic distance is important in leading to and maintaining differentiation. This was shown statistically by a significant relationship between genetic and geographic distances (Figure 2). We have shown genetic differentiation between zones that are less than 60km apart (S/OT/02 & S/OT/03). This is similar to distances reported in one study of desert bighorn (Boyce et al. 1999), but less than that found in a Rocky Mountain bighorn study (Luikart & Allendorf 1996).

When compared to other mammalian studies, the gradient of the isolation by distance plot is higher than carnivores, but of a similar magnitude to bighorn sheep (Forbes & Hogg 1999). This positive relationship is typically caused by limited dispersal. Wild sheep are highly philopatric with little migration from the natal region, and strong association with winter range. Low dispersal is evident in this study through high FIS values, large degree of zonal differentiation, and the large positive gradient on the isolation by distance plot.

Values of the genetic distance statistic FST were similar to those found in other mountain ungulates (Maudet et al. 2002), but were higher than distances associated in carnivores (Paetkau et al. 1999, Kyle & Strobeck 2001). This again indicates high levels of population structure in Dall's sheep.

There was no evidence that sheep of differing colour polymorphism within the same zone showed genetic differentiation. In fact, the FST of 0.02 observed between Dall's and Stone's sheep in Yukon zone 2 was just as expected given the isolation by distance relationship (intercept on Figure

2). It is only when comparing between Yukon zone 4 (mostly Stone's) and NWT zones (Dall's) that we see trends towards a different isolating mechanism. This could be the result of historical separation of these zones, possibly during past glaciation events. Such separation during evolution could lead to the trend seen in figure 2, where sampling across these areas resulted in higher than expected genetic distances. A similar result was reported by Forbes & Hogg (1999) when sampling over subspecies of bighorn. If there are genetic differences present between thinhorn subspecies, they may be subtle. It could be that interbreeding of animals in zones where both subspecies are present has obscured any subspecies level differentiation. It is only when subspecies are geographically isolated that we are able to see levels of differentiation greater than expected (as we see in comparisons with Yukon zone 4). More data is needed to examine these differences before definite conclusions can be made. Greater power required to detect significant results will be provided when numbers of genetic markers are increased. Therefore, at present this issue remains unresolved.

The high proportion of correct assignments reflects the genetic distances separating zones. Probability of assignment has previously been shown to be related to FST (Maudet et al, 2002). We would expect that when more Yukon zones are sampled, filling in the geographic gaps, the proportions assigned would fall to similar levels to those of NWT zones. Levels of correct assignment show that we would have a good chance of identifying geographical origins of unknown samples using the set of microsatellites in this study, especially for geographically isolated populations. With the use of more loci, finer details of structure could be determined by this method, with possible migrants and their descendents being identified within each zone.

All measures of genetic differentiation presented here are likely to be conservative when considering the species as a whole, as only rams are included in the sample. In mammals it is generally the males that are the dispersive sex (Greenwood 1980). The same is true for wild sheep, although in a lesser degree as even rams have shown very low incidences of permanent dispersal (Festa-Bianchet 1991).

Management implications

We have shown that thinhorn populations of the Yukon and Northwest Territories contain high levels of genetic variation, greater than those seen in some other mountain ungulate species. Already with only five loci we have identified eight differentiated genetic stocks of thinhorn sheep in the Yukon and Northwest Territories. We would suggest that these stocks should be managed separately. It is important to identify genetically distinct populations so that one such group is not selectively targeted over all others by hunting. Although the hunting pressure on the species as a whole is very small and has no substantial impact on the population (Veitch & Simmons 1999), it could have effects on specific genetic stocks, if hunter pressure is not equally distributed across zones. Maintaining a sustainable harvest in the future means attention to the rate of harvest at each genetic unit. This would prove especially important if horn size is later found to have a genetic component, in addition to wishing to avoid problems associated with inbreeding. Bias towards harvesting those rams with the largest horns may also be targeting some genetic stocks over others, decreasing genetic variation for horn growth, and thereby reducing horn size in future generations. This is especially relevant in wild sheep species, as no senescence is seen (Coltman et al, 2002) and old rams that are more likely to be hunted are still siring offspring. Although environmental factors such as forage quality in the year of birth; whereby rams born in good forage years can attain greater horn size that those born in poor years, play a part in determining horn size, the genetic component would remain important. Rams still pass on the genetic component of their horn size to their sons, who may be born in a differing quality year.

We recorded high probabilities of assignment to source management zone based on genotype data alone. This makes these tests useful tools for thinhorn forensics cases. With the use of more markers, success of this method will increase. In the future we may be able to assign suspected illegal rams to likely kill sites of a reasonably small area, using this expanded dataset as a reference. This will be possible due to the relatively small distances dividing genetically differentiated populations in this species.

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Commentary

Dall Sheep Disagreements: An Alaskan Management Controversy

Wayne E. Heimer, Sarah Watson-Keller, Valerius Geist, Samantha Castle Kirstein, and T. C. Smith III

Dr. David Klein, long-term Alaska Cooperative Wildlife Unit leader at the University of Alaska in Fairbanks, was honored by a special symposium where several of his former students presented papers. The papers were published in the moose-centered journal, ALCES Volume 37. One of these papers was a critique of Dall sheep research and management by Ken Whitten, who has presented several papers at symposia of the Northern Wild Sheep and Goat Council. The ALCES citation for this critical article is given in the abstract reproduced below. We think rebuttal of articles such as this is required, but will not submit our full rebuttal to ALCES because we suspect the primary readership of ALCES will not find the details of our rebuttal particularly germane to their interests. Our submission to ALCES will be summary and tailored to that readership. In contrast, the readership of the Proceedings of the Northern Wild Sheep and Goat Council should have considerable interest in the details of this argument because it is about sheep management, not moose. Hence, we have petitioned the Northern Wild Sheep and Goat Council to include the abstract of Whitten's critique and the text of our rebuttal in this proceedings even though it was not presented in Rapid City. We were, at that point, blissfully unaware if its existence. Readers are encouraged to consider Whitten's entire article in evaluating our rebuttal.

