Northern Wild Sheep and Goat Council

PROCEEDINGS OF THE 18TH BIENNIAL SYMPOSIUM

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Symposium Chairs: Mari Wood and Steve Gordon

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Editors: Steve Wilson, Steve Gordon, Mari Wood

Committee members: Kevin Hurley, Doug Jury, Gerry Kuzyk, Sue Lemke, Chris Proctor, Helen Schwantje

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Northern Wild Sheep and Goat Council

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NORTHERN WILD SHEEP AND GOAT COUNCIL SYMPOSIA

Date	Symposium	Location	Symposium Coordinator/ Chair	Proceedings Editor(s)	NWSGC Exec. Director
May 26-28, 1970	NWSC 1	Williams Lake, BC	Harold Mitchell		
April 14-15, 1971	NAWSC 1	Fort Collins, CO	Eugene Decker/Wayne Sandfort	Eugene Decker	
April 11-13, 1972	NWSC 2	Hinton, AB	E.G. Scheffler		
April 23-25, 1974	NWSC 3	Great Falls, MT	Kerry Constan/James Mitchell		
Feb. 10-12, 1976	NWSC 4	Jackson, WY	E. Tom Thorne		
April 2-4, 1978	NWSGC 1	Penticton, BC	Daryll Hebert/M. Nation	Daryll Hebert/M. Nation	
April 23-25, 1980	NWSGC 2	Salmon, ID	Bill Hickey		
March 17-19, 1982	NWSGC 3	Fort Collins, CO	Gene Schoonveld	James Bailey/Gene Schooneveld	
Apr. 30-May 3, 1984	NWSGC 4	Whitehorse, YK	Manfred Hoefs	Manfred Hoefs	Wayne Heimer
April 14-17, 1986	NWSGC 5	Missoula, MT	Jerry Brown	Gayle Joslin	Wayne Heimer
April 11-15, 1988	NWSGC 6	Banff, AB	Bill Wishart	Bill Samuel	Wayne Heimer
May 14-18, 1990	NWSGC 7	Clarkston, WA	Lloyd Oldenburg	James Bailey	Wayne Heimer
Apr. 27-May 1, 1992	NWSGC 8	Cody, WY	Kevin Hurley	John Emmerich/Bill Hepworth	Wayne Heimer
May 2-6, 1994	NWSGC 9	Cranbrook, BC	Anna Fontana	Margo Pybus/Bill Wishart	Kevin Hurley
Apr. 30-May 3, 1996	NWSGC 10	Silverthorne, CO	Dale Reed	Kevin Hurley/Dale Reed/Nancy Wild (compilers)	Kevin Hurley
April 16-20, 1998	NWSGC 11	Whitefish, MT	John McCarthy	John McCarthy/ Richard Harris/Fay Moore (compilers)	Kevin Hurley
May 31-June 4, 2000	NWSGC 12	Whitehorse, YK	Jean Carey	Jean Carey	Kevin Hurley
April 23-27, 2002	NWSGC 13	Rapid City, SD	Ted Benzon	Gary Brundige	Kevin Hurley
May 15-22, 2004	NWSGC 14	Coastal Alaska	Wayne Heimer	Wayne Heimer / Dale Toweill/Kevin Hurley	Kevin Hurley
April 2-6, 2006	NWSGC 15	Kananaskis, AB	Jon Jorgenson	Margo Pybus/Bill Wishart	Kevin Hurley
April 27-May 1, 2008	NWSGC 16	Midway, UT	Anis Aoude	Tom Smith	Kevin Hurley
June 7-11, 2010	NWSGC 17	Hood River, OR	Craig Foster	Vern Bleich	Kevin Hurley
March 12–15, 2012	NWSGC 18	Kamloops, BC	Steve Gordon/Mari Wood	Steve Wilson/Mari Wood/Steve Gordon; Vanessa Craig (compiler)	Kevin Hurley

Northern Wild Sheep and Goat Council

GUIDELINES OF THE NORTHERN WILD SHEEP AND GOAT COUNCIL

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

This purpose will be achieved by:

1) Providing for timely exchange of research and management information;

2) Promoting high standards in research and management; and

3) Providing professional advice on issues involving wild sheep and goat conservation and management

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

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

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

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

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

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

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

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

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

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

FOREWORD

The papers/abstracts included in these proceedings were presented during the 18th Biennial Symposium of the Northern Wild Sheep and Goat Council, held March 12-15, 2012 at the Kamloops Convention Centre in Kamloops, British Columbia.

A heart-felt thanks is extended to the sponsors of, and participants in, the 18th Biennial NWSGC Symposium. In addition, Steve Gordon and Mari Wood (Symposium Co-Chairs), and Steve Wilson (Program Chair) were instrumental in leading the dedicated British Columbia organizing committee and delivering a first-class symposium. Proceedings were edited/assembled by Mari Wood and Vanessa Craig.

All manuscripts were peer-edited by Steve Wilson, Mari Wood, Steve Gordon, and numerous volunteer NWSGC members, prior to publication. Suggested editorial comments were provided to each senior author; senior authors had opportunity(ies) to accept or reject suggested edits, prior to submission of their final manuscripts. Formatted page proofs were forwarded to respective senior authors prior to inclusion into the final proceedings. Final content, particularly verification of literature citations, is the responsibility of the authors.

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

Kevin Hurley
NWSGC Executive Director
July 25, 2013

Photo: Roma Allen

We were pleased to honour three folks with awards presented at the BBQ associated with the conference, including (left to right) Mari Wood, Bill Wishart, and Kevin Hurley. All 3 biologists have worked extensively on wild sheep and goat conservation and management during their careers, and have been involved with the Northern Wild Sheep and Goat Council (NWSGC) for many years. Mari, a BC-based biologist, was honoured for her exceptional service to the NWSGC and wildlife management in BC. Bill, an Alberta wildlife biologist, was presented with a lifetime achievement award. Kevin was honoured for his 20 years of service as the NWSGC Executive Director; he has been an active member of the NWSGC since 1982 and has volunteered since 1992 as their Executive Director.

Congratulations! And thanks to all of you for your service.

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TOWARDS AN UNDERSTANDING OF THE GENETIC BASIS OF DIFFERENCES IN HORN SIZE IN BIGHORN SHEEP

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Abstract: Large horns are a defining feature of bighorn sheep (*Ovis canadensis*). Horn size affects many aspects of bighorn sheep ecology and life-history, and is the basis for many regulatory and management decisions. Yet, we know little about the genetic mechanism underlying this trait. Using a suite of 241 genetic markers genotyped in 310 pedigreed animals from the population on Ram Mountain (Alberta, Canada), we identified a specific region of DNA associated with differences in horn dimensions. Based on this result, and similar findings in feral Soay sheep (*Ovis aries*), we are now employing a candidate gene association approach to develop additional markers and fine-map the association to specific genes. Once found, the prevalence of genetic variants associated with large horns can be assessed in the current Ram Mountain population, and changes in allele frequency tracked through time. This suite of markers could also easily be applied to other populations of bighorn sheep to rapidly assess the genetic potential of the sheep in that population to grow large horns, a statistic known as genetic merit. In many populations it is impractical to directly measure horn size of every sheep. Instead, the genetic merit of horn size can b eassessed and monitored based on population level genetic diversity. Cross population comparisons would further shed light on the genetic basis of horn morphology, and help define an evolutionary stable management strategy.

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GENETIC ANALYSES OF THE NORTH AMERICAN MOUNTAIN GOAT (*OREAMNOS AMERICANUS*)

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Abstract: For this talk we will review recent molecular studies regarding the evolutionary ecology of mountain goats (*Oreamnos americanus*). We will briefly review the evolutionary history, immunogenetic diversity, and population / landscape genetic structure of the mountain goat across its native range. We will discuss the observed temporal dynamics in genetic variability at Caw Ridge (CR) and the ongoing gene-trait association studies involving CR and southeast Alaska. Specific emphasis will be placed on the potential conservation and management considerations that stem from this work.

Key words: *Oreamnos americanus*, Alberta, Alaska, genetic variability.

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REGIONAL AND CLIMATIC INFLUENCES ON GROWTH OF MOUNTAIN GOAT HORNS IN SOUTHWESTERN MONTANA

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Abstract: Because free-ranging mountain goats (*Oreamnos americanus*) are difficult to study, efforts to increase our understanding of population status and responses to environmental stressors from hunter-harvested horns may be valuable despite ad hoc sampling and limited data. As in other ungulates, the investment young mountain goats make in horn growth generally responds to body condition. We used data routinely collected by the Montana Department of Fish, Wildlife and Parks on harvested mountain goats in the southwestern Montana region during 1981–1998 to examine patterns in horn growth as affected by location, time period, and climatic variables. Our sample was limited to goats in which yearly growth increments (up to the fourth summer of life) were recorded; we quantified horn growth by approximate volume. We used site-specific temperature and precipitation data obtained from Parameter-elevation Regressions on Independent Slopes Model (PRISM), and site-specific Normalized Difference Vegetation Index (NDVI) data from Advanced Very High Resolution Radiometer satellites in an exploratory investigation of trends with yearly meteorological conditions. Age-specific horn growth varied among mountain ranges within the region, and was greater among introduced than native populations. Overall trophy size and age-at-harvest showed few trends with time. In one population in which both indices declined significantly (Crazy Mountains), age-specific horn growth did not change while aerial population trend counts and kid:nanny ratios increased dramatically, suggesting that hunters sampled unselectively from an increasingly larger and younger population. In contrast to previous work, we found little evidence for compensatory horn growth within the first 3 growth increments; our use of volume rather than length may explain this difference. Yearly patterns in precipitation and temperature explained little of the variation in annual horn growth; however, we found weak indications that horn growth was positively correlated with mean NDVI, and negatively correlated with the rate of NDVI increase in early spring, as well as with maximum September temperature. Documentation of growth increments from hunter-harvested mountain goats may aid managers in discriminating among plausible competing hypotheses related to population performance.

Many mountain goat (*Oreamnos americanus*) populations in Montana, particularly native populations, have recently been faring poorly (Carlsen and Erickson 2008, Koeth 2008). Whereas regulated harvest levels may have been excessive in earlier years through the 1980s, most jurisdictions have now reduced harvest quotas substantially; over-hunting thus seems an unlikely explanation. Remaining hypotheses for the slow response to conservative harvests seen among some mountain goat populations include increasing human disturbance in winter, and changes in vegetation resulting from climate change. In particular, mountain goats are sensitive to warmer summers, but are also dependent on the short-term flush of alpine vegetation in summer to sustain them through the long winter period (Bailey 1991, Côté and Festa-Bianchet 2001a).

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Patterns of horn growth may also be informative to managers interested in regional variation in habitat quality (Foster 1978, McDonough et al. 2006, Clarke 2010). In Montana, mountain goats exist in both native and introduced populations, and the latter populations have generally shown greater resilience to harvest (Swenson 1985). The potential for artificial selection produced by selective hunting for larger-horned bighorn sheep (*Ovis canadensis*) has generated interest (Coltman et al. 2003, Festa-Bianchet 2003, Hengeveld and Festa-Bianchet 2011, Mysterud 2011), but not been investigated specifically in mountain goats. Whether or not annual horn growth within individuals is compensatory is relevant to the potential for artificial selection: if growth is not compensatory, animals producing small horns when young will still have relatively small horns when old, whereas if animals compensate for poor horn growth in early years later on, older animals will feature greater uniformity in horn size. Thus, compensatory growth would limit the opportunity for artificial selection based on horn size (Rughetti and Festa-Bianchet 2010).

In addition to generating insights into responses to harvest, data provided by regulated hunts, and thus already on hand, may assist our understanding of how goats interact with climate by providing insight into patterns of yearly body growth associated with broad-scale measures of vegetation and weather. Mountain goat horns grow throughout their lives, with most growth occurring during the first two years and progressively less thereafter (Brandborg 1955, Côté et al. 1998). Length and circumference of goat horns vary by age and sex, but are also highly correlated with body mass and chest girth (Bunnell 1980, Côté et al. 1998), so may act as proxies for body condition generally. Importantly, Festa-Bianchet and Côté (2008) found that among yearling goats at Caw Ridge, AB, horn growth was positively associated with indices of spring forage quality, suggesting that goats responded to annual variation in habitat conditions by allocating more resources to horns in good years. Pettorelli et al. (2007) found that rapid spring green-up accompanied by rapid senescence typical of warmer summers was associated with lower mass gain among mountain goat kids. Horn growth

among young nannies at Caw Ridge was lower in years they lactated than years not tending a kid (Festa-Bianchet and Côté 2008). Among alpine ibex (*Capra ibex*), Giacometti et al. (2002) found relationships between horn growth and ambient spring temperature as well as spring plant phenology. Similarly, Hik and Carey (2000:88) found substantial annual variation in horn growth among Dall sheep (*Ovis dalli*) rams, and concluded that "annual horn growth increments appear to provide an integrated climate signal that is related to precipitation and temperature cycles which likely influence plant productivity."

We used hunter harvest registration data to examine the following hypotheses: 1) that patterns of horn growth would conform to previously reported patterns in which mountain goats in introduced populations would display more vigorous growth than in native populations (despite these introductions having been made approximately 50 to 70 years ago; Swenson 1985, McCarthy 1996, Lemke 2004); 2) as reported by Côté et al. (1998) and Festa-Bianchet and Côté (2008), that horn growth would be compensatory within the first few annuli (i.e., we would observe negative correlations between growth in successive years within individual goats); and 3) that age-at-harvest would be a negative function of early horn growth (suggesting that hunters might selectively remove animals with faster-growing horns). We also examined 4) time-series within populations with sufficient data for evidence of trends in horn size at harvest, age-at-harvest, and horn growth (standardized by sex and age).

With these variables controlled, we then explored the data for evidence of yearly effects that were explainable by reference to climate variables similar to those that have been postulated as affecting mountain goat body mass and survival (Côté and Festa-Bianchet 2001a, Pettorelli et al. 2007). We hypothesized that horn growth would be positively correlated with annual growing season precipitation; we investigated numerous hypothetical relationships between horn growth and annual growing season temperature. We further expected to observe that horn growth would be a positive function of integrated NDVI (normalized difference vegetation index) during the growing season (Pettorelli et al. 2005, Hamel et al. 2009), and, following Pettorelli et al. (2007),

negatively associated with the slope of increasing NDVI during early spring green-up.

METHODS

Study Area

We assigned goats horns to a total of 14 mountain ranges in southwestern Montana (Fig. 1) based on the hunting district (HD) in which they were harvested (Table 1). Because we had no information on possible exchange of individuals among these mountain ranges we initially treated them as geographically isolated; however, statistical tests (see below) supported combining these 14 into 5 groups of populations.