EFFECTS OF HORN-CURL REGULATIONS ON DEMOGRAPHY OF DALL'S SHEEP" A CRITICAL REVIEW

Kenneth R. Whitten
Alaska Department of Fish and Game, 12300 College Road, Fairbanks, AK 99701-1599, USA

*ABSTRACT: Researchers studying Dall's sheep (*Ovis dalli dalli*) associated with a large mineral lick on Dry Creek in the central Alaska Range south of Fairbanks, Alaska, USA, claimed that removal of nearly all mature males by intensive harvest of three-quarter curl or larger males by hunters during the 1980s resulted in accelerated mortality of young males and low productivity in female sheep. Changing to a more conservative harvest of seven-eights and then full-curl males purportedly reversed these trends and resulted in higher overall sustained harvest of males. Review of Dry Creek study reports and of original data records revealed questionable assumptions and errors in data analysis and study design. Conclusions about accelerated mortality of young males were based primarily on resighting data from marked males at the mineral lick, but data from aerial surveys of the larger study area around the lick indicated much higher abundance of males than was apparent at the lick. Reanalysis of data showed that males had low fidelity to the lick, and many years the lick was not observed frequently enough to detect all sheep that may have used it. Harvest only reduced abundance of mature males by about one-half and had no discernable effect on survival of younger males. Low ovarian activity and high rates of parturition in 2-year old females (thought to be associated with alternate year reproduction in later life, and therefore undesirable) were attributed to low abundance of mature males from 1972 to 1979, but most* *data were actually collected either before or after those dates, when male abundance supposedly was high. Harvest of mature males increased through the 1980s, but an apparent correlation with more restrictive horn-curl regulations disappeared in the 1990s. Harvests of mature males under full-curl management in recent years have been far lower than ever occurred under three-quarter curl regulations. I conclude that trends in sheep harvested at Dry Creek were not driven by horn-curl regulations, but by long-term weather patterns that affected sheep productivity, survival, and abundance.*

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Key Words: *Alaska, Dall's sheep, harvest, horn-curl, management, mortality, Ovis dalli dalli*

THE SHEEP MANAGEMENT COMMUNITY RESONDS:

Abstract: We understand practice of the natural sciences as systematic effort to find truth outside one's self. At its best, this human enterprise often leads to disparate interpretations because it is difficult to remain objective; and criticism occasionally becomes highly personalized. Still, we appreciate the benefits of critical review, and were most interested and anxious to read what Mr. Whitten (ALCES 37(2):2001) had to say about our collective efforts. Unfortunately, we found the review more hostile than helpful. We rate the review as flawed in four major aspects. First, the evident scholarship is inadequate for the task, and compromises the credibility of the critique. Second, the over-emphasis on aerial survey data, the least reliable data relevant to the issue, focuses distractingly on details and obscures the larger picture. Third, the critique focuses excessively on retrieval of our clearly stated caveats, cautions, and stated assumptions from a relatively minor paper modeling ram survival as ignorant or deceptive; they were neither. Fourth, the review mistakenly represents the certainty with which we presented our earlier work, and ignores large body of qualifying work over the last fifteen years, which frames our conclusions as a working management hypothesis for in-field testing. Alaska's full-curl ram harvest regulation is an example of management and pursuit of biological fact through an articulated working hypothesis based on a synoptic view of Dall's sheep autecology. Unfortunately, the review erroneously reduces this biologically-driven regulation to the level of an arbitrary management convenience which does not culture compliance by hunters. After having considered the critique, we argue that integration of the complete biological data set rationalizes restriction of open harvest of Dall's rams to those at full maturity for purposes of biological conservation and maximum sustained yield.

Keywords: Alaska, Dall sheep, harvest, horn-curl, working management hypothesis, *Ovis dalli dalli*

We, the authors, are a diverse group. We have been collectively studying and managing North American and Dall sheep since the 1960s. Our areas of specialty range from the evolution and behavior of mountain sheep (VG), through typical management-related Dall sheep surveys and research projects (TCS, SW-K, WEH), to economic analysis of Dall sheep hunting (SW-K), rigorous nutritional analyses and the physiology of Dall sheep (WEH), and service on the Alaska Board of Game (SCK). Alaska's present Dall sheep harvest program (its full-curl regulation) resulted from our applied synthesis and implementation of this cumulative experience. Responsibility for Alaska's full-curl regulation is much broader than the critique appreciates, and cannot be assigned to one individual or a couple of researchers.

Collectively we have pursued our share of apparently erroneous directions over this 40-year period, found them to be unproductive, and redirected our thinking to "embrace null hypotheses" when warranted by the cumulative weight of data. It is our hope, and indeed our assertion, that we have done so honestly, and in the best traditions of the natural sciences. Our embrace of the null hypothesis where density-dependent nutritional constraints are concerned has put us at odds with the prevailing dogma of classical wildlife management. We suggest the harsh critique to which we must respond at this time is best defined as defense of this dictum. We must address some of the critique's specific criticisms before offering more significant, management-relevant arguments in our DISCUSSION segment.

Inadequate Scholarship Relating To Criticized Work

We found the review less helpful than we had hoped because of inadequate scholarship. This inadequate scholarship appears, throughout the critique, to highlight our alleged failures of concentration and conscience. Unfortunately, the critique is demonstrably out of touch with the work it criticizes. This is not surprising considering the critique focuses on data and published analyses from "the 1970s and 1980s." Further detailed analysis and synoptic papers, which would have been beneficial for the critique's credibility, have been published over the last 15 years; but were arbitrarily excluded from review. Consequently, the critique is outdated, and simply wrong in many instances. Unfortunately, we are obligated to list at least a few examples to support our conclusion of inadequate scholarship. We'll begin with the summary of our hypothesis in the critique's first paragraph, which says (*emphasis added*):

> Subsequent *early reproduction among females was hypothesized to have stunted female body growth, ultimately leading to alternate year reproduction*, as opposed to annual production of young that would have occurred had females delayed breeding until they were at least 2 years old (Heimer and Watson 1986). (*ALCES 37(2):484 column 1, lines 6-13*)

Even though this interpretation seems intuitively understandable and attractive because it is buttressed by the cumulative experience of domestic animal husbandry, the critique errs in defining it as our position. Work on wild cervid species, specifically caribou (Dauphine, 1976) and red deer (Hamilton and Blaxter, 1980) suggested nutritional limitations (which could lead to stunting) resulted in compromised reproductive performance in these species. Intuitively, one would suspect nutritional limitations might have a similar effect in other wild ungulate taxa, perhaps including Dall sheep. We admit to once being attracted to this idea. However, after WEH had thoroughly investigated the nutritional resource profiles in contrasting populations of Dall sheep in Alaska (Heimer, 1983), we embraced the null hypothesis (that nutrition was not a factor in alternate-year reproductive success) and abandoned the "stunted" line of thinking. The evolution of our thoughts on nutrition may be found in Heimer and Watson (1986 page 30 paragraphs 2 and 3, and page 31). However, that Federal Aid report is sparingly available so we shall quote our explicit summary:

> We conclude differences in ovulation rate are not explained by factors which determine body condition. There was no statistically significant difference in the nutritive values for washed rumen contents, no reasonable expectation of significant differences between the nutritive values for summer range plants, and no difference in breeding body condition between the 2 [radically different] study populations. (Heimer and Watson (1986) page 35 paragraph 3).

Errors as basic as the just-documented misrepresentation demonstrate inadequate scholarship for the critique from its outset.

Still, we can understand how a cervid specialist might project this conclusion to us. After all, it is considered proven that ovulation is a function of female body mass in caribou. By extension, it is intuitively apparent that a sufficiently skinny Dall ewe probably can't ovulate. Still, there is no evidence the caribou body mass/ovulation relationship is relevant to Dall sheep. In contrast to yearling caribou cows (which occasionally ovulate if high quality forage is abundant, as do other members of the deer family), every yearling Dall sheep ewe ever examined, regardless of location or circumstance has shown evidence of ovulation (Heimer 1999). This suggests sheep reproductive physiology is, in fact, distinct from that of the *cervidae*, and takes us to the critique's first apparent assumption.

Assumption #1: Sheep do not have a unique social biology

The assumption, that sheep autecology is no different than generalized ungulate synecology arises in the review's second paragraph, where the critique states:

> Not everyone, however, agreed with the conclusions of the Dry Creek studies. Wildlife managers in Alaska were familiar with numerous situations in which unrestricted hunting of male moose (*Alces alces*) and caribou (*Rangifer tarandus*), which also have complex social structures had resulted in far lower sex ratios and much greater skewing of the age structure toward young males than three-quarter curl only hunting has ever caused in Dall's sheep, yet far greater consequences from harvesting were being claimed for sheep. (page 484 column 1 paragraph 2, lines 1-13)

We argue simply stating that moose and caribou have "complex social structures" reflects inadequate consideration of behavioral adaptations of differing taxa to differing habitats. Contemporary evolutionary thinking argues these differences should have produced disparate survival strategies. We think they have. One of us (VG) defined mountain sheep behavior in the context of adaptation to environment thirty years ago (Geist 1971). A comparable comprehensive work on moose and caribou behavior does not exist. Hence, we cannot compare the social biology of the *bovidae* with *cervidae* in detail. However, this does not mean moose and caribou social structures are the same as those of sheep or that altering social structures should be expect to produce the same results (or lack thereof) in all three species.

As one of us (WEH) has argued in detail moose are cervids adapted to successional habitats; and have a completely different reproductive strategy (including nutrition-driven multiple births) than climax-adapted sheep. Caribou are cervids adapted to climax habitats, while sheep are bovids adapted to climax habitats. Even though both caribou and sheep are climax-adapted species, caribou are largely migratory, and sheep aren't (Heimer 1999). Hence, attempting to discredit our adaptation-based assertion, that sheep social biology is specific to sheep, lacks credence and supporting data at the most basic level (recent texts cited by the critique notwithstanding). The critique's dismissal of our position citing a generalized one-paragraph summary (pp 48-49) in Toweill and Geist (1999) rather than the more rigorous paper (Heimer 1999), with which the critique's author was intimately familiar, also suggests selective exclusion or inadequate consideration of this concept.

The critique's attempt to further credential the assumption that sheep do not manifest unique adaptations to their environment, by citing Murphy et al. 1990, occurs in this same paragraph (lines 13-20), where the critique says:

> Furthermore, researchers studying other populations of sheep were unable to corroborate a relationship between abundance of older males and the survival of young males (Murphy et al. 1990), and increases in production of young, similar to those at Dry Creek after harvest was restricted,…

Invoking Murphy et al. (1990) to support the notion that sheep do not have unique behavioral systems is specious. Murphy et al.'s aerial survey methodology simply did not have the resolving power to address the question he and his coauthors presumed to address. Those data were, as Murphy put it using language stolen shamelessly from (WEH's) review of his manuscript, "snapshots in time." Not only were Murphy et al.'s data 'but snapshots' they were snapshots of differing populations in differing mountain ranges during differing years where unknown pre-existing conditions (with the possible exception of harvest by humans), had certainly affected ram age structures on the days the snapshots were taken.

Citation of Murphy et al. as credible with respect to population parameters highlights a historical bias on the part of the critique. In Murphy and Whitten (1976), use of Adolph Murie's ram skull collection data (Murie 1944) was taken to task for not demonstrating stable population structures. Curiously, that standard was not a concern for Murphy et al. (1990). Nevertheless, this citation of Murphy et al. (1990), and the critique's emphasis on aerial survey data leads to identification of the critique's second assumption.