Data Collection

We collated and screened mandatory harvest report forms from successful mountain goat hunters maintained at Montana Fish, Wildlife, and Parks (MFWP) Region 3 headquarters in Bozeman, MT, selecting only those that met the following criteria: 1) growth increment lengths and circumferences were recorded consistently with MFWP instructions (i.e., outermost growth increment considered youngest, lengths and circumferences logically consistent with each other; 2) the documented age estimated from annuli was
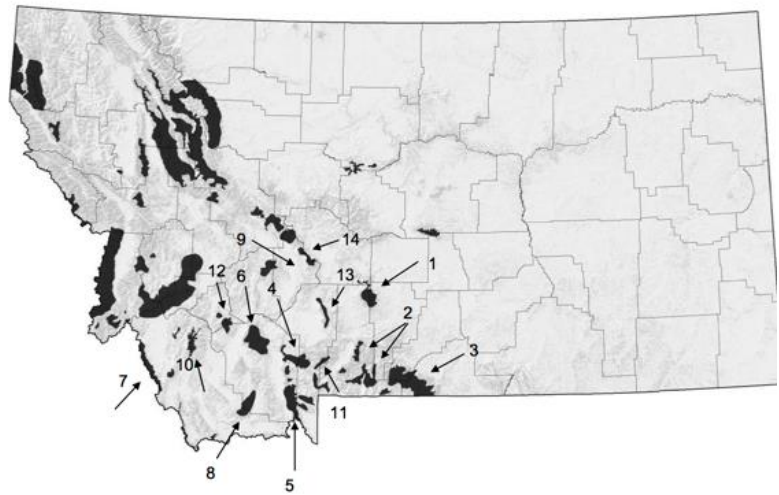
Fig. 1. Map of Montana, USA, showing approximate mountain goat ranges as of 2002 (adapted from Carlsen and Erickson 2008). Numbered arrows show ranges in southwestern Montana that provided hunter-harvested horns for this study: (1) Crazy Mountains; (2) Absaroka Mountains; (3) Beartooth Mountains; (4) Spanish Peaks; (5) Madison Range; (6) Tobacco Root Range; (7) Beaverhead Range; (8) Snowcrest Mountains (9) Elkhorn Mountains; (10) Pioneer Mountains; (11) Gallatin Range; (12) Highland Mountains; (13) Bridger Mountains; (14) Big Belt Mountains. All except 7, 10, and 14 are introduced goat herds.

consistent with recorded annulus measurements; and 3) no additional concerns were raised from indications on the data form (e.g., broken or excessively worn horns) that data would be unreliable. Earliest records came from goats harvested in 1982; documentation of annual growth increment records ceased in 1998 (annuli were not documented for all harvested goats after 1998). To minimize influence of broken or distorted horns, we used the larger of the right or

Table 1. Mountain ranges, whether mountain goats were introduced or native, years included in sample, and sample sizes by number of goat horns and horn increments.

Mountain range	Introduced or native	Years represented (annulus growth)	Number of horns	Number of increments
Crazy Mountains	I	1983-98	20	51
Absaroka Mountains	I	1976-97	75	200
Madison Mountains	I	1973-85	39	100
Native Populations (Beaverhead, Pioneers, Big Belts)	N	1972-85	22	63
Other Introduced Populations (Beartooths, Spanish Peaks, Tabacco Roots, Snowcrest, Elkhorn, Gallatin, Bridgers)	I	1971-96	21	58
Total		1971-98	177	472

left horns (and thus did not examine asymmetry; Picton 1994, Côté and Festa-Bianchet 2001b, Clarke 2010). We calculated the age at birth as the year of harvest minus the estimated age. Teeth were collected and aged using cementum annuli (Mattson Laboratories, Milltown, MT) for only 24 of the 177 useable samples. Ages from cementum annuli were identical to those previously estimated from increments in 12 cases, and differed by 1 year in an additional 5. We replaced ages estimated from horn increments with those estimated from teeth in all 24 cases. We had no way to independently verify the accuracy of horn measurements or age.

Although we also examined lengths and circumferences of horns, we chose approximate volume as the best single metric to reflect the energetic investment made by goats in somatic horn growth. For total horn volume and volume of the first growth increment (i.e., corresponding to kid and yearling growth; Brandborg 1955, Côté et al. 1998), we used the equation for conical volume:

$$\text{volume} = r^2 \pi\, L / 3$$

where r equals the radius at the horn (or increment) base, in cm, and L equals the length of the horn (or increment), in cm (Foster 1978, Hik and Carey 2000). For volume of the second and third growth increments, we used the equation for conical frusta:

$$\text{volume} = \frac{\pi\, L\, (R^2 + Rr + r^2)}{3}$$

where R and r are the radii of the 2 annuli bounding the growth increment (Hik and Carey 2000).

Climate Variables

Having first considered the effects of sex, age, and region, we investigated possible relationships between horn growth and 6 climatic variables: i) total integrated mean weekly NDVI during the growing season (Julian days 129-258 [May 9-September 15, except one day earlier during the leap years of 1992 and 1996]); ii) the maximum NDVI recorded during the growing season; iii) the slope of mean weekly NDVI on time during the first 5 weekly periods; and iv) the slope of mean weekly NDVI on time during the first 10 weekly

a)

b)
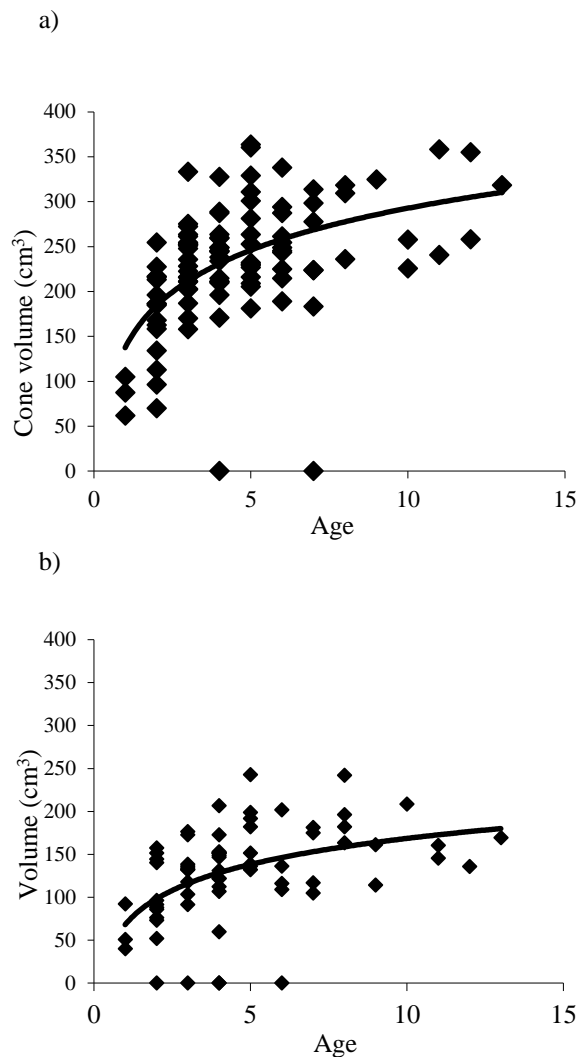
Fig. 2. Volume of male (a) and female (b) mountain goat horns with age at hunter harvest, southwestern Montana mountain ranges, 1971–1998.

periods. When used as a covariate for growth of mountain goat horns in mountain ranges other than the Crazy, Absaroka or Madison Ranges, we used the mean of the 3 values for the 3 sites; v) monthly accumulated precipitation during the vegetation growing season, and vi) maximum monthly temperature.

We obtained NDVI data at the 1-km^2 pixel resolution from Advanced Very High Resolution Radiometer (AVHRR) satellites (http://phenology.cr.usgs.gov/ndvi_avhrr.php) centered at 3 locations (Crazy Mountains: 46.018°, -110.277°, elevation 3,418 m; Absaroka Mountains: 43.950°, -109.333°, elevation 3,653 m; Madison Range: 45.158°; -111.479°, elevation 2,556 m) for the years 1989–1998. AVHRR data were not available

for earlier years, and Landsat Multispectral Scanner (MSS) data proved to be too inconsistent (e.g., cloud cover too great) to be useful. Each individual NDVI record consisted of the mean daily NDVI during weekly periods. We obtained estimates of monthly precipitation and maximum monthly temperature for the same 3 sites at the 2.5 minute resolution scale from the Parameter-elevation Regressions on Independent Slopes Model (PRISM) model (Daly et al. 2008) for the years 1971–1998 (http://prismmap.nacse.org/nn/, accessed December 8, 2011). We created new annual temperature and precipitation variables by combining monthly means across combinations of months during the growing season (April–October).

MFWP conducted aerial surveys for the Absaroka and Crazy Mountains during only a few years covered by the horn data (see Lemke (2004) for methods); we were thus unable to include them in formal analyses relating mountain goat population density to horn growth variables.

STATISTICAL ANALYSES

To investigate patterns of growth with age, we regressed total horn volume at harvest on age for each sex. To examine differences in horn growth among mountain ranges, we used one-way and 2-way ANOVA with i) total volume at death and ii) volume of the first and second growth increments as response variables, and mountain range as a blocking variable. When overall ANOVA tests were significant, we used Tukey (HSD) multiple comparison procedures to group populations.

Previous studies of mountain goat horns had found weak signals of compensatory growth within the first 3 growth increments. The presence of compensatory growth within individuals would generate auto-correlation if analyses were conducted on individual increments without including the animal as a random factor. Thus, we tested for these animal effects separately for males and females, for increment length, circumference, and volume within each mountain range with sufficient data, by regressing older growth increments on younger ones (e.g., Festa-Bianchet and Côté 2008). As detailed below, we concluded that the first 3 growth increments measured by volume were independent, and thus conducted subsequent analyses using increments (rather than
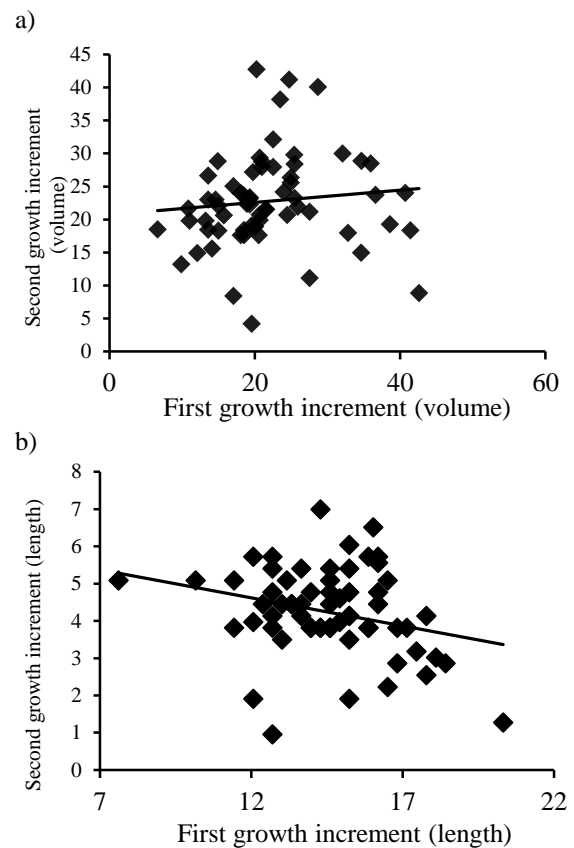
Fig. 3. Scatterplot showing second growth increment on first growth increment for female mountain goats, SW Montana, 1971–1998. (a) Horn volume: second increment $= 0.078 + 0.112$ (first increment); $F = 0.48$, df $= 1,62$; $P = 0.49$, $r^2 = 0.008$. (b) Horn length: second increment $= 6.507 − 0.159$ (first increment); $F = 5.55$, df $= 1,65$; $P = 0.02$, $r^2 = 0.079$.

goat horns) as experimental units. To facilitate comparisons among mountain ranges, sexes, and increment ages, we transformed each growth increment to its standardized z-value by subtracting it from its sex × age × mountain range-specific mean and dividing by the corresponding standard deviation. We used least-squared multiple regression to model horn growth on age-at-harvest and on time in years.

To examine associations of horn growth with climatic variables, we used least-squared multiple regression with z-transformed annual increment as the response variable. Because these latter series of analyses were exploratory and not premised on clearly articulated *a priori* hypotheses relating climatic variables to horn growth, probability values may not be reliable and results should be viewed with caution. We used the software

Table 2. Regressions of volume of older on younger growth increments (GI) of mountain goats in 3 independent mountain goat populations, southwestern Montana, 1988-1999. Shown are mountain range name, sex, specific regression, regression slope (β), F statistic, probability value (P), and coefficient of determination (r^2). Models denoted with (*) suggest compensatory growth; models denoted with (**) suggest an individual animal effect.

Mountain range group	Sex	Regression	β	F	P	r^2
Absaroka	M	GI 2 on GI 1	-0.015	0.01	0.904	0.001
		GI 2+3 on GI 1	-0.179	1.43	0.241	0.047
		GI 3 on GI 2*	-0.255	4.48	0.043	0.130
	F	GI 2 on GI 1	0.349	2.07	0.162	0.071
		GI 2+3 on GI 1	0.081	0.11	0.746	0.005
		GI 3 on GI 2	0.022	0.02	0.884	0.001
Crazy	M	GI 2 on GI 1**	0.776	6.60	0.026	0.375
		GI 2+3 on GI 1	0.100	0.06	0.811	0.008
		GI 3 on GI 2	0.164	0.79	0.399	0.090
	F	GI 2 on GI 1	0.329	0.16	0.713	0.052
		GI 2+3 on GI 1	-0.374	0.06	0.828	0.030
		GI 3 on GI 2	0.223	0.58	0.526	0.225
Madison	M	GI 2 on GI 1	-0.008	0.00	0.963	0.001
		GI 2+3 on GI 1	0.134	0.41	0.534	0.036
		GI 3 on GI 2	-0.052	0.05	0.831	0.004
	F	GI 2 on GI 1	0.078	0.48	0.492	0.008
		GI 2+3 on GI 1	0.023	0.02	0.889	0.001
		GI 3 on GI 2**	0.275	7.79	0.007	0128

package Statitix7 (Analytical Software, Tallahassee, FL).

RESULTS

1. Patterns of Growth

As previously documented (Brandborg 1955, Côté et al.1998, Festa-Bianchet and Côté 2008), horns of both sexes grew asymptotically, with most growth occurring in the first few years (Fig. 2a, 2b). Using the relationships total volume = intercept + ln(age), horns of males had grown to a mean of approximately 72% of their asymptotic 10-year-old volume by the end of their fourth summer (i.e., the first 3 growth increments). Females had attained approximately 59% of their estimated 10-year volume by this time. Although asymptotic horn lengths at age 10 were similar for males (predicted $\bar{x}$ = 24.0 cm) and females (predicted $\bar{x}$ = 24.2 cm), volume of the stouter male horns was approximately twice that of females by the end of the third summer. Female horns subsequently grew at a somewhat faster pace so that at age 10, volume of male horns was roughly 1.5 time that of female horns.