Assumption #2: Aerial survey data have sufficient resolving power to disqualify other data sets

Much of the critique hangs on the critical author's notice that the 1974 aerial survey by WEH and TCS (Heimer 1975) reported higher percentages of legal rams than those reported in Heimer 1973. We (WEH and TCS) have no quarrel with this 'discovery.' However, we assert the critique formulates two incorrect assumptions based on this 'discovery.' The first is the critique's assumption that the increase from 3.3 percent to 8 percent legal rams was biologically significant. It wasn't. Even after this transient increase, the percentage of three-quarter curl rams remained at half the percentage of full-curl rams in the moderately harvested Tok Management Area. We shall discuss this situation in detail later where the critique retrieves this unstated assumption as fact in criticizing our pooling of ovarian data for analysis. The critique's second failure associated with the 'discovery' of aerial survey data was blurring of chronological events associated with the transient increase in young-but-legal rams reflected in the 1974 survey. The history of the reported increases in legal, three-quarter curl and greater, rams is as follows (if this doesn't interest you, skip to "Criticism of ovarian function analysis):

Heimer (1973) reported the percentage of legal, three-quarter curl rams, calculated from around-the-clock mineral lick observations extending from mid-May through June of 1972, was 3.3 percent. Then, Alaska's 42-day ram harvest season allowed for harvest of any three-quarter curl or larger ram from August 10 through September 20. Following the ram harvest, one of us (TCS) flew a ram composition survey (as prescribed by the survey/sampling regimen of the day (Nichols 1970)), and reported 2% legal rams in December. This sample contained 256 of the 1473-sheep (17%) estimated in the population immediately after lambing in June. Ram abundance should have been lower following hunting season. It was. Also, rams should have been dispersed among ewe populations for rut thus limiting possible errors in adequately sampling ram home ranges.

As for the increase to 8 percent legal rams, the critique correctly reports that a summer 1974 survey (WEH and TCS) indicated 7.8% legal, three-quarter curl or greater rams. Much of the critique turns on the difference between this legal ram percentage and that from the 1972 estimates, and the critique's assumption that it was biologically significant. On page 485, column 2, lines 15-23, the critique states:

> Researchers claimed legal males (three-quarter curl) had declined to about 3% of the population by the *mid-1970s* (Heimer 1973), but aerial surveys of the larger study area showed a very different pattern. There were at least 8% legal males in the *1975* survey, *when males were supposedly at their lowest level.* (*emphasis added*)

We suggest the estimate of 2-3% legal rams in 1972, (the year the data reported in Heimer (1973) were gathered) was credible. After all, it was produced using two differing techniques, which were in substantial, consistent agreement. We think these credible estimates indicated legal, three-quarter curl rams were scarce, and fully mature rams were virtually absent. Similarly, we have no trouble understanding that the 1974 survey (reported in Heimer, 1975) contained 7.8% legal rams. Indeed, a November "ram count" that same year (reported in Heimer (1975) but not mentioned in the critique) indicated almost 10% legal rams in a small (86-sheep) sample. We agree the data indicated the percentage of legal rams had increased. If one assumes these data were accurate, the increase was 2.4-fold. While striking, this percentage increase resulted in population compositions remaining indicative of a severely suppressed ram abundance skewed toward young males. The question is: Was the increase biologically significant? We don't think so (see ovarian function analysis).

Furthermore, this increase was expected based on recruitment data gathered at the mineral lick. Reference to Heimer and Watson (1990), cited by the critique, indicates the yearling recruitments in from 1969-1971 averaged 38 yearlings per 100 ewes, the highest three-year average yearling recruitment in Dry Creek history. These large yearling cohorts were recruited from lamb productions averaging 61 lambs per 100 ewes. No data on ram abundance or age structure are available from these years of spectacular lamb productions, but ram harvests from 1968-1972 averaged 121 rams/year in the area encompassing the study area. This was the highest of any five-year period prior to the full-curl period (critique Table 6.). Obviously, rams were relatively abundant for hunters to kill and report them in the harvests from 1968-1972. The coincidence of this relatively great ram abundance with high lamb productivity is consistent with predictions from our hypothesis that high ram abundance (attended by the presence of more adult rams) facilitates higher lamb productions. This finding illustrates the importance of "internal" population dynamics in interpreting aerial survey data (Heimer 1994).

Excluding the three outstanding years of yearling recruitment from 1968-1972, yearling recruitment between1968 and 1978 averaged only 18 yearlings per 100 ewes. If the three years of high yearling recruitments actually represented what was happening in the population, it is reasonable to think the percentage of legal (but young) rams showed a transient increase between the surveys of 1972 and 1974, and that the percentage of legal, three-quarter curl rams declined in the following years because yearling recruitments which would have driven increased legal ram numbers returned to the low average levels while harvests continued to average about 100 rams per year. Taking aerial survey data as valid unto themselves is risky business. The critique's author seemed to agree when he wrote:

> However, accuracy and precision of past sheep population estimates are unknown, and most long-term data sets show fluctuations in numbers and/or composition which are inconsistent with reasonable mortality and recruitment. These aberrations cast doubt on our ability to detect short-term population changes using existing survey techniques. (Whitten 1997, page 2 paragraph 3).

We could not agree more when aerial survey data reflecting "external" population dynamics are interpreted without the presence of supporting "internal" data estimating yearling recruitment and overall ewe mortality (Heimer 1994). Consequently, we wonder at the critique's emphatic use of aerial survey data to discredit our gathering, handling, and interpretation of independent data sets focusing on body composition, nutritive quality of rumen contents, social behavior, female reproductive success, and harvest statistics.

In attempting to 'debunk' our hypothesis that statistically significant changes in most of the above-mentioned data sets coincided with what we inferred were biologically significant changes in ram abundance, we notice the critique blurs the timelines involved, the second mistake associated with 'discovery' of variable ram percentages in aerial survey data. The critique then attributes these asynchronous timelines relating to aerial surveys to us.

We object. We can't understand why the critique would represent 1972 (or even 1974) as "the mid-1970s" when citing Heimer (1973). After all, the 1973 paper reported data gathered a year earlier, in 1972, which certainly wasn't the "mid-

1970s. Also, we can't find any reference linking the conclusion, imputed to us, "*when males were supposedly at their lowest level*" [in the "mid-1970s"] in the material the critique cites.

The most likely source we can offer to explain this statement is a typographical error in an unedited draft manuscript we (WEH and SW-K) provided to the critique's author as a courtesy circa 1992. That erroneous statement attributed to us (as though it represented our position during the 1970s and 1980s review period chosen by the critique) *was present in that unedited (and unpublished) draft* manuscript. Because of the nature of that draft manuscript, we would rather not receive credit for asserting that rams were at their lowest level in the mid 1970s.

Misinterpreting sequence or chronology would be a less important error if the critique did not similarly blur the chronological relationships between aerially observed ram abundance with respect to ovarian collections. Ovarian activity is more fundamentally related to our hypothesis than ram abundance.

<u>Criticism of the ovarian function analysis:</u> Amplifying these misunderstandings, the critique reaches its rational nadir when it uses aerial survey data to discredit our inference that presence of mature rams in Dall sheep populations facilitates ovarian activity. Here, the critique's approach appears twofold. First, it denies that ram abundance was ever low enough to affect lamb production (and by implication ovarian activity). Second, it alleges that the transient increased percentage of three-quarter curl rams in the Dry Creek aerial survey data invalidated the comparisons of ovarian activity between Dry Creek and the Tok Management Area.

After we had utterly failed to find even the faintest suggestion of nutritional advantage for the strikingly better ovarian performance by ewes in the Tok Management Area compared with Dry Creek in the late 1970s, and after we had noted huge disparities in ram abundance between Dry Creek and the Tok Management Area, we (WEH and SW-K) stated:

> Low ram abundance, which usually includes low Class III [three-quarter] and IV ram [full-curl] abundance, may be the most likely cause of lowered ovarian activity. When ovarian activity was low in Dry Creek (1972-1979), the total ram:100 ewe ratio was 17, and the Class III and IV ram:100 [ewes] ratio was 8. In contrast, when ovarian activity was determined for the Robertson River [Tok Management Area] population, there were 40 total rams:100 ewes and 15 *Class IV* rams:100 ewes. (Heimer and Watson (1986) page 37, paragraph 4, lines 1-8 *emphasis added*)

With overall ram abundance during the ovarian sample period being 2.4 times greater in the Tok Management Area, and the Class IV (i.e. full-curl) ram ratio being almost twice as great in the Tok Management Area as was the three-quarter curl ratio in Dry Creek, we think the critique's argument against valid ovarian sample comparisons vanishes. Our records indicate (almost two decades after the fact) that approximately half of the ovaries sampled from Dry Creek were collected between 1972 and 1975. The rest (slightly more than half of the Dry Creek ovaries) were collected from 1976-1979. If, as the critique argues, pooling these ovarian samples was bad science because there was a transient increase in ram abundance in Dry Creek during the "mid-1970s," the pooled sample should have shown greater statistical variance than it did. Consequently, statistical significance would have been correspondingly more difficult to demonstrate in our relatively small samples (n=19 from Dry Creek and n=13 from the Tok Management area). Nevertheless, the differences were statistically significant ($P<0.05$). Mean ovulation rates in Dry Creek were lower than in the Tok Management Area even though the composition of whole body homogenates and quality of washed rumen contents showed no hint of nutritional difference (Heimer 1983).

Based on the statistical significance of this sample (which the critique, page 492 column 1 paragraph 2, says was compromised), we hypothesized that lowering the overall rams:100 ewes ratio from 40 to 17 was biologically significant. Perhaps even more significant was the decrease from 15% full-curl rams to 8% three-quarter curl rams. There is no rational basis to argue ovulation rates in Dry Creek were not at least coincidentally linked, statistically, to lowered ram abundance.

Nevertheless, the exact percentage of ram population reductions doesn't really matter. Our hypothesis has acknowledged from the beginning that these data were neither necessarily accurate nor precise. However, the changes they reflected were apparently of high biological significance because the adverse affects statistically associated with low ram abundance and the absence of mature rams were reversed when ram abundance increased while ewe population densities remained unchanged (Heimer and Watson 1990). This experiment went significantly beyond inferring cause from a single statistical correlation.

We (WEH and SW-K) have consistently acknowledged (Heimer and Watson 1986 and forward) that we did not have the opportunity to check actual ovarian activity after changes in ram abundance in Dry Creek. We inferred an increase in ovulation among Dry Creek ewes because statistically significant differences in lambs:100 ewes ratios between the two study populations, when rams were scarce in Dry Creek, vanished once ram abundance was reestablished in Dry Creek through changes in ram harvest regulations.

The critique's attempt to discredit the subsequently observed 6.6-fold increase in observed consecutive-year reproductive success following reestablishment of ram abundance and an older age structure in Dry Creek must be discussed in this context. On page 491, column 2, paragraph 1, the critique says:

> The authors…reported the mean young to female ratio for…a good weather period…was higher than the mean for…bad weather. Nevertheless, they argued that factors other than weather also must have affected productivity, because frequency of consecutive-year reproduction increased >6-fold between those periods while young to female ratio only doubled. Heimer and Watson (1986) thought that weather accounted for the change in young to female ratios, but increased abundance of mature males must have cause the larger rise in consecutive-year reproduction.