2. Variation Among Mountain Ranges

Goat horn sizes varied among mountain ranges within the southwestern Montana study area (one-way ANOVA for volume of the first growth increment among males ($F = 2.45$, df = 11,93, $P = 0.010$) and females ($F = 7.00$, df = 8,60, $P < 0.001$)). First growth increments among females in the Spanish Peaks (43.0 cm^2) and Crazy Mountain ranges (37.2 cm^2) were significantly ($\alpha = 0.05$) greater than those in the Absaroka (22.0 cm^2), Madison (19.1 cm^2) and Pioneer mountain ranges (15.2 cm^2). No other pairwise comparisons were significant. The 3 native goat populations (Beaverheads, Pioneers, Big Belts) considered as a group, had smaller first growth increments ($\bar{x} = 40.5$ cm^2, SE = 3.93) than introduced populations among males ($\bar{x} = 48.7$ cm^2, SE = 1.44; $t = -2.25$, 103 df, $P = 0.027$) but this trend was not significant among females ($\bar{x} = 19.6$ cm^2, SE = 2.81 vs. $\bar{x} = 22.8$ cm^2, SE = 1.05; $t = -1.20$, 67 df, $P = 0.234$). Sample sizes for the Spanish Peaks, Pioneers, Beaverhead, Big Belts, and all other introduced populations were small, however. Thus, we conducted subsequent analyses by considering goats as belonging to one of 5 mountain range groups: 1) Crazy Mountains, 2) Absaroka Mountains, 3) Madison Mountains, 4) native populations, 5) all other introduced populations.

3. Compensatory Growth Within Young Individuals

We found little evidence of compensatory growth within the first three growth increments, as measured by approximate horn volume, in either male or female mountain goats (Table 2). Of 18

Table 3. Regressions of length of older on younger growth increments (GI) of mountain goats in two independent mountain goat populations, southwestern Montana, 1988-1999. Shown are mountain range name, sex, specific regression, regression slope (β), probability value (P), F statistic, and coefficient of determination (r^2). Models denoted with (*) suggest compensatory growth; models denoted with (**) suggest an individual animal effect. Models with neither effect significant are not shown.

Mountain range group	Sex	Regression	β	F	P	r^2
Horn length						
Absaroka	M	GI 2 on GI 1*	-0.267	10.65	0.002	0.214
		GI 2+3 on GI 1*	-0.325	12.23	0.001	0.283
Madison	M	GI 2 on GI 1*	-0.257	9.81	0.006	0.380
Horn radius						
Absaroka	M	GI 2 on GI 1 **	0.674	78.10	< 0.000	0.661
		GI 2+3 on GI 1 **	1.240	121.06	< 0.000	0.614
Madison	M	GI 2 on GI 1 **	0.761	27.56	<0.000	0.663

linear models regressing volume of an older (or combination of two older) growth increments on a younger one (3 tests × 3 goat populations × 2 sexes), only 1 was significantly negative (Absaroka males; increment 3 on increment 2) as would be expected if compensatory growth occurred, and this model explained only 13% of the variation. Slopes for 12 of the 18 models were positive (although only 2 were significant). Thus, growth of horn volume during ages 2 and 3 were largely independent of growth occurring during the preceding 2 or 3 years. We took advantage of this independence to conduct further analyses using growth increment (rather than individual goats) as our experimental units.

Examination of these same regressions using horn length (c.f., Côté et al 1998, Toïgo et al. 1999, McDonough et al. 2006, Festa-Bianchet and Côté 2008) suggested that previous reports of early compensation in horn growth may have resulted from this choice of metric (Fig. 3, Table 3). In 3 cases, regressions that displayed no trend for volume were significantly negative for length (Table 3), but significantly positive for radius. No other models testing increment length against earlier increment lengths were significant.

4. Early Growth and Age-at-Harvest

Males with faster growing horns early in life (as measured by volume) were harvested at younger ages than those with slower growing horns (normalized increment volume = 0.236–0.049 [age at harvest]; $F = 4.34$, df = 1, 282, $P =$ 0.038). However, this relationship explained very little of the total variation ($r^2 = 0.015$), and was not significant among females.

5. Trends With Time

With one exception, we failed to find evidence of mountain range-specific temporal trends of age-at-harvest (accounting for sex), total volume at harvest (accounting for sex and age), or growth increment (all $P > 0.16$). The exception occurred in the Crazy Mountains, where age-at-harvest declined during the period 1990–1996 from a predicted mean of ~ 8 yrs in 1982 to <4 yrs in 1996 (linear regression of age on year: $\beta_1 = -0.728$, male effect $\beta_2 = 0.0128$; 2,17 df, $F = 6.76$, $P = 0.018$). However, this increasing youthful harvest was not accompanied by a decrease in trophy size (horn size on year, accounting for factors sex and age: $\beta = 0.025$, 2,17 df, $t = 0.14$, $P = 0.891$), or by a decrease in growth increment with time (increment Z score on time, $\beta = 0.037$, 1,49 df, $t = 0.53$, $P = 0.600$).

6. Climatic Variables

In general, the independent climatic variables we were able to examine supported our hypotheses, but added relatively modest amount of explanatory power to base models describing variation in relating *z*-transformed horn growth increments. Models that included precipitation and/or temperature improved model fit over those lacking these variables, but only slightly.

The strongest association of (standardized) horn increment volume with climatic variables

Table 4. Results from best-fitting linear models relating standardized horn growth increment to mountain-range specific temperature and precipitation variables. Both sexes were modeled. (a) first 3 growth increments (i.e., through age 4), $F = 3.18$, $P = 0.024$, $r^2 = 0.025$; (b) first 2 growth increments only, $F = 3.95$, $P = 0.009$, $r^2 = 0.042$.

a)

Predictor	β	SE	t	P
Constant	0.0582	0.0532	1.09	0.275
June maximum temp	0.2719	0.0903	3.01	0.003
September maximum temp	-0.1537	0.0670	-2.30	0.022
April-August precipitation	0.1436	0.0703	2.04	0.042

b)

Predictor	β	SE	t	P
Constant	0.0784	0.0619	1.27	0.206
June maximum temp	0.3707	0.1079	3.44	0.001
September maximum temp	-0.1790	0.0803	-2.23	0.027
April-August precipitation	0.1749	0.0809	2.16	0.031

Table 5. Results from best-fitting linear models relating standardized horn growth increment to mountain-range specific NDVI and temperature variables. Both sexes were modeled, shown are models with first two growth increments only (a) $F = 5.44$, $P = 0.006$, $r^2 = 0.124$; (b) $F = 3.49$, $P = 0.035$, $r^2 = 0.083$

a)

Predictor	β	SE	t	P
Constant	0.4358	0.1343	0.24	0.002
Mountain-range specific mean NDVI during April-October	0.4652	0.1522	3.06	0.003
Maximum September temperature	-0.9433	0.3149	-3.00	0.004

b)

Predictor	β	SE	t	P
Constant	1.2226	0.4744	2.58	0.012
Mountain-range specific mean NDVI during April-October	0.2607	0.1230	2.12	0.037
NDVI slope during first 5 bi-weekly periods of growth season	-3.707	1.6317	-2.27	0.026

was found by modeling it as a positive function of mountain-range specific precipitation during April–August of the year of growth, a positive function of maximum temperature in June, and a negative function of maximum temperature in September (Table 4). These relationships were slightly stronger when limiting the response variable to the first 2 growth increment, but even then, explained only about 4% of total variation.

No variables were significant when modeled in isolation.

In models considering NDVI (which extended back only as far as growth year 1989), horn growth was consistently positively (albeit not always-significantly) associated with growing season NDVI and negatively associated with maximum temperature during September (Table 5a); these relationships were strengthened when examining only the first two growth increments, and excluding animals killed at age >6. We found some evidence that early horn growth was negatively associated with the slope of increasing NDVI during the first 5 (but not the first 10) bi-weekly periods in each year's growing season (Table 5b). As with models examining only temperature and precipitation however, explanatory power was weak even for models that were statistically significant.

DISCUSSION

As also noted by Hik and Carey (2000) for Dall sheep, mountain goats required more years to approach their asymptotic horn size when measured by volume than by length. Thus, the suggestion from our data that goats in southwestern Montana grew more slowly than in Alberta (where nearly all growth had taken place by age 4; Côté et al 1998), is likely an artefact of the choice of metric.

Despite modest sample sizes, we detected differences in early horn growth rates among mountain goats living in different ranges within southwestern Montana. We lacked ancillary data with which to explore causes for these differences (e.g., population density, [e.g., Pérez et al. 2011], habitat [McDonough et al. 2006, Clarke 2010],

genetics), but note that most comparative studies have found population-specific differences in growth rates, body size, and/or resilience to harvest rates (Côté and Festa-Bianchet 2003, McDonough et al. 2006, Clarke 2010). We found that the 3 native populations in southwestern Montana were characterized by slower rates of horn growth than nearby introduced populations. The reasons that introduced populations generally grow more vigorously than native populations remains unclear; one hypothesis to consider is that introduced populations that have persisted long enough to be studied represent those inhabiting relatively productive habitats (Guenzel 1980).

Perhaps because horns of mountain goats are relatively small and hunter selectivity assumed to be modest, the species has not been the focus of concerns regarding potential artificial selection from hunting (c.f., Coltman et al. 2003, Festa-Bianchet 2003, Hengeveld and Festa-Bianchet 2011, Mysterud 2011). We detected no signals that would be consistent with a decline in horn size attributable to artificial selection. That said, our results regarding compensation, as well as the relationship between early growth and age-at-harvest, suggest that mountain goats may not be as immune to potential artificial selection as previously assumed, should harvest pressure, hunter selectivity, and trait heritability be sufficiently strong.

Compensation in horn length, as demonstrated by Festa-Bianchet and Côté (2008) weaken the potential for artificial selection (as shown further by Rughetti and Festa-Bianchet 2010 for the closely related alpine chamois (*Rupicapra rupicapra*)), because all individuals would tend, over time, toward similar horn sizes. Although our data confirmed weak compensation in horn length in early growth increments, we found no evidence of compensation in horn volume. Mountain goats with large volume horns when young thus have large volume horns when older. To the degree this is heritable and hunters respond to horn volume rather than length, this suggests the potential for artificial selection.

Given the small differences in size among horns of adult males, we were surprised by our finding that faster growing horns were associated with being harvested at a younger age. Thus, male mountain goats predisposed toward growing larger horns were removed at slightly younger ages than those with slower growing horns, potentially reducing their reproductive success. This suggests some selectivity among hunters, who may target males with stouter or longer horns, independent of the billy's age. While this also suggests the potential for hunter-mediated selection against faster horn growth, this effect would appear to be quite weak. In addition to explaining only a negligible percentage of variation in early growth (<2%), the fitted relationship suggested that whereas males harvested at ~ age 4 or 5 grew horns at close to mean rates early in life, even a billy harvested at the relatively old age of 10 had earlier produced horn volume only 0.25 standard deviation units below the mean, suggesting little scope for hunter-selection. Thus, that we observed only the potential — but no evidence — of artificial selection on goat horn size suggests that hunter selectivity, harvest intensity, or both would have to be stronger than was evidently the case for it to be manifested on a population-wide scale.

In general, our data provided no evidence of systematic trends of either age-at-harvest or horn growth with time that would suggest overharvest. The one exception was in the Crazy Mountains, where we observed a negative trend of both horn total volume at harvest and age-at-harvest during the 1990–1996 period for which we had increment data, superficially tending to suggest overharvest. However, age-specific horn volume did not decline during these years, which we would have expected had genetic or climatic effects been having a deleterious effect on this population. As well, the Crazy Mountain goat population increased markedly prior to and during these years, total horn volume at harvest did not continue to decline after these years (T.O. Lemke and K. Loveless, Montana Department of Fish and Wildlife, unpublished data), and the population was newly exposed to hunting following a 14-year cessation. Thus our interpretation is that hunters in the early 1990s encountered a Crazy Mountain goat population with a relatively large number of old males, and as recruitment continued to increase, hunters harvested from an increasingly younger age structure. We point this out to emphasize the importance of interpreting simple hunter-harvest statistics (e.g., age-at-harvest)

within the appropriate context: without information on the status of this population prior and subsequent to our years of horn annulus data, we could easily have misinterpreted these trends.

Our data provided only weak support for our *a priori* hypotheses regarding climate's potential effect on horn growth. Exploratory analyses suggested that horns tended to grow faster in years with more precipitation and more vegetation biomass (as indexed by mean NDVI during the growing season). Horn growth tended to be negatively associated with higher temperatures in September, and faster spring green-up (early slope of NDVI). Although our best models were statistically significant, they explained relatively little variation. That said, non-significant slopes of all climatic variables remained consistent among all models, and all were consistent with what we would have expected had these climate-related hypotheses been more strongly supported. These analyses do not resolve questions regarding the future of mountain goats in the face of climate change, but offer some tantalizing hints that concerns expressed by Pettorelli et al. (2007) deserve additional consideration. Mean and maximum NDVI values estimated at the mountain top location used to index the Absaroka population have declined in recent years (1989–2010), and spring green-ups (as indexed by the slope of NDVI increase) have become faster (unpublished data). Thus it is possible that horns may be giving us some indication mountain goats are being stressed by these climatic trends.

In contrast to horns from mountain sheep (Bunnell 1978, Hik and Carey 2000, Festa-Bianchet et al. 2004) and alpine ibex (Giacometti et al. 2002), the first growth increment of mountain goat horns spans 2 growing seasons, which clouds the ability to detect yearly effects early in life. Our power to detect effects of annual changes in meteorological conditions was also compromised by errors in aging of goat horns (Foster 1978); whereas small errors in measurements would not necessarily have a large impact, a difference of only a year in aging the goat from annuli could easily have had the effect of changing the relative growth recorded from a climatologically favorable to an unfavorable year (or vice versa), and thus induce considerable noise in the data.

For mountain goats, body size is a more important determinant of reproductive success than horn size (Côté et al. 1998, Festa-Bianchet and Côté 2008). Thus, we were not surprised to find weak relationships with hunting- and climate-related explanatory variables. That said, our investigation did add some insight into these populations' responses to both. With climate change and artificial selection hypotheses yet untested, mountain goat populations being challenged by multiple stressors, and funds for engaging in in-depth ecological studies limited, we suggest that management agencies would do well to obtain data from harvested horns, including measuring length and circumference of annuli, as well as ageing goats using cementum annuli from teeth.