This analysis represents a misreading of Heimer and Watson (1986). In the 1986 report, we (WEH and SW-K) were dealing with acknowledged, implicit weaknesses in establishing consecutive-year reproductive success. In discussing those weaknesses we identified the sequence of events from ovulation to observation of a pair-bond, which were necessary for us to make a positive consecutive-year finding for any given ewe. The unknowns included weather effects on lamb survival at birth. In this discussion we wrote:

> Hence, the question of the magnitude of weather influence on our ability to accurately detect changes in frequency of consecutive-year reproductive success merits discussion.
>
> We can gain some insight about the magnitude of weather influence on this reproductive parameter by considering the mean lamb:ewe ratios for the 2 differing periods in Dry Creek. During the 1972-1976 period, when consecutively observed reproductive success was 6%, the mean lamb:100 ewe ratio was 29. For the 2nd period, 1981-1984, when consecutively observed success was 40%, the mean lamb:100 ewe ratio was 54. This is an increase of 1.9 times. If our ability to document consecutive-year reproductive production were directly proportional to changes in lamb:100 ewe ratio [accounting for potentially more favorable weather influences], we should have seen a consecutive-year frequency increase of 1.9 times. The documented increase was 6.7 times. This increased frequency was 3.5 times greater than expected from the increased lamb:100 ewe ratio [alone]. Something besides weather appears to be influencing changes in frequency of consecutively observed reproductive success. Pregnancy rates in ewes collected during this period was only 36% of 11 ewes collected in springs of 1972, 1973, 1975, 1976, and 1977. We think this probably confirms the significantly (P<0.05) lower incidence of consecutive-year reproductive success during the mid-1970's was real, and suggests that it resulted from a failure to ovulate and/or breed. (Heimer and Watson 1986, page 29 paragraph 2)

The critique's subsequent mathematical machination is too esoteric for us. The observed increase in documented Dry Creek ewe consecutive-year reproductive success was at least 6.6-fold. That is, it increased from an observed 4-year mean of 6% to an observed 4-year mean of 40% (which subsequently matched the Tok Management Area rate). Over the same period, the lambs:100 ewes ratio doubled (to also coincidentally match the Tok Management Area ratios). The critique's statement, "…the 6-fold increase…could only result in the observed doubling in young to female ratio—no more or less." escapes us, unless further unstated assumptions about the role of weather are invoked.

In the end, we hypothesized the management-desirable results, increased lamb production and subsequent increased legal ram harvests, were caused by a combination of increased lamb production and survival of rams to harvestable age (Heimer and Watson 1990). The critique contests this latter suggestion because it alleges there were problems with a ram survivorship model we dallied with in 1984.

The Ram Survivorship Issue

We (WEH, SW-K, and TCS) engaged in a ram survivorship modeling exercise in 1984. Criticism of this exercise occupies approximately 50% of the 12-page critique. The critique did not review our earlier paper (Heimer et al. 1984), but focused on a summary treatment presented in Heimer and Watson (1986). The caveats the critique retrieves were, for the most part clearly identified in our 1984 paper where we said, in summary:

We have suggested a major departure from established sheep harvest management. We believe the data are sufficiently compelling that experiments with changes in harvest regime are in order. Still, we realize that much of what we have offered may be equivocal. Most criticism should be directed at our use of presumptive death when we could no longer locate marked rams. Cessation of re-sightings does not necessarily demonstrate a given ram is dead. (p 431 paragraph 2).

In short, what we (WEH, SW-K, and TCS) did was simply to model the survivorship of collared rams, following Deevey's (1947) methods as exactly as possible to produce a comparable survivorship curve. We treated Murie's data (Murie 1944) exactly the same way we treated ours. As a consequence, we violated (in some cases purposefully) the theoretical conventions emphasized in the critique. Some of these conventions were listed earlier by Murphy and Whitten (1976) in their criticism of Deevey. The critique's litany of our "mistakes" stems, not from scholarly research which unearthed our efforts to conceal them; but from our careful documentation of methods used in the modeling exercise.

Setting aside the theoretical conventions was necessary for two reasons. First, if everyone eschews analysis until all theoretical conventions can be satisfied, nobody will ever do anything. Second, we did it to make our work comparable with Deevey's classic treatment of Murie's data. We reproduced Deevey's curve with the techniques we used for both data sets. Using the unedited data, the Dry Creek curve suggested increased mortality among young rams, but the curve did not break sharply as does Deevey's curve. As an experiment in "cleaning up the signal" we edited the data as reported, and produced the curve we published. These methodologically-comparable curves (ours and Deevey's) were identical up to 3.5 years of age. At that point, the curves diverged radically, with the increased mortality phases starting earlier (by almost five years) in the heavily harvested population. Strikingly, the increased mortality portions of the curves had virtually identical slopes, a difference of only one percent in ram deaths per year.

This coincidence in rate between the increased mortality phases of both curves seemed biologically important to us because it was consistent with predictions from behavioral observations and energetic theory. Had these curves not supported these rational connections, we would never have reported them. However, we were comfortable with the hypothesis (drawn in large measure from Geist's (1971) behavioral work) that younger rams assume dominance roles in the absence of older rams for two reasons. First, lambs continued to be born in the virtual absence of mature rams in Dry Creek just as reported by Nichols (1978) from the Kenai Peninsula. However, lamb productions in the Alaska Range were statistically significantly lower when older rams were not present present. Second, work by Hogg (1984) and Jenni et al. (pers commun. 1986), demonstrated rutting behaviors change with altered ram age structures in bighorn sheep.

We found this exciting because the virtually identical slopes in both curves seemed likely, as mentioned above, to represent the mortality cost of ram dominance. After all, 8-year and older rams in un-hunted Dall sheep populations, as well as in other species of sheep (Bradley and Baker 1967) don't die because their teeth are gone or their bones are brittle. They are not "old," yet they die at almost six times the rate after age 8. Why? Probably because the metabolic costs of dominance "age them before their time." The energetic theory and behavioral observations were consistent with what our model produced. We (WEH, SW-K, TCS) covered these arguments in 1984 and 1986 (WEH, SW-K).

Consequently, we (WEH and SW-K) formulated (as quoted above) the hypothesis that absence of dominant Dall rams results in dominant behaviors by young Dall rams (and their paying the associated mortality costs, which are by logical extension, energy-mediated). We proposed further research, aside from our admittedly inferential methods, to test this hypothesis; but these suggestions were not well received. Instead, Alaska Department of Fish and Game leadership sought to set aside the collective work of the wild sheep research community. Apparently, with the critique bearing the ADF&G imprimatur, that quest continues to the present day. Throughout the critique, the author flirts with the agency-generated myth that Alaska's full-curl regulation is not biologically-based. This takes us to the critique's section on the relevance of Alaska's full-curl regulation to modern management.