ACKNOWLEDGMENTS

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CALCULATING HARVEST RATES FOR ALASKAN DALL RAMS USING REPORTED HARVEST AGE STRUCTURE: IMPLICATIONS FOR DALL SHEEP MANAGEMENT IN ALASKA

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Abstract: Alaska's regulated Dall (*Ovis dalli*) ram harvest management system, limiting harvest to full-curl, double-broomed, or eight-year-old rams and mandating reporting of harvested ram ages, has been codified for 20 years. During 2010-2012, contemporary management needs drove an age structure-driven method of estimating cohort harvest rates using reported age structures gathered over the last 20 years (n>20,000 rams). Using reported ages at harvest over the life span of any cohort of harvested rams allows calculation of the harvest rate during the first year of age-legality. Beginning with the obvious realization that legal rams from age 8-years and up were alive until they were killed, and adding the number of rams harvested in successive years from each age-cohort harvested over the life span of harvested rams from that cohort allows calculation of the minimum cohort harvest percentage upon becoming legal. These analyses indicate ram harvest rates during the first year of age-defined harvest liability for rams of any given cohort during the first 15 years of Alaska's full-curl harvest period have ranged from 40% to 60% of the minimum number of age-legal rams known with certainty (because we killed them) to be present when each cohort became age-legal for harvest. Age distributions among sheep harvested by both resident and nonresident hunters match the generalized survival templates from unhunted wild sheep populations, thus calling into question the folklore associated with ram hunter selectivity. There has been no change in per capita hunter effort for successful or unsuccessful hunters regardless of residency over the last 20 years in Alaska. The data suggest that restricting nonresident opportunities to favor resident hunters or reducing harvests to mitigate perceived threats to ram social biology or the ultimate outcome of the average sheep hunt are biologically unnecessary at this time. Management context and implications are discussed.

Wildlife managers tasked with allocating harvests of wild mountain sheep are necessarily concerned with harvest rates. In practice, harvest objectives in most states and provinces are set based on aerial surveys or formulae which extrapolate numbers or percentages of harvestable wild rams based on survey data. Aerial surveys for Alaskan Dall sheep (*Ovis dalli*) are notoriously variable, and reflect only external population dynamics (Heimer 1994). The actual harvest rate is seldom known or knowable, and the impact of trophy hunting on wild mountain sheep genetics in the absence of definitive harvest rate data has been vigorously debated (Heimer et al 2004, Coltman et al 2005, Festa-Bianchet et al 2006). A similar controversy involving a perceived need for "genetic conservation" in the absence of a quantifiable harvest rate has also occurred in Alaska (Heimer 2005).

For approximately 50 years, harvest of Dall rams in Alaska has been open to anyone purchasing a license and requesting (for residents) or purchasing (for non-residents) the mandatory report form/tag. Some limited-entry permit areas have been established in Alaska, but the dominant management scheme in Alaska has always been open-but-regulated-by-bag-limit hunting opportunity available to both residents and non-residents. Throughout this time period, the legal ram definition has changed from 3/4 curl to 7/8 curl, and ultimately full-curl rams. For the last 20 years, a legal ram in Alaska has been defined as a ram, the tip of whose horn has grown through 360 degrees of a circle as seen from the side, is

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broomed (broken) on both sides, or has reached a minimum age of eight years (Heimer and Watson 1990). Alaska's full curl regulation was justified biologically because of Dall sheep population performance where ram age structures containing significant mature ram influence on breeding were significantly correlated with higher ovulation rates in ewes, greater reproductive synchrony, higher lamb production, better apparent survival, and empirically measured increases in ram harvests when compared with populations lacking mature rams (Heimer and Watson 1986, 1990). Some subsistence ewe hunting is allowed (Heimer 1999a), but is insignificant for purposes of this paper.

Dall ram hunting in Alaska has always been associated with the data-free assumption that Dall ram hunters overwhelmingly select the largest rams rather than taking legal rams across all age and size classes as they occur in a huntable population. This assumption will be evaluated in this paper.

Starting in the early 1990s, changes in weather (Heimer 1995, Pfeifer et al 2010) and predator abundance (Heimer 1999b) correlated with declining Dall sheep numbers throughout Alaska. Coyote predation over the last 20 years seems particularly significant because of the expansion of coyotes into sheep habitats which had previously been essentially coyote-free. Coyote/Dall sheep predation studies (Scotten 1998, Arthur and Prugh 2010) indicated that coyotes were responsible for between 25% and 12% of Dall lamb mortalities. Availability of alternate prey (primarily hares) seemed to transiently lessen the impact on Dall sheep Nevertheless, the emergence of coyotes as a significant predator on Dall sheep lambs temporally coincided with overall population declines. The apparent declines in Dall sheep numbers were of natural concern to resident hunters heir to the developed culture of Alaskan Dall ram hunting. Here's why:

Residents reasoned that if sheep numbers were in decline, competition for quality rams and hunting experiences would increase. Here, they presumed that Dall ram hunter numbers would remain stable or increase. Activist resident hunters also alleged that the presumed relative scarcity of legal or trophy rams was a compounded by non-

resident hunting. Guided non-resident hunters have taken about 40% of the Dall ram harvest since Alaskan harvest statistics were first compiled beginning in 1967. The resident hunter suspicion that non-resident hunting was a significant cause of perceived ram scarcity was amplified by the impression that non-resident hunters (who must have a registered guide under Alaskan law) were taking the largest rams in the population. In addition, the interested resident hunters hoped to establish management practices (e.g. preference points, restriction of non-residents, increased non-resident fees, and *de facto* relative enhanced resident harvest allocation) borrowed from other jurisdictions they deemed more progressive than the existing Alaska system.

The primarily negative sentiment expressed by these resident hunters was focused on professional guides, particularly non-resident guides. In Alaska, guiding is considered a commercial enterprise, and non-residents needn't establish Alaska residence to engage in commerce. They must simply purchase the necessary commercial licenses. This results in the rather paradoxical situation where a non-resident may guide for a species (say Dall sheep) he/she may not legally harvest for him/herself. This inconsistency troubles many resident hunters. Every Alaskan resident seems to have his/her own personal or shared story of negative interaction with the guiding industry.

The cumulative effect of these perceptions and perspectives has been that "everyone" has come to accept the notion that legal rams were becoming increasingly scarce for the proposed reasons, and that the harvest rate was approaching 100% of each cohort as it became legal (Heimer 2005). Guides and non-residents were assigned primary blame because guided non-resident hunting success approaches an average of 70% while resident success has averaged about 30% over time, and may arguably be seen as trending downward recently. Naturally, resident hunters wanted to eliminate the competition they perceived from guides and guided non-residents.

Until the resident hunter's push to severely reduce non-resident hunting elevated the harvest allocation issue, Alaska's Dall sheep managers were content to manage according to established tradition, public perception, and area management

biologist impressions. A compounding factor was the perception of some Alaskan management biologists that selective trophy harvest was altering horn growth genetics in Alaska's Dall ram populations (Heimer 2006). These factors, acting in concert, drove the development of a technique for assessing known cohort harvest rates from reported harvest age structure. The technique and the management results to date are reported in this paper.

METHODS

Harvest Rate:

When Alaska's legal definition of a full curl ram was codified more than 20 years ago, it included an "or eight years of age" component. This was never intended to be a field identifier of legal rams because of the risk to the hunter of incorrectly aging rams in the field. Rather, the "or eight years old" provision was a 'safety net' allowing hunters to harvest mature rams which might not be full curl or broomed on both sides. Maximizing harvests in Alaska is important because Alaska's constitution (Article VIII) and the Alaska Statutes (Title 16) prescribe maximal, sustainable harvests in the interests of the economy and general well-being of the State of Alaska.

Hunters have been required to report the age of their harvested rams from counting horn growth annuli for the last 20 years. This they have done with acceptable accuracy based on comparative sampling of about a quarter of the harvest for five years following establishment of the full curl regulation. Sheep specialists (W. Heimer and D. Harkness) aged horns in taxidermy shops, compared the ages with those reported by hunters, and established that the hunters were sufficiently accurate for management purposes (Heimer, Alaska Department of Fish and Game, unpublished data). As a result, a data base of >20,000 ram ages was accumulated during the ensuing 20 years. The ages, harvest locations, resident status of the hunter, and horn sizes (base diameter and length) were available in this huge data base. The data base was sorted by harvest year, ram age, horn length, harvest location, and residency of the reporting hunter. Analysis was at the Game Management Subunit level, which

separated Alaska's huntable Dall sheep into 16 subpopulations with the estimated total number of Dall sheep in the aggregate ranging from approximately 50,000 to 75,000, and declining toward 50,000 Dall sheep over the sample period.

In considering the management issue, the primary analyst, J. Want, noted that the entry age ram harvest rate from any ram cohort could be calculated for that cohort once rams of that age-cohort dropped out of the reported harvest due to all having either been harvested or died of old age. Dall rams in unhunted populations have a generally accepted 95% life expectancy of 12 years (Deevey 1947), but older rams have been harvested throughout Alaska. For purposes of this analysis, a mean maximal life expectancy for Dall rams was assumed to be 13 years of age. Hence the known cohort harvest rates were accurately calculable back to the year each cohort reached legal harvestable age after five years of harvest liability had elapsed. J. Want observed that every ram was technically legal-for-harvest at age eight regardless of its degree of horn development or brooming status. He then postulated that, technically, every ram harvested at an age greater than eight years had been available for harvest from the opening day of sheep season the year he turned eight years old. Thus, J. Want summed the number of rams harvested in subsequent years (which had survived from age eight years until they were harvested) and divided it into the reported harvest from that ram cohort at its first year of harvest eligibility. Multiplied by 100, this quotient gave the harvest rate in percent of that individual cohort during its first year of being legal for harvest.

Table 1 illustrates this rationale from Game Management Unit 12, the Northern Wrangell Mountains, a long-term, high volume producer of full-curl rams in Alaska. Game Management Unit 12 was representative of the amazingly uniform pattern of harvest across all of Alaska's Dall sheep habitats.

Dall Ram Survival

To test the assumption that hunters were killing "all of the legal rams" as they became legal, life tables (see Deevey 1947) were constructed and survival rates calculated as had been done by Deevey (1947) for Murie's (1944) data from

Table 1. Cohort age distributions from Alaska's Game Management Unit 12 from 19900- 2009. Shaded portion represents age-legal harvest from known cohort size.

				Dall Ram Harvest GMU 12								Age Legal Total Harvest	Could Have Harvested	% of Available Harvested
Year/Age	5	6	7	8	9	10	11	12	13	14	15			
2009		13	32	23	17	15	10	3	3	1		72		
2008	4	10	12	20	36	29	10	2	2			99		
2007	4	5	9	41	41	25	16	3	1			127		
2006		4	21	47	38	27	11	3	1			127		
2005	2	6	27	49	34	20	9	2		1		115		
2004	3	14	37	44	37	19	4	1				105		
2003	1	4	8	58	65	23	7	1				154	269	57%
2002		3	20	51	41	22	4			1		119	256	46%
2001	4	3	20	45	24	32	5	2	1	1		110	218	50%
2000		2	8	48	22	23	8	6	1			108	210	51%
1999		3	12	39	55	32	12	8	1			147	255	58%
1998		3	14	40	58	45	20	3	4			170	326	52%
1997		2	12	39	31	43	13	7	2			135	338	40%
1996	2	3	20	61	42	31	12	6		1	1	154	353	44%
1995		2	16	67	63	29	11	4		1		175	371	47%
1994	2	6	27	48	49	26	10	3	2		1	139	328	42%
1993		8	23	58	53	22	14	1				148	317	47%
1992	3	6	25	63	42	22	10	6	1			144	302	48%
1991	2	11	44	74	71	45	18	10	4			222	363	61%
1990	5	13	38	55	46	42	27		4	1	1	176	387	45%

Mount McKinley National Park, Alaska and by Heimer and Watson for the Eastern Alaska Range (Game Management Unit 20A) (Heimer and Watson 1986, 1990).

If the assumption that hunters were literally killing "all the legal rams" as they became legal were correct, the survival curve should have indicated "no survival" after age eight (see Fig. 1).

Survival curves were constructed for harvested ram populations in all 16 sub-population ranges using the "Murie/Deevey survival plot," and compared with the assumption of total mortality (a vertical drop to zero survival at age eight) based on the assertion that, "We're killing them all when they become legal." Figure 1 also illustrates the contrast between the expected survival among Dall rams and that mortality predicted by the total harvest at legal age assumption.

RESULTS

Resident and Non-resident Comparisons

Resident and non-resident comparisons from mandatory hunter reports: percent success, mean horn size, ram age, and hunt length by residency over the last 20 years:

Hunter participation: Overall participation in Dall sheep hunting has steadily declined by about 30% over the last 20 years. The major decline has been in hunting by resident Alaskans. Non-resident hunting has remained relatively constant. Hence, the common assumption that hunting pressure would remain stable or increase over time was shown to be false.

Hunter success: Although resident hunting success may have declined slightly from the long-term mean of 30% to the upper 20%, there is sufficient variability that defining a trend is questionable. Resident hunter success has remained stable, at around 30% over the last 20 years. Non-resident hunter success seems stable as well, averaging in the neighborhood of 70% for guided non-residents over the same time period.

Horn size: Mean horn sizes for resident and guided non-resident hunters were virtually identical. This has been the stable pattern for the last 20 years. There was so little difference or change in horn sizes for residents and non-residents (they were virtually identical) that no statistics quantifying differences were run.

Ram ages: Mean ram ages by area and year were virtually identical for residents and non-residents throughout the 20-year sampling period.
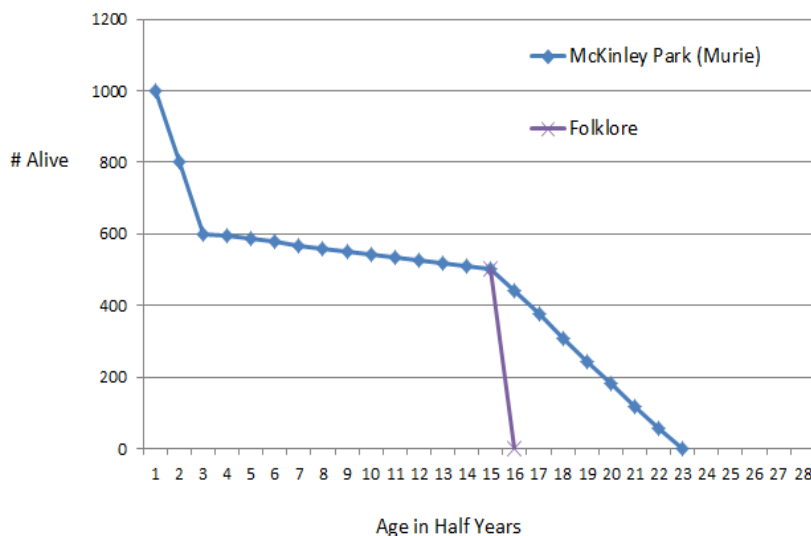
Fig. 1. Survival of unhunted Dall rams from Murie's data in McKinley Park, Alaska compared with hypothetical "folklore" assumption of total harvest upon becoming a legal ram in hunted populations of Alaska 1989-2009.

Hunter effort (length of hunt): Guided non-residents have always hunted longer than residents. Hunter effort did not change appreciably over the last 20 years for either group as sheep populations declined.

Harvest Rate Determined From Age Structure

The harvest rate calculations failed to support the assumption that harvest rates were approaching 100% at legal age. The most heavily hunted area in Alaska yielded a calculated first-year-legal harvest rate of 60% of known age-legal ram cohorts. The most lightly hunted area was harvested at 40 % of emerging age-legal ram cohorts, and the overall statewide average indicated a calculated harvest rate of about 50% of what could be known, with certainty, to have become age-available in that cohort when it became legal for harvest. Percent harvests from limited-entry permit hunt areas also fell within this range, as did areas where "genetic conservation" has been proposed. During any given year from 1989 through 2006, hunters averaged taking about half of the age-legal rams the year they became legal for harvest. Cohort harvest rates for 2006-2012 are not yet calculable, but appear to be following this general pattern.

Survival Rates of Rams in Hunted Populations

No populations of rams in Alaska, including those considered most heavily hunted, approached the "total harvest mortality" model. Actual survivorship curves of harvested rams (Fig. 2) bracketed the "Murie/Deevey unhunted ram survival curve" with the highest survival being recorded from the Northeastern Brooks Range. Ram survival in this area was significantly better than indicated by Murie's data from McKinley Park. The lowest survival rate was recorded from the Talkeetna Mountains. The survival rate from this area was significantly lower than reported from McKinley Park by Murie (1944).

Overall Results Summary

The data indicated the 'total Dall ram harvest assumption' which was generally accepted by managers and regulators is false, and that no restrictive management action is currently necessary to limit overharvesting of rams. There was no material difference in ram age or size between resident and guided non-resident hunters over the 20-year sample period. Ram age/size and harvest parameters appear to have changed little over the last two decades. Cumulative cohort harvest rates averaged about 50% per year rather than approaching a "total" harvest at legal age. The striking observed change has been an approximate 30% decrease in resident hunter effort.

Corroborating Evidence

Seven years of data collected pursuant to Alaska's sealing (or plugging) of all harvested Dall rams in Alaska (~6,000 rams) were analyzed independent of the larger sample. ADF&G biologists determined the ages of all these rams in the sealing (plugging) process. Although sample size was notably smaller, the results from this
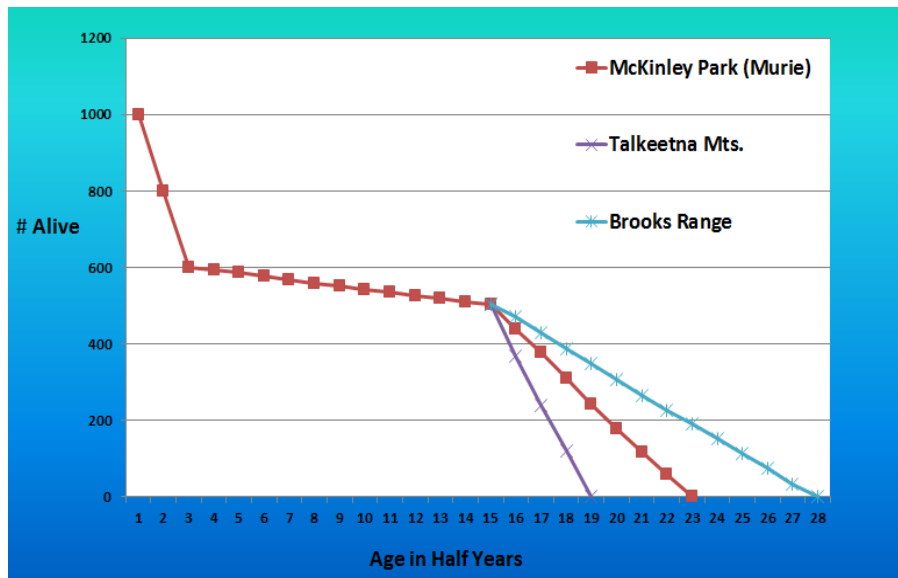
Fig. 2. Extreme survival rate ranges among full-curl Dall rams harvested since 1989 compared with Murie's data from McKinley Park, Alaska circa 1933.

subsample of the total harvest agreed almost exactly with the results from the overall sample.

DISCUSSION

Traditional Criticisms

The methodology for estimating harvest rates is strictly harvested cohort-size based. This could introduce some error because of variations in cohort size. Cohort size at legal age is primarily a function of initial birth-cohort size, but is also affected subsequent survival to harvestable age. However, the overall consistency of harvest rates for individual cohorts over the many harvest areas in Alaska and across the 20-year time span argues for the robustness of this approach to estimating overall harvest rate by averaging cohort harvest rates over time for each area.

The individual cohort harvest rate data were pooled to produce a 20-year average survival rate for each subpopulation. This approach was chosen to assure an adequate sample sizes and smooth individual-year variations. Consequently, these plots are heir to the many criticisms which have attended Deevey's approach to Murie's data for decades (Murphy and Whitten 1976). However, the survival rates estimated in this case were from essentially "closed" (or known) ram populations. This is because the only rams which entered the

sample were "marked" by being shot by hunters, and constituted the entire sample.

Variations in Sheep Abundance and Hunter Numbers

While harvest rates within the cohort-based data were strikingly consistent, the interaction of declining Dall sheep populations (from an estimated statewide population of 75,000 in 1991 to an estimated 50,000 at present) during the 20-year sample period with changes in resident hunting pressure should not be overlooked. In the GMU 12 data example (Table 1), there appears to be an upward trend in percent harvest starting about 1999. This probably reflects lower cohort size in relation to hunter pressure because ram cohorts which should have entered the harvestable-age population in 1999 would have been born eight years earlier, in 1991. These dates coincide with generally increased environmental resistance due to the onset of an apparent unfavorable weather cycle (see Hik and Carey 2000). It should also be noted that the presence of coyotes and cessation of wolf control coincided with the period of difficult weather. There is more to be gleaned from this set of harvest data than has been covered here. This should not be considered the last word on this issue.

Review of Specific Critiques Already Registered

Dall rams in Alaska are legally harvestable when eight years of age (determined by horn annuli), if both horns are broomed (broken, not merely worn), or if the horn tip has grown through 360 degrees of a circle as seen from the side. Due to natural variability (Heimer and Smith 1975), it is obvious that (even though full curl at eight years is the norm) not all rams reach full curl of horn development on their eighth birthday. Some rams,

particularly those with smaller diameter curls, reach full curl before age eight, and some rams may never quite make full curl. Brooming in Dall rams is less common and less extensive than is typical among bighorns (Geist 1971, Heimer, confirmatory unpublished data).

This lack of uniformity coupled with the strong oral tradition associated with Dall ram hunting culture has occasioned some criticism of this age-structure/harvest rate methodology. Some individuals have argued that hunters don't select rams on the basis of age, but rather on the basis of horn development. I acknowledge this is the case, but fail to see how that compromises these estimates of cohort harvest rates. I argue that the calculated harvest rates should be seriously considered by managers because these rates deal only with what we know with certainty was in the population because we eventually killed it. Rams that may have been in any individual cohort, but were never killed by hunters do not enter into these calculations. Because Alaska Dall ram hunters presently seem only able to kill about half of any cohort the year it becomes legal, and cohort harvest was never total for any year thereafter (save the final year the cohort was represented in the sample), it seems probable there are some rams in every cohort that live and die of old age without ever entering our sample. If so, the overall harvest rates may actually be lower than calculated. There are certainly mortality factors beyond (and probably more significant) than hunting by humans.

Management Relevance

The finding of no definable difference in horn size (or age) between rams taken by resident hunters and guided non-residents indicates the legendary selectivity credited to both resident and guided non-resident Alaskan Dall ram hunters is unsupportable by data. Comparison of mean-age distributions between both groups of hunters force toward the purposeful suggestion that ram harvest choices over the last 20 years have been more random than selective. Certainly, there are Dall ram hunters who selectively harvest only very large rams. However, the overall data set indicates both resident and non-resident hunters took rams in what would be expected (from both age and horn length) to occur in a random sampling from

normal distributions of horn size and age at and above the full curl minimum.

Similarly, horn length distributions within each harvested age class were striking in the uniform "normality" of their bell-shaped distributions. That is, there was no evidence that hunters were effectively selecting (by killing) the larger rams from each age class. These data appear to obviate the negative implications expanded from bighorn sheep to Alaskan Dall rams extrapolated from the original work of Coltman *et al* (2005). There is no reason to suspect that harvest across all horn lengths in every specific age-cohort should be linked to theorized genetic damage due to full-curl "trophy" hunting as it is managed in Alaska.

A management inconvenience associated with this method of calculating cohort harvest rate is that the first-year harvest rate cannot be accurately calculated for any given age cohort until that cohort disappears from the age distribution. This generally occurs at least five years after the year that cohort first became age-legal for harvest. That is, a definitive calculation of initially-legal year cohort harvest rate can't be accomplished until all the rams in that cohort are no longer reported in the harvest. Hence, "this year's" initial-cohort harvest rate cannot be calculated. However, the overall consistency of the data set seems to argue that barring unusual biological events (which do happen), Dall ram harvests in Alaska appear to have been essentially random among legal rams as well as sufficiently conservative that this lightly harvested resource remains sufficiently resilient to preclude the need for rapid management responses to transient drops in numbers of legal rams seen on aerial surveys.

After all, if rams are generally not legal for harvest until they are eight years old, lamb production failures will not be reflected in harvest till eight years later. Hence, consistent monitoring of lamb production/yearling survival should indicate an upcoming "shortage" of legal rams and its seriousness well ahead of necessary management actions. Additionally, severe weather events chronicled to date seem to affect lamb production and older-age cohorts on the mountain most severely (Watson and Heimer 1984). Certainly, monitoring production, survival to yearling age, adult survival, weather, and predation will indicate potential harvest scarcities

and trends well ahead (eight years in the case of failed lamb productions) of changes inferred from harvest data.

Alaska's Constitution and Statutes call for maximizing harvests under the sustained yield principle. The intent of these mandates is to maximize benefits to the economy and general well-being of the state (Alaska Statutes Title 16). Currently, the harvest of Dall rams has an estimated economic annual benefit of about $20 million to the state of Alaska. Of this total, the Pittman-Robertson funding match of federal conservation dollars (about $11 million annually), is a result of non-resident participation in Dall ram hunting. A non-resident license costs $85, and a non-resident sheep tag costs $425 for citizens of the USA. Costs to foreigners are greater. Consequently, unless there is a conservation issue that requires decreased harvests, it is not in the best interests of the economy of the state ($20 million per year or the ADF&G budget $11 million per year) to curtail non-resident hunting. Neither would it be beneficial for the guiding industry which provides the bulk of other economic benefit deriving from Dall ram hunting in Alaska. If the range of maximal known harvest rates has averaged 50% (ranging from 40% to 60% of any age-legal cohort for the last 15- and possibly 20 years), it seems unlikely there is a conservation issue associated with Dall ram hunting as currently managed in Alaska.

A Final Biological Note

It should be noted that the range of survival rates in hunted populations of rams (from Fig. 2) bracketed the survival rate of Dall rams in unhunted McKinley Park during the late 1930s. The poorest survival of any subpopulation in Alaska was from the Talkeetna Mountains. Survival there was notably lower than that of unhunted rams indicated by Murie's data from McKinley Park. The greatest survival was seen among rams from the northeastern Brooks Range.

Ultimately, survival rate is determined by overall environmental resistance, which varies from area to area and over time with weather and predation influences being the more powerful components of environmental resistance. Consequently, I can conceive no valid reason to assume that the survival rate of Dall sheep anywhere in Alaska should match that calculated from McKinley Park 70 years ago. Not having any better choice, I elected to use the calculated survival from birth to seven years of age from Deevey's 1947 actuarial analysis of Murie's data published in 1944. There may be some weakness associated with this choice, but that should not affect the cohort survival curves from age eight years onward. While hunting mortality is most likely additive among full curl Dall rams, it does not seem to be the dominant force in Dall ram survival where rams are hunted in Alaska. As important as full-curl Dall ram hunting is to hunters, managers, and the economy of Alaska, it doesn't seem that influential on Alaska's Dall sheep populations as currently managed.

ADDENDUM

Results of these analytical exercises were presented to the Alaska Guide and Commercial Services Board (which regulates guiding) and the Alaska Board of Game as relevant to proposals to drastically restrict non-resident (and some resident) hunting based on the premise that harvest at legal age/size was close to 100%. After these data were reviewed, the Alaska Board of Game made no changes to Dall sheep hunting regulations. Non-resident hunting is still open to anyone who wants to go, as long as they can afford the license, tag fee, and the hire of a registered guide as required by law. Similarly, there were no additional restrictions on (or liberalization of) resident hunting. The Alaska Board of Game retained Alaska's full-curl law as it currently existed. This, however, is certainly not the end of the story. Politics and special-interest pressure may yet alter Alaska's Dall ram harvest management program.

ACKNOWLEDGEMENTS

and Figures for this report. The Wild Sheep Foundation funded travel to Commercial Services Board meeting in Anchorage for Joe and me. Jessica Mitchell of ADF&G facilitated provision of the harvest data base. All I've done is tell the story and bring my particular perspective to management relevance.

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THE COST OF TRYING: WEAK CORRELATIONS AMONG LIFE-HISTORY COMPONENTS IN MALE UNGULATES

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Abstract: Although life-history trade-offs are well known in female mammals, little is known about the extent of trade-offs among males in polygynous species. I compared age-specific growth, weapon growth, survival and reproductive success in male ungulates, including 3 populations of bighorn sheep (*Ovis canadensis*) and one of mountain goats (*Oreamnos americanus*), and found weak interspecific correlations among these life-history traits. Although young males in rapidly-growing species tended to have higher reproductive success than young males in slow-growing species, there was no clear interspecific trade-off between early reproduction and early survival. Age-specific patterns of reproductive success differed widely among species, but were weakly related to differences in age-specific survival. Reproductive senescence was evident in most species. The main determinant of male reproductive success in most polygynous species is the ability to prevail against competing males. Consequently, the number and age (or size) structure of competing males should strongly affect an individual's ability to reproduce. Classic trade-offs among life-history traits, such as between growth and survival, or between early and late reproduction, may have a limited impact on the reproductive success of males in many of these species. The greatest fitness costs of reproduction in most males may arise from the energetic costs and injuries sustained while attempting to mate. The correlation of these costs with reproductive performance may be weak.

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"DID WE ACTUALLY DO ANYTHING?"—THE ??? MILLION DOLLAR QUESTION

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Abstract: It is unusual for a wild sheep biologist to enter the profession and survive long enough as a specialist/manager to effect a regulatory change in season or bag limit. It is even more unusual for a sheep manager to then live long enough to see the results of that change in management. After wrestling with "what management is" for decades, I have come to define "management" in the general sense as intervening in any established system to enhance a pre-defined benefit. In Alaska, the pre-defined benefit from wildlife management is set by Constitutional and Statutory mandates. These mandates call for maximizing benefits to the economy and general well being of Alaska in a sustainable manner. Working under these guidelines, my friends and I stumbled onto a regulatory change linking Dall sheep (*Ovis dalli*) behavior to Dall ram harvest which manifested itself as Alaska's full-curl regulation 20 years ago. Throughout the full-curl era to date, Alaska has harvested about 23,000 rams. The economic value of each ram in today's dollars can be extrapolated from economic valuation studies in 1983 and 1994. The adjusted economic benefit from Dall ram hunting in Alaska over the last 20 years sums to an astronomical figure, $437 million. The annual economic benefit to Alaska in today's economy is approximately $20 million per year. Benefits to the "general well-being" of the state probably represent general satisfaction of Alaskans with the sustainability of the Dall sheep resource, its status and availability to them, and the degree of public empathy the hunting community and other Alaskans have with their public trust interest in Dall sheep. The economic and "general well-being" benefits derived from Alaska's Dall sheep resource over the last 20 years of full-curl management are presented and discussed in an effort to define whether "We actually did anything" in establishing the full-curl management scheme--or not.