Relevance Of The Critique To Modern Management In Alaska

On page 484 column 2 paragraph 2 the critique states:

> Although many biologists disagreed with the Dry Creek hypothesis, those ideas held immense appeal for traditional sport hunters because of their implication that trophy hunting was the optimal harvest strategy for sheep. The Alaska Board of Game incrementally enacted more conservative horn curl regulations and by 1993, full-curl hunting for males only was normal for most of Alaska. The Board still receives proposals from the public for more rigorous enforcement of full-curl only management whenever sheep populations are faring poorly. Disagreement and confusion continues among professional biologists….

The critique goes on to say (Page 492, column 2 paragraph 2, lines 1-13) [*Our responses bracketed in italics*]:

> Numerous papers…attempted to explain how abundance of large males moderated Dall's sheep social behavior and ecology and was the key to population vitality. Findings on which those hypotheses were based, however, were unsubstantiated. Harvest never removed all mature males. [Response: *We never alleged it did, only that male age structures were skewed to the point of biological significance.*] Depressed survival of young males in the Dry Creek population never occurred. [Response: *We consistently stressed the inferential nature of our conclusions from population composition data and reported harvests.*] Reduced productivity could not be linked to male abundance, but was correlated with weather. [Response: *While weather could be inferentially tied to production, the statistically significant changes in ovulation rate and observed consecutive-year reproductive success were tightly linked with ram abundance, and not just statistically. After demonstrating these statistically significant linkages, management-level experiments confirmed predictions based on the statistical correlations. Additionally, unpublished multiple regression analysis available to the critique's author gave correlation*

coefficients of –0.295 for winter severity, 0.408 for favorable lambing weather, 0.519 for projected weather effects on breeding condition, and 0.655 for ram abundance over the 16-year period in Dry Creek. Hence, more variation in lamb production was associated with changes in ram abundance, crude as the estimates were, than with physical environmental factors.] Nevertheless, regulations allowing harvest of only full-curl males now apply in nearly all general hunts for Dall's sheep in Alaska. In retrospect, restrictive horn-curl regulations were not necessary for conservation of this mountain ungulate. [*Here the critique presumes to know what would have happened if no changes in harvest management had occurred. This is, of course pure speculation.]*

Significantly, the critique's position inferred from the above-quoted paragraphs reifies ADF&G's mythic position that the Alaska Board of Game established Alaska's full-curl ram regulation as a concession to "traditional sport hunters" rather than out of respect for the specific biological adaptations of Dall sheep. This myth has its roots in the Department's rationalization of its bitter failure to defeat Alaska's publicly-proposed full curl regulation. Here's that story:

Traditionally, the Department biologist most conversant with the data on any proposal before the Alaska Board of Game presents those data to the Board. According to traditional practice, one of us (WEH) would have presented the Department's data on the effects and implications of Dall ram harvesting to the Board. This tradition was set aside when the Board considered Alaska's full-curl regulation. Department leadership was stridently opposed to the proposed regulation and acted specifically to keep WEH from presenting the relevant data. The Wildlife Division Director of the day, Lew Pamplin, ordered WEH's supervisors to make certain "Heimer doesn't get within 200 miles of the Board meeting." (D. Harkness, ADF&G Anchorage Area Biologist pers commun.). Heimer didn't participate, but two of us (SCK and VG) did.

With the Department openly and strongly opposed to the full-curl proposal, and being committed to withholding Department-reviewed and approved data from the Board, the laymen responsible for the full-curl proposal presented the Department's data to the Board themselves. After the laymen's presentation, ADF&G leadership argued the data and analyses were not valid. To counter this assertion, the laymen arranged for VG, the recognized world authority on wild sheep, to testify concerning the validity of WEH and SW-K's work. Based on his lengthy study of the Department's (WEH, SW-K, and TCS's) published work, VG testified that the Department's data were validly gathered and correctly interpreted. Subsequently, SCK, the other of our review group present (who was serving on the Board at the time), supported the official "Board Finding" (a legally-required decision of record), that Dall sheep biology demanded management of ram harvests at the full-curl minimum to produce the maximum sustained yield required by Alaska law. Hence, the record demonstrates the basis of Alaska's full-curl regulation was biological, even though some Department-ordained biologists (including the author of the critique) disagreed. The fact that the Department chose not to participate in presenting its review-approved data does not change the legal finding of the Board. Neither can this critique's shallow reinterpretation of the existing-but-hoary data, its damning misrepresentations of our position, or its invocation of the skepticism of “many biologists” effect that change.

DISCUSSION

In its discussion of the benefits of Alaska’s full-curl regulation, the critique states, that although not necessary for conservation, Alaska’s full-curl rules have “served a useful purpose.” The critique states that this useful purpose has been administrative simplicity and reduction in the need for biological research and monitoring resulting from, “a hands-off, self-regulating, popular, and inexpensive regime of harvest.” (page 492 bottom of column 2). The critique closes:

> Management challenges are beginning to change…Full-curl regulations cannot ensure hunter satisfaction…full-curl regulations alone cannot ensure trophy quality…at minimum full-curl size or age. These are problems that hunters now petition the Board of Game to solve through stricter full curl management; [*Here the critique retrieves an earlier statement from page 484 column 2 paragraph 2 that “The Board still receives proposals…for more rigorous enforcement of full-curl…*]…(page 494 column 1 paragraph 1)

We acknowledge the first two of these summary statements are correct, but argue the negative consequences the critique subsequently predicts can only be secondary results of the way the Alaska Department of Fish and Game manages the full-curl regulation. Most of the regulatory enforcement concerns and predicted eventual hunter dissatisfaction are predictable results of ADF&G’s continued reluctance to accept the biological basis of the full-curl regulation, even as a working hypothesis. We suggest the critique is evidence this reluctance has its roots in the dogma that “principles of ungulate management” offer a higher probability of management success than the respect for the autecology of a particular species. For example, if the agency’s position is that distorting Dall sheep ram age structure is no different than distorting a moose population’s age structure, because both have “complex social structures,” the full-curl regulation devolves from a biologically based regulation to increase human benefits to an administrative convenience for the agency.