It is unusual for wildlife managers, particularly managers of long-lived species such as wild sheep, to know with certainty whether they achieved anything beyond implementing a specific regulatory change. With respect to management of wild sheep harvests by human hunters, the success of regulatory changes often takes years or decades to define. Because Dall (*Ovis dalli*) rams do not generally become legal for harvest in Alaska until eight years after their birth, the rationale for regulatory change has often been long-forgotten by the time the results are apparent.

Even if a biologist lives long enough to effect a regulatory change, evaluation of success or failure seldom occurs (perhaps due to the long lag-time required to evaluate the effects of regulatory change). In the absence of a viable evaluation, one opinion seems as good as another while miscellaneous, opinion-based changes befuddle hunters. If success should ever be evaluated, it will most likely be subjectively judged by subsequent generations of opinion-driven hunters or managers. This is not surprising because management itself is not well defined in these postmodern times (Heimer 2004, 2008). In this philosophical environment, there can be no objective criterion for judging success or failure. If there is no objective measure of success, one has to wonder at the logical validity of the enterprise we, as sheep managers, take so seriously we risk our lives in its pursuit (Heimer 1999a).

In an effort to answer the query of a long-time friend and cooperator in Alaskan Dall sheep management, "*Did we actually do anything?*" I

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began with a definition of management which will certainly date me as "modern" (as opposed to contemporary or "postmodern"). This, perhaps antiquated, definition of "management" is:

Intervening in an established system to enhance a pre-defined benefit.

In business management, the pre-defined benefit is profit; in human resource management, efficiency and worker satisfaction are the pre-defined benefits. In wildlife management as a discipline, the pre-defined benefit seems undefined, except perhaps in Alaska. Because the predefined benefit we "manage" to achieve is clearly defined, evaluation of success or failure becomes possible in those terms. It's just a matter of doing it.

In Alaska, the pre-defined benefits mandated as measures of management success are clearly articulated in the Alaska Constitution and Alaska Statutes. The existence of these mandates does not automatically eliminate argument on this matter because of social and political influences and personally held meta-values about wildlife. Nevertheless, Alaska Statutes (16.05.020) define the duties of the chief wildlife manager of the state, the Commissioner of Fish and Game. The Commissioner's second duty (after being the chief wildlife management officer) is to:

(2) manage, protect, maintain, improve, and extend the fish, game, and aquatic plant resources of the state in the interest of the economy and general well being of the state;

This statute gives force to the Alaska Constitution Article VIII which mandates management of maximal harvests (for human use as clearly intended in the notes of the Resource Committee at Alaska's Constitutional Convention) based on the sustained yield principle. Consequently, a legalistic or semantically rigorous approach to defining management success or failure seems to require intervening in established ecosystems, whether "natural" or not, to maximize the predefined benefits to the economy and general well-being of the state.

Measuring or quantifying the economic benefits produced by managing hunting and harvest of Alaska Dall sheep was relatively straightforward in concept. The devil was in the details, and the details were managed by my

colleague of those days, Sarah Watson-Keller in a pioneering study of the economic value of Alaska Dall ram hunting in 1983 (Watson 1984, 1986). Following this groundbreaking work, in 1994 a subsequent joint economic study overseen by Alaska Department of Fish and Game (ADF&G)'s Suzanne Miller and the US Forest Service repeated the process for all big game hunting in Alaska in 1994. These studies both defined the economic value of Dall ram hunting using established non-market valuation techniques (Watson 1984). When dollar values of both studies were adjusted to express the overall value in today's dollars, they gave remarkably similar estimates of the primary expenditures in Alaska related to Dall ram hunting. In today's dollars, the average primary benefit to the Alaskan economy is about $19,000 dollars per harvested ram (this figure includes the expenditures of unsuccessful hunters). If we multiply the estimate of harvest (23,000 full-curl rams harvested over the last 20 years) by today's average dollar value per ram ($19,000), the cumulative primary economic benefit to Alaska over the 20-year full-curl management period has been about $437 million in today's dollars.

This is a dazzling figure which shows the economic importance of Dall ram hunting to the Alaskan economy, but offers little to answer the question of whether the full-curl regulation produced an economic benefit to the State of Alaska. The best we can do to address this question is to review the original justification for the full-curl regulation. About 1984, Heimer and Watson made the initial counter-intuitive argument that harvests from ram-depleted populations would increase if more mature rams were present during rut, established a demonstration project, and reported confirmatory results in 1990. The data indicated a 35% increase in full-curl ram harvest over 3/4 curl and 7/8 curl harvests under those regulation schemes in a stable, carefully monitored, ram-depleted population of about 2,000 Dall sheep over a five year test period (Heimer and Watson 1986a, 1986b, 1990). If sustainable harvests increased 35% statewide, the net economic benefit from the full curl regulation over the last 20 years would calculate at 35% of $437 million or about $150 million. This sum, while it represents the upper

limit of what might have been possible is simply too large to be credible. For it to approach reasonability, all ram populations in Alaska would have had to have been ram-depleted like the study population. They weren't.

Because the harvest from this ram-depleted population increased by 35 percent following the change from 7/8 to full-curl harvest regulation with no changes in ewe population size, it may be reasonable to suggest ram-depleted population harvests in other areas might have shown similar increases. However, not all populations in Alaska were ram-depleted when the full-curl regulation was implemented. At that time (in the mid- and late-1980s) statewide huntable sheep numbers were at the recorded maximum of about 50,000 Dall sheep of the 72,000 estimated to be present in Alaska (about 25 percent of Alaska's sheep were, and remain off limits to hunters because they are in National Parks).

Hence, the experimental ram-depleted population (numbering about 2,000 sheep) represented 4% of the total huntable population. Taking 35% of the gross revenues from 4% of the estimated $437 million benefit produced by Dall ram harvesting gives a regulation-assignable benefit of 4% of $437 million total dollars produced from the study population alone. This figure is still significant, summing to $17.5 million dollars over the last 20 years. The net increase in harvest, 35 percent, contributing to this figure gives a minimum benefit to Alaska's economy of about $6.1 million present-day dollars accruing to the economy of Alaska from these 2,000 huntable sheep. This calculates to an average of something above $300,000 annually as a minimum economic benefit from the full-curl regulation produced by a ram-depleted population amounting to only 4% of the total huntable population over the last 20 years.

These calculations are somewhat similar to the popularly accepted, simple arithmetic approach to calculating carbon emissions and their effect on global climate change for any given human endeavor. Both seem based on reasonable assumptions at the start, but when the arithmetic has been done, astounding totals result.

In the end the net result of intervening in the existing Dall ram harvest allocation system to maximize biological stability and economic benefits to the economy of the state seems to have

been positive. The upper limit of economic benefit might have been as high as $150 million in 2012 dollars (an unrealistically expansive calculation sum simply extrapolated to the entire state) or as low as $6.1 million dollars (if limited to just the realized increase from the first experimental population). By either of these standards, it would seem that Dall ram hunting as presently managed maximizes the opportunity for economic benefit to the state under current harvest allocation procedures (see Heimer, pages 15–24, these proceedings). Consequently, I think the answer to my friend's question, "*Did we actually do anything?*" should be answered in the affirmative. I think we intervened in the established system to increase the pre-determined benefit to the economy of the state. Just how much we'll probably never know—but it was a LOT of money. Dall ram hunting remains a major "profit center" for the state of Alaska.

Still, we should not forget that Alaska's mandate to its wildlife managers goes beyond economic benefit to the state, also including the state's general well-being. Did we maximize the benefit to the general well-being of the state? Here, I argue the answer should be, "Yes."

I have previously argued that the North American wildlife management model, as applied in the United States, makes hunting the lynchpin of conservation in the United States. When the general citizenry identifies itself as an active participant in realizing benefits from its resources (the Alaskan public-trust model from Article VIII of Alaska's Constitution), the money to effect conservation flows freely (from hunting licenses and matching federal revenues). Also, an interested public is protective of its personal interest in benefits resulting from resource management. Hence, it should follow that the chances for successful conservation increase with heightened public support and interest. For Dall sheep in Alaska, this still means ram hunters.

After looking at the Alaskan situation for four decades, I suggest the major benefit we provided for the general well-being of the state (and its Dall sheep) was heightened identity of the Dall ram hunting public with its Dall sheep resource. When I arrived in Alaska 44 years ago, it was difficult to find a resident who was not closely tied to the land, the water, or the wildlife in some way. As time

passed, this bond seemed to erode. Building the Trans-Alaska Oil Pipeline attracted a differing type of person to Alaska. These newcomers were not here to bond with Alaska's land, waters, and wildlife, but to make money building the pipeline. As I have written, perhaps too extensively, determining who would own the land the pipeline sat on (and thus receive royalty money and have taxation power) first required settlement of long-standing Alaska Native Land Claims. In the course of this settlement, folks with a new and different conservation model (coercive protection of resources) gained the upper hand (Heimer 1999b).

The resulting ascendancy of managing agencies as "owners" further eroded the bond Alaskans had with land, water, and wildlife. The separation of Alaskans from land, water, and wildlife was particularly accelerated by the re-assumption of ownership of all these essential elements of the Alaskan lifestyle by the federal government. The state agencies were not immune from this trend, and the "manager as owner" began to emerge as the dominant ethos at the state level as well. This was the condition with respect to Dall sheep when my friends and I stumbled onto the notion that meeting the constitutional and statutory mandates in Alaska would require we take steps to maximize harvests that had not yet entered the general management consciousness.

Our Department of Fish and Game leadership was uniformly unprepared to factor animal behavior into harvest regulations (which is the principle upon which the full-curl regulation rests). Consequently, the management agency was virulently opposed to the counter-intuitive notion that waiting till rams were full-curl or eight years old would actually increase harvests (which it did by 35% in a study population—see above or the references to papers by Heimer and Watson).

As events unfolded, because of my advocacy for this change, I was punitively reassigned from the research section to the management section at ADF&G. This gave me ready access to the sheep-hunting public which invariably wanted not only to know where they could hunt, but what was "new" in sheep biology. This was a logical question for hunters because I had been the "research face" of Dall sheep at ADF&G for 15 years at that time. Naturally, I shared our data, and explained what we had learned to hunters. It all

seemed quite reasonable to them. As a result, proposals from the sheep hunting public were submitted to establish the full-curl regulation to increase benefits (harvests). Although the struggle over this issue when it came before the Board of Game was bitter and epic, the will of the Dall ram hunting public eventually prevailed over the strident resistance of ADF&G leaders, and our now 20-year old full-curl regulation was passed.

I argue that this public involvement in a fundamental management change basically wrested "ownership" from the managing agency (ADF&G) and returned it to the people of Alaska. This, I further suggest, was of immense, even if un-measurable, benefit to the "general well-being of the [people of] the state" as prescribed by AS 16.05.020. Not only did it vindicate data-based species biology as the basis of management (including harvest), it empowered Alaska's Dall sheep hunters, and effectively raised the status of sheep hunters and sheep hunting. All these years later, Dall sheep research and management budgets have grown to levels unimaginable during my tenure as a sheep researcher and manager.

Of course, owner-hunters can be more troublesome for managing agencies to "satisfy" than passively managed predators, which is what hunters become when they fail to assert their ownership of Alaska's resources. The other paper I have in this symposium demonstrates that the "owner-hunters" may not always have the most enlightened view of management, allocation of harvests, and Alaska's constitutional and statutory mandates. Still, as long as they're actively participating in the system (whether in harmony or acrimony), the chances for successful Dall sheep management appear to remain higher.

So, to my friend who asked, "Did we actually do anything?" my answer is an emphatic yes. Others may disagree, but I think things are better than they might have been in spite of the challenges faced over the years.

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ECOTYPIC VARIATION IN RECRUITMENT OF REINTRODUCED BIGHORN SHEEP

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Abstract: Prior to settlement, the North Dakota badlands were occupied by Audubon's bighorn sheep (*Ovis canadensis auduboni*). The North Dakota Game and Fish Department subsequently reintroduced California bighorn (*O. c. californiana*) descended from the Williams Lake region of British Columbia, Canada (WL ecotype), and Rocky Mountain bighorn (*O. c. canadensis*) descended from the Sun River region of Montana, USA (SR ecotype). Although California and Audubon's bighorn were recently reclassified as Rocky Mountain bighorn (*O. c. canadensis*), the native bighorn of North Dakota occupied a harsher climate than the Williams Lake region of British Columbia and were more similar to bighorn from the Sun River region. Because reintroductions still play a key role in bighorn sheep management and local adaptation may have substantial demographic consequences, we used mixed-effects logistic regression to evaluate causes of variation in lamb recruitment of bighorn sheep reintroduced in North Dakota.

During 2006–2010, SR ecotype bighorn recruited 0.54 lambs/ewe (n = 113 ewes), whereas the WL ecotype recruited 0.24 lambs/ewe (n = 562 ewes). Our most plausible candidate model (53% of model weight) attributed variation in recruitment to differences between source populations (odds ratio = 4.5; 90% CI = [1.5, 15.3]). Greater recruitment of SR bighorn (fitted mean = 0.56 lambs/ewe; 90% [0.41, 0.70]) contributed to a net gain in abundance (r = 0.16), whereas WL bighorn (fitted mean = 0.24 lambs/ewe; 90% CI [0.09, 0.41]) declined (r = - 0.03). Translocations are the primary tool used to augment or restore wild sheep populations but often fail to achieve desired results. Our results are the first experimental evidence that the similarity of source stock to native bighorn may have long-term implications for population performance.

*Key words***:** Audubon's bighorn sheep, *Ovis canadensis auduboni,* Rocky Mountain bighorn, *Ovis canadensis Canadensis*, recruitment, reintroduced population.