There is little adaptive benefit (beyond avoiding prosecution) for an Alaskan hunter to comply with or philosophically embrace a regulation established for the administrative convenience of the managing agency. Conversely, there is every reason for hunters to embrace, comply with, and build a societal peer pressure to embrace biologically based regulations. It is, after all, in the individual hunter’s best interest to identify with biologically based regulations because they are designed and implemented to increase user benefits.

Still, the nature of management in natural ecosystems makes it virtually impossible to assure that any regulation will inevitably produce desirable results because its underlying biology is perfectly known and predictable. Consequently, enforcement of regulations through police powers has been a consistent fixture of North American wildlife conservation. However, coercive conservation has never been the long-term basis of successful wildlife conservation.

The success of North American wildlife conservation has more probably resulted from voluntary compliance with biologically based regulations, which hold the promise of continued or more successful participation by the necessary user/supporter/benefactors. Traditionally, these benefactors have a rational, tradition-based expectation that regulations be biologically based. The support of "traditional sport hunters" for any biologically based harvest regulation (whether it suits them in the short run or not) is predictable, and should not be understood to compromise the biological validity of the full-curl regulation. Similarly, the fact that these "traditional sport hunters" had to take the Department's then-certified data to the Board of Game in the face of Departmental opposition should not implicitly argue against the regulation's biological relevance.

We have never asked the managing agency to endorse the full-curl model as proven truth. Instead, we have championed the notion that it should be included as part of a comprehensive working management hypothesis (Heimer 1999a). We have argued that the hunting and conservation-minded public should be partners in the management enterprise, and that this requires constant testing of our management hypothesis and refinement as appropriate. Unfortunately, many management agencies (including the Alaska Department of Fish and Game in this case) have come to view hunters more as regulated predators than management partners. Arbitrary, administratively convenient regulations reflect this distressing trend. We find it particularly tragic, and indeed risky, when a managing agency elects to justify decisions using self-serving administrative rationale when it could take the higher road in partnering with hunter/conservationists in pursuit of functional biological truths upon which to manage.

Before the Alaska Department of Fish and Game took this road with the full-curl regulation, it had chosen it in moose management with "spike-fork or 50-inch" bull moose regulations. The work of Strigham and Bubenik (1984) on red deer and chamois, plus the work of Child (1983) and Child and Aitken (1989) established an acceptable biological rational for limiting harvest to mature bull moose. Unfortunately, rather than defining the restriction of moose harvests to mature bulls as part of a biologically based working hypothesis for moose management, ADF&G synthesized a finely tuned rationale (Schwartz et al. 1992), which lay in administrative management convenience and efficiency. The critique's presentation of Alaska's full-curl harvest regulation is homologous to ADF&G's "50-inch" moose regulations.

We consider this high-risk, elitist management that respects neither the biological adaptations of the managed prey species nor the human harvesters involved. Our collective approach to Dall sheep management in Alaska has been based on recognition of and respect for both. Additionally, we have tried to be as honest, inclusive, and scientifically rigorous as circumstances (primarily limited by budgets and logistics) allowed. We are saddened that this rebuttal was required, but realize science is a human enterprise where objectivity is difficult. We also realize our interdisciplinary synoptic approach has been unorthodox. Nevertheless, we think we have chosen a practical, biologically based route to providing increased human benefits from Alaska's Dall sheep populations. If we have been mistaken, and if we keep in mind that we are all involved in testing a hypothesis, we should end up better off in the future than in the past. Consequently, we will argue for continuing the experiment in progress and against throwing it out because of narrowly focused critiques such as the one we reviewed here. Thank you for your patience

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Northern Wild Sheep and Goat Council Symposia

Date	Symposium	Location	Symposium Coordinator/Chair	Proceedings Editor(s)	NWSGC Executive Director
May 26-28, 1970	NWSC 1	Williams Lake, BC	Harold Mitchell		
Apr. 14-15, 1971	NAWSC 1	Ft. Collins, CO	Eugene Decker/ Wayne Sandfort	Eugene Decker	
Apr. 11-13, 1972	NWSC 2	Hinton, AB	E. G. Scheffler		
Apr. 23-25, 1974	NWSC 3	Great Falls, MT	Kerry Constan/ James Mitchell		
Feb. 10-12, 1976	NWSC 4	Jackson, WY	E. Tom Thorne		
Apr. 2-4, 1978	NWSGC 1	Penticton, BC	Daryll Hebert/ M. Nation	Daryll Hebert/ M. Nation	
Apr. 23-25, 1980	NWSGC 2	Salmon, ID	Bill Hickey		
Mar. 17-19, 1982	NWSGC 3	Ft. Collins, CO	Gene Schoonveld	James A. Bailey/Gene Schoonveld	
Apr. 30-May 3, 1984	NWSGC 4	Whitehorse, YK	Manfred Hoefs	Manfred Hoefs	Wayne Heimer
Apr. 14-17, 1986	NWSGC 5	Missoula, MT	Jerry Brown	Gayle Joslin	Wayne Heimer
Apr. 11-15, 1988	NWSGC 6	Banff, AB	Bill Wishart	Bill Samuel	Wayne Heimer
May 14-18, 1990	NWSGC 7	Clarkston, WA	Lloyd Oldenburg	James A. 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
Apr. 16-20, 1998	NWSGC 11	Whitefish, MT	John McCarthy	John McCarthy/ Richard Harris/ Fay Moore (Compilers)	Kevin Hurley
May 31-Jun 4, 2000	NWSGC 12	Whitehorse, YK	Jean Carey	Jean Carey	Kevin Hurley
Apr. 23-27, 2002	NWSGC 13	Rapid City, SD	Ted Benzon	Gary Brundige	Kevin Hurley