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MODELING RESOURCE SELECTION OF MOUNTAIN GOATS IN SOUTHEASTERN ALASKA: APPLICATIONS FOR POPULATION MANAGEMENT AND HIGHWAY DEVELOPMENT PLANNING

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Abstract: Mountain goats (*Oreamnos americanus*) are among the most culturally and economically important large mammal species in Alaska. Due to their low population growth rates and relatively high degree of sensitivity to natural and anthropogenic disturbance, resource management decisions must be carefully evaluated to ensure sustainable populations. In this study we combined data collected from 124 GPS radio-marked mountain goats and remote sensing data layers in a GIS-based resource selection function (RSF) modeling framework. Modeling output was used to characterize the spatial distribution of mountain goat habitat in an area subject to construction of an all-season highway. We characterized the extent to which the proposed highway overlapped with predicted mountain goat wintering habitat in order to assess the need for and recommend appropriate modifications of mountain goat population management strategies and highway mitigation methods. We determined that the proposed highway would transect 25.3 km of predicted high-to-moderate-use mountain goat wintering areas. In the event the proposed highway is constructed we propose specific changes to existing mountain goat hunting regulations and management strategies and provide recommendations for how highway design, construction, maintenance, and use can be implemented to reduce deleterious effects to local mountain goat populations.

Mountain goats (*Oreamnos americanus*) are among the most culturally and economically important large mammal species in Alaska. Consequently, mountain goats are carefully managed to account for a broad array of human uses and considerations including subsistence and sport hunting, wildlife viewing, and native customary uses involving blanket weaving and handicrafts. Effective management of mountain goats requires field-based data and an empirical understanding of factors that influence population dynamics such as winter severity, human harvest, disease or industrial disturbance. Ideally, model-based frameworks informed by field data are used to predict specific outcomes or qualitative assessments of proposed management actions.

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However, in many cases basic knowledge about population biology and resource selection are lacking, particularly in relation to risk factors, and studies are needed to articulate appropriate management responses to natural and anthropogenic changes to the environment.

Mountain goats have very specialized habitat requirements, a conservative life-history strategy and low population growth rates relative to other ungulates (Fox et al. 1989, Festa-Bianchet and Côté 2006). These characteristics likely contribute to the species' sensitivity and apparent vulnerability to industrial development activities. Past studies have documented negative impacts of industrial development activities that include temporary range abandonment, alteration of foraging behavior, and population decline (Chadwick 1973, Foster and Rahs 1983, Joslin 1986, Côté 1996, Côté and Festa-Bianchet 2003, Hurley et al. 2004). Thus, in the context of proposed development activities, acquisition of knowledge about mountain goat resource selection patterns and distribution represents a key preliminary source of information needed to assess the extent to which industrial development has potential to affect a given population.

Southeastern Alaska is a maritime region sparsely populated by small cities and rural communities, and connected by a network of state ferries and, in a few cases, roads. Juneau (population = 31,000), the capital of Alaska, is located 110 km south of the small rural community of Haines and the continental highway system. The state of Alaska (Department of Transportation and Public Facilities) has proposed the construction of an 83.6 km all-season highway from the Juneau road system to the Katzehin river flats (i.e. the Juneau Access Highway Improvements Project), a project that would substantially shorten the existing 4.5 hour ferry ride required for Juneau residents to access the continental highway system in Haines. The proposed highway alignment traverses steep, rugged, and largely inaccessible terrain along the shore of Lynn Canal and Berners Bay. Substantial portions of the proposed highway corridor transect expected mountain goat winter habitat. As such, activities associated with construction, maintenance and use of the proposed highway are
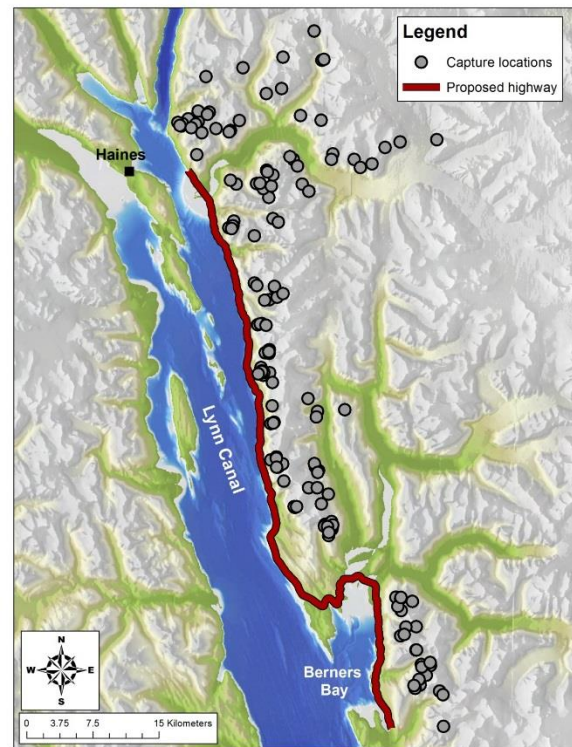
Fig. 1. Locations of mountain goats captured and subsequently monitored in the study area, 2005-2011.

expected to affect local populations and require altered mountain goat management strategies.

The intent of this study was to combine mountain goat GPS location data with remote sensing data layers in a resource selection function (RSF) modeling framework to quantitatively characterize mountain goat habitat in the vicinity of the proposed highway development area. Assessment of the extent of overlap between the proposed highway corridor and mountain goat habitat will then be used to identify appropriate highway mitigation methods and explore the degree to which existing mountain goat management strategies need to be modified.

STUDY AREA

Mountain goats were studied in an approx. 1,077 km² area located in a mainland coastal mountain range east of Lynn Canal, a marine fjord located near Haines in southeastern Alaska (Fig. 1). The initial study area was oriented along a north-south axis and bordered in the south by Berners Bay (58.76N, 135.00W) and by Dayebas Creek (59.29N, 135.35W) in the north. Because winter elevational distribution differed between

areas east of Berners Bay (hereafter "East Berners") and in Lynn Canal (Lions Head, Mt. Sinclair and Mt. Villard), the study area was further subdivided for resource selection function analyses.

Elevation within the study areas ranges from sea level to 1,920 m. This area is an active glacial terrain underlain by late cretaceous-paleocene granodiorite and tonalite geologic formations (Gehrels 2000). Specifically, it is a geologically young, dynamic and unstable landscape that harbors a matrix of perennial snowfields and small glaciers at high elevations (i.e. above 1,200 m) and rugged, broken terrain that descends to a rocky, tidewater coastline. The northern part of the area was bisected by the Katzehin River, a moderate volume (approx. 42 m^3/second; US Geological Service, unpublished data) glacial river system that is fed by the Meade Glacier, a branch of the Juneau Icefield.

The maritime climate in this area is characterized by cool, wet summers and relatively warm snowy winters. Annual precipitation at sea-level averages 140 cm, and winter temperatures are rarely less than -15º C and average -1º C (Haines, AK; National Weather Service, Juneau, AK, unpublished data). Elevations at 79 m typically receive approx. 635 cm of snowfall, annually (Eaglecrest Ski Area, Juneau, AK, unpublished data). Predominant vegetative communities occurring at low-moderate elevations (<450 m) included Sitka spruce (*Picea sitchensis*)-western hemlock (*Tsuga heterophylla*) coniferous forest, mixed-conifer muskeg, and deciduous riparian forests. Mountain hemlock (*Tsuga mertensiana*)-dominated 'krummholtz' forest comprised a subalpine timberline band occupying elevations between 450–760 m. Alpine plant communities were composed of a mosaic of relatively dry ericaceous heathlands and moist meadows dominated by sedges and forbs and wet fens. Avalanche chutes were common in the study area and bisected all plant community types and often terminated at sea-level.

METHODS

Mountain Goat Capture and Collar Deployment

Mountain goats were captured using standard helicopter darting techniques, and immobilized by injecting 3.0–2.4 mg of carfentanil citrate, depending on sex and time of year (Taylor 2000), via projectile syringe fired from a Palmer dart gun (Cap-Chur, Douglasville, GA). During handling all animals were carefully examined and monitored following standard veterinary procedures (Taylor 2000) and routine biological samples and morphological data were collected. Following handling procedures, the effects of the immobilizing agent were reversed with 100 mg of naltrexone hydrochloride per 1 mg of carfentanil citrate (Taylor 2000, White et al. 2012). All capture procedures were approved by the State of Alaska Animal Care and Use Committee.

GPS Location Data

Telonics TGW-3590 GPS radio-collars (Telonics, Inc., Mesa, AZ) were deployed on most animals captured. GPS radio-collars were programmed to collect location data at 6-hour intervals (collar lifetime: 2–3 years). Complete datasets for each individual were remotely downloaded via fixed-wing aircraft at 8-week intervals. Location data were post-processed and filtered for "impossible" points and 2D locations with PDOP (i.e. position dilution of precision) values greater than 10, following D'Eon et al. (2002) and D'Eon and Delparte (2005).

Habitat Selection, Activity and Movement Patterns

Wintering Strategies and Elevational Distribution

GPS locations were intersected with the NASA Shuttle Radar Topography Mission (SRTM) digital elevation model (http://srtm.usgs.gov/ index.php) using Geospatial Modeling Environment (http://www.spatialecology.com /gme) in order to determine elevation for each GPS location. Average daily elevation was then estimated for each individual animal and summarized by individual animal, sex and day in order to estimate sex-specific average daily

Table 1. Remote-sensing covariates used to derive mountain goat resource selection functions, 2005-2011, Lynn Canal, AK.

Variable	Definition	Source Data
Elevation	elevation (meters)	SRTM DEM[1]
Slope	slope (degrees)	SRTM DEM[1]
Distance to escape terrain	distance to areas with slope > 40 degrees	SRTM DEM[1]
Solar radiation (Jan 1)	solar radiation calculated for January 1	SRTM DEM[2]
Solar radiation (August 1)	solar radiation calculated for August 1	SRTM DEM[2]
VRM	vector ruggedness measure	SRTM DEM[3]

[1]Calculated using the Spatial Analyst Extension in ArcGIS 10

[2]Calculated using the solar radiation algorithm in ArcGIS 10 (Fu and Rich 2002)

[3]Calculated using methods described in Sappington et al. (2007)

elevation. These data were then used to describe seasonal patterns in distribution, specifically to determine when animals conducted altitudinal migrations between summer and winter ranges.

Habitat Selection and Modeling

Resource selection function (RSF) models (i.e. Boyce 2002) were developed using mountain goat GPS location data and remote sensing covariate data layers in a GIS framework in order to describe where important winter and summer habitats occurred in the study area. A resource selection function can be defined as: a model that yields values proportional to the probability of use of a given resource unit (Boyce et al. 2002). Specifically, we employed a logistic regression-based "used" vs "available" study design to estimate resource selection patterns at the population-level (i.e. first-order selection, Johnson 1980). In order to estimate resource availability in the study area we randomly selected locations throughout the study area at a density of 30 locations per km^2, a density determined to reliably describe resource availability patterns in our study area (D. Gregovich, Alaska Department of Fish and Game (ADFG; unpublished data). Mountain goat GPS locations (i.e. "used") and "available" locations were then intersected (using GIS) with a suite of biologically relevant remote sensing data layers (Table 1). These data were then analyzed using logistic regression (GLM function, stats package, Program R, ver. 2.13.1) to derive selection coefficients for each covariate by individual animal. With the exception of the "distance to cliffs" variable both linear and quadratic terms were used to describe selection functions for each variable. In a few cases variable

coefficients calculated for individual animals resulted in extreme values (i.e. <3 standard deviations of the mean), apparently due to unusual individual selection patterns. Such individuals were considered outliers and systematically removed from analyses. This procedure was necessary to ensure that models accurately represented selection patterns of a majority of animals and that final model coefficients were not unduly influenced by animals exhibiting atypical behavior.

The average inter-individual coefficient value (and confidence interval) was computed for each covariate (ie. the "two-stage" modeling framework; Fieberg et al. 2010) and stratified by season (winter vs. summer) and study area (East Berners vs. Lynn Canal). Stratification by study area was deemed appropriate because animals in the East Berners study area wintered at slightly higher elevations than those along Lynn Canal. Covariates considered to be significant were evaluated by examining whether confidence intervals for a given covariate included zero. Significant coefficient values were then multiplied by respective covariate remote sensing data layers in GIS using the following equation:

$$w(x) = \exp(\beta_1 x_1 + \beta_2 x_2 + \ldots + \beta_n x_n) \qquad (1)$$

where w(x) represented a RSF that was proportional to the probability of use of variables $x_1 + x_2 + \ldots + x_n$. The resulting output was then categorized (using the quantile function in ArcGIS10) to characterize areas across the study area that differed in their relative probability of use by mountain goats. The predictive performance of RSF models was validated using k-fold cross validation (Boyce et al. 2002).

RESULTS

Mountain Goat Capture and Collar Deployment

Mountain goats were captured during August–October 2005–2011. Overall, 159 animals (75 females and 84 males) were captured including 7 re-capture events. One hundred and thirty-five animals were fitted with Telonics GPS radio-collars, and 23 animals were fitted with conventional (i.e. non-GPS) VHF-only collars. Analyses were based on data collected from 124 GPS radio-marked mountain goats; adequate data were not collected from the 11 remaining GPS collar deployments. Data collected from the 23 VHF-collared animals were not included in analyses.

GPS System Performance

Overall, 193,681 GPS locations were acquired from the 124 GPS collars included in analyses. This comprised 83% of the total possible GPS fixes attempted (n = 233,497), an acceptable fix success rate. Field testing during 2006 indicated that location dispersion (an index of accuracy) was lowest in open habitats (median = 20.1 m, mean = 28.3 ± 3.0 m, n = 11), intermediate in cliff habitats (median = 46.8, mean = 50.7 ± 15.4 m, n = 3) and highest in forested habitats (median = 40.6 m, mean = 69.7 ± 15.1 m, n = 11). Because remote sensing data layers used for habitat modeling are typically refined to 30 m resolution, these levels of accuracy are acceptable for routine applications.

Wintering Strategies and Elevational Distribution

Nearly 95% of the mountain goats monitored with GPS radio-collars wintered in low-elevation forested habitats. Typically, migration from low elevation winter ranges to alpine summer range commenced in mid-May; females tended to initiate migrations approx. 2 weeks earlier than males on average (Fig. 2). Migration from summer range to winter ranges typically commenced in mid-October and coincided with the first annual significant alpine snowfall event (Fig. 2).

Resource Selection Modeling

Mountain goat resource selection was analyzed separately for the winter and summer seasons
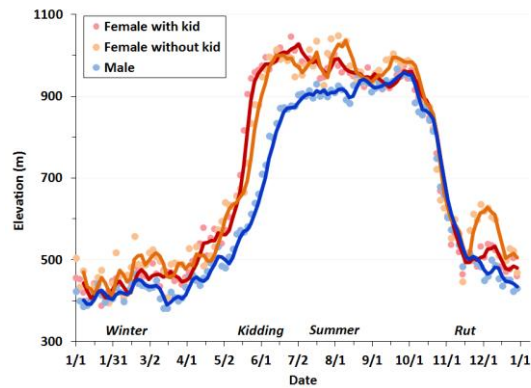
Fig. 2. Elevation distribution on GPS radio-marked mountain goats (n = 124) in relation to time of year, Lynn Canal, AK, 2005-2011. Elevation was calculated by summarizing daily mean values, by individual, and based on GIS estimates via the SRTM digital elevation model.

based on previously described differences in seasonal altitudinal distribution (Table 2a, 2b). Overall, resource selection was modeled using five terrain variables (Table 2b), with the exception of the East Berners summer model which included three terrain variables (Table 2a). In general, mountain goat selection patterns for most terrain variables were similar during winter and summer; elevation was the only variable for which seasonal selection patterns differed substantially (Table 2a, 2b). Overall, mountain goats selected areas close to cliffs with moderately steep, rugged slopes that had moderate-high solar exposure. Within this context, mountain goats selected low elevation areas during winter and moderate-high elevation areas during summer. Interestingly, mountain goats tended to winter at slightly higher elevations in the East Berners study area relative to the Lynn Canal study areas. In the Lynn Canal area steep rugged terrain often continuously extended from alpine areas to sea level. Whereas, on the east side of Berners Bay steep terrain often terminated at mid-elevation upland areas of moderate slope and less commonly extended to sea level.

Despite these general patterns in resource selection it is important to note that individual variation in resource selection was detected such that some individual animals demonstrated resource selection patterns that differed from the majority of animals. For example, the few marked animals in the upper Meade Glacier and Antler

Table 2. Resource selection function (RSF) coefficients for remote-sensing variables used to derive RSF models for mountain goats in the a) East Berners area, Alaska, 2006-2011 and b) Lynn Canal area, Alaska, 2006-2011.

a)

Variable	Winter			Summer		
	Coefficient	LCI	UCI	Coefficient	LCI	UCI
elevation	-2.812129	-4.650915	-0.973344	2.161979	1.764804	2.559154
elevation^2	-2.556290	-3.365947	-1.746633	-2.427439	-2.883036	-1.971843
cliffs	-5.235536	-7.275517	-3.195555	-2.436600	-3.431124	-1.442076
slope	-0.653048	-0.949059	-0.357037	--	--	--
slope^2	-0.233425	-0.441483	-0.025367	--	--	--
solar (Jan 1)	1.376696	0.586528	2.166864	NA	NA	NA
solar (Jan 1)^2	-0.438847	-0.861545	-0.016149	NA	NA	NA
solar (Aug 1)	NA	NA	NA	0.266072	-0.072772	0.604916
solar (Aug 1)^2	NA	NA	NA	-0.265269	-0.429749	-0.100790
VRM	0.173776	-0.174946	0.522499	--	--	--
VRM^2	-0.310421	-0.516873	-0.103968	--	--	--

b)

Variable	Winter			Summer		
	Coefficient	LCI	UCI	Coefficient	LCI	UCI
elevation	-7.424985	-8.805059	-6.044912	1.606339	1.167352	2.045325
elevation^2	-2.946404	-3.644584	-2.248223	-3.326321	-3.640783	-3.011859
cliffs	-1.843572	-2.158784	-1.528361	-0.651351	-0.833230	-0.469473
slope	1.190326	0.974464	1.406187	0.599884	0.413313	0.786455
slope^2	-0.363247	-0.445018	-0.281475	-0.367023	-0.445540	-0.288505
solar (Jan 1)	0.541136	0.235795	0.846477	NA	NA	NA
solar (Jan 1)^2	-0.883769	-1.089006	-0.678532	NA	NA	NA
solar (Aug 1)	NA	NA	NA	0.221452	0.059737	0.383167
solar (Aug 1)^2	NA	NA	NA	-0.221750	-0.325468	-0.118032
VRM	0.722373	0.563777	0.880968	0.233641	0.151278	0.316004
VRM^2	-0.272687	-0.330349	-0.215025	-0.052771	-0.070885	-0.034657

Lake areas wintered at high elevations, a phenomenon that was probably linked to local climate and/or inaccessibility of low elevation forested winter ranges. Consequently, as described previously, it is important to recognize that our models represent "average" resource selection patterns and may not be representative for every animal and specific locality in the study area.

Model validation results indicated that resource selection models accurately predicted actual use patterns of GPS-marked mountain goats (Table 3a, 3b). The Lynn Canal models tended to perform better than models for East Berners. Since the Lynn Canal models were developed with substantially more mountain goat GPS location data it is not surprising that the Lynn Canal models more accurately predicted actual use patterns than the East Berners models. The winter model for East Berners was characterized by the lowest performance (though validation results still indicated a significant relationship between actual and predicted use). This occurred because the model tended to under-represent use in some areas (i.e. areas with low RSF scores were used more than predicted). Consequently, the winter modeling output for the East Berners area should be considered a conservative representation of actual mountain goat winter use and distribution in this area.

DISCUSSION

Elevational Distribution

Along the Pacific coast, mountain goats exhibit elevational migrations from alpine summer range to low-elevation, forested winter ranges where snow depths are relatively reduced (Herbert and Turnbull 1977, Fox et al. 1989). This pattern

Table 3. Resource selection function (RSF) model validation results for the a) Lynn Canal area, and b) East Berners area, relative to season. Cross-validated Spearman-rank correlations (r_s) between RSF bin ranks and area-adjusted frequencies for individual and average model sets reported below provide an indication of the extent to which RSF models accurately predicted actual use of iteratively withheld data from GPS-marked animals.

a) Lynn Canal

Set	Winter r_s	Winter *P*-value	Summer r_s	Summer *P*-value
1	0.99	<0.001	0.99	<0.001
2	1.00	<0.001	1.00	<0.001
3	0.99	<0.001	0.99	<0.001
4	1.00	<0.001	0.99	<0.001
5	0.96	<0.001	1.00	<0.001
Average	0.77	0.014	0.99	<0.001

b) East Berners

Set	Winter r_s	Winter *P*-value	Summer r_s	Summer *P*-value
1	0.66	0.044	0.99	<0.001
2	0.88	0.002	0.61	0.066
3	0.19	0.608	0.96	<0.001
4	0.79	0.010	0.99	<0.001
5	0.94	<0.001	0.99	<0.001
Average	0.77	0.014	0.99	<0.001

Fig. 3. Resource selection function modeling output describing mountain goat winter range in the Lynn Canal area. The area juxtaposes the proposed highway alignment and predicted mountain goat winter habitat. The map encompasses an area near the Katzehin river mouth, near the northern terminus of the proposed highway and is included for illustrative purposes.

contrasts with mountain goat populations in colder, drier (generally interior) climates where mountain goats typically winter at high elevations on windblown slopes. In our study area, nearly all animals exhibited migrations to low elevation habitats between 300–450 m, on average (Fig. 2). In some instances, particularly along Lynn Canal, mountain goats spent considerable time below 150 m, including several cases where animals wintered in close proximity to high tide line. In contrast, in a few isolated instances (n = 7) mountain goats in specific locations wintered at high elevations. This was likely linked to colder, drier and windier climates in these areas and/or restricted access to warmer, less snowy coastal wintering habitats. Nonetheless, nearly 95% of the mountain goats monitored with GPS radio-collars in this study wintered in low elevation forested habitats.

Resource Selection Modeling

Our analyses described a strong affinity of mountain goats for areas with steep rugged terrain in close proximity to cliffs, a pattern previously described for the species in southeastern Alaska (Fox et al. 1989) and elsewhere (Festa-Bianchet and Côté 2007). In fact, terrain characteristics can be considered a key prerequisite for predicting mountain goat habitat, irrespective of season. However, during winter, mountain goat selection is further constrained to include lower elevation habitats that are typically vegetated with closed canopy conifer forest. Such habitats have reduced snow depths (Kirchhoff 1987) and thus greater forage availability (Fox 1983, White et al. 2009) and reduced costs of locomotion (Dailey and Hobbs 1989). Nonetheless, snow shedding characteristics of steep terrain also reduces snow depth, resulting in use of non-forested habitats in some cases (particularly if sites are characterized by high solar radiation). In locations where steep terrain continuously extends from high elevation summer range to sea level such as along Lynn Canal, mountain goats will winter at extremely low elevations, including on cliffs immediately

Table 4. Proportion of the proposed highway that transects mountain goat winter habitat in the Lynn Canal and East Berners areas, Lynn Canal, AK, 2005-2011. Resource selection function (RSF Categories) were binned using the quantile function in ArcGIS 10 and intended to represent biological meaningful delineations for management and planning purposes.

RSF Bin	RSF Category	Lynn Canal		East Berners	
		km of road	Proportion	km of road	Proportion
0	Not Habitat	14.2	0.22	1.0	0.05
1	Low	19.4	0.31	18.5	0.92
2	Low-Moderate	4.6	0.07	0.5	0.03
3	Moderate	5.2	0.08	0.1	0.00
4	Moderate-High	8.4	0.13	0.0	0.00
5	High	11.7	0.18	0.0	0.00
Total		63.5	1.00	20.1	1.00

above high tide line (Fig. 3). In eastern Lynn Canal, 25.3 km of the highway alignment intersected areas in the "moderate" to "high" RSF categories (Table 4). However, in other localities, such as east of Berners Bay, steep terrain did not consistently extend to sea level, and mountain goats winter at slightly higher elevations, on average.

MANAGEMENT IMPLICATIONS AND RECOMMENDATIONS

Human Access

The construction of the Juneau Access highway would result in increased human access to areas determined to be high value mountain goat habitats. Increased human access (i.e. recreational and industrial) will increase the potential for disturbance of mountain goats, particularly in low-elevation wintering habitats. However, perhaps more importantly, large numbers of hunters from Juneau (population: 31,000) will be afforded unprecedented access to high quality mountain goat range. Such access will result in difficulties managing harvest quotas under existing (registration hunt) regulations; similar to outcomes resulting from construction of the Skagway-White Pass highway (30 km north of the present study) in the 1970s (Ryan Scott, ADFG, pers. obs.). Following road construction, hunting opportunities in this area should be regulated using more restrictive limited-entry drawing hunts in order to avoid overharvest. In addition, smaller more geographically distinct hunt areas should be

created to avoid localized depletion of mountain goats. Regulations should also take the timing of winter migration into account, as animals will be particularly vulnerable in overwintering areas near the road corridor. Finally, a specific management strategy should be considered for areas in the vicinity of Haines in order to respect and to maintain traditional harvest patterns.

Post-construction Highway Effects

As described above, findings from this study documented spatial overlap of the Juneau Access highway corridor and high value mountain goat wintering habitat. In such areas the probability of lethal and sub-lethal (i.e. Frid and Dill 2002) highway effects on mountain goats will increase following highway construction. Such effects should be carefully documented and explicitly integrated into mountain goat harvest strategies. For example, coordination between the ADFG and law enforcement agencies will be required to accurately document mountain goat-vehicle collisions and reduce harvest quotas accordingly. In order to assess the extent to which sub-lethal effects alter population size and productivity future studies are recommended that compare the existing baseline data to comparable data collected during and after construction of the highway. Such studies would help wildlife managers determine how the highway affects mountain goat habitat use and population dynamics and, ultimately, ensure that local mountain goat populations are managed in a manner that explicitly incorporates sub-lethal effects.
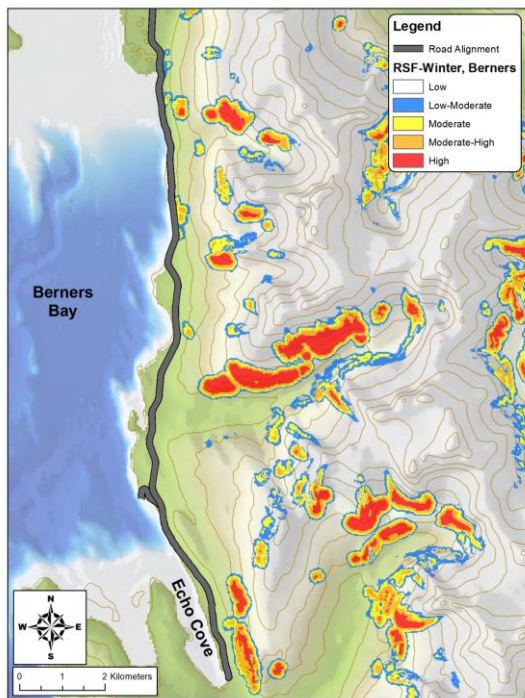
Fig. 4. Resource selection function modeling output describing mountain goat winter range in the East Berners area. The map encompasses an area east of Berners Bay, near the southern terminus of the proposed highway, and is included for illustrative purposes and juxtaposes the proposed highway alignment and predicted mountain goat winter habitat.

Mountain Goat-Vehicle Collisions

The Alaska Department of Transportation and Public Facilities (DOT/PF) has a stated interest in reducing or mitigating the likelihood of mountain goat-vehicle collisions along the Juneau Access highway, in the event it is constructed. Findings from this study indicated that highway alignment intersects areas of moderate-high mountain goat winter use (i.e. 25.3 km) along eastern Lynn Canal and, to a lesser extent, east of Berners Bay (Table 4, Figs. 3, 4). Consequently, to mitigate mountain goat-vehicle collisions DOT/PF should concentrate mitigation and design efforts in the eastern Lynn Canal and Berners Bay areas. Mountain goat-vehicle collision risk is only prevalent during the winter months (November– early May). During this season periods of reduced daylight and poor driving conditions may result in increased difficulty seeing and avoiding animals in low-light conditions. Appropriate design strategies for reducing mountain goat-vehicle

collisions would involve, but are not limited to, "wildlife crossing" signage, reduced speed limits, structural design features (i.e. Singer et al. 1985, Clevenger and Huijser 2011) and adequate sight lines to enable drivers to see mountain goats that are in close proximity to the road (particularly relevant in conifer forest areas). Ultimately, fine-scale highway design that integrates field visits to identify traditionally used mountain goat trails, mountain goat GPS location data and geotechnical highway construction constraints is recommended in order to maximize efficacy of mountain goat-vehicle collision planning and mitigation. Such site-specific analyses was beyond the scope of the current study but is recommended via future collaboration between ADFG and DOT/PF.

Avalanche Control

Avalanche chutes are prevalent along the eastern side of Lynn Canal and Berners Bay and intersect the highway alignment in many areas. Human safety concerns require avalanche control activities upslope from the road corridor in areas adjacent to or currently used by mountain goats during winter. Avalanche control activities (ie. helicopter surveillance, blasting) will cause significant disturbance to mountain goats in such areas. Further, because mountain goats occasionally forage in avalanche chutes during winter (including during times of high avalanche danger) the likelihood exists for mountain goats to be killed in human-instigated avalanches that occur during routine control activities. Such direct mortalities could be mitigated if avalanche control crews examined avalanche chutes for the presence of mountain goats prior to blasting and adjusted avalanche control scheduling to occur during times when mountain goats were not present in avalanche paths.

Monitoring Efficacy of Recommendations

The above mentioned mitigation strategies are designed to reduce the impact of road construction, maintenance , and continued use on mountain goats, via direct mortality or indirect reduction in productivity. However, implementation success is uncertain based on limited previous study. Detailed post-development studies designed to determine effectiveness of site-specific mitigation

prescriptions are recommended to ensure mitigation strategies are optimized for reducing mountain goat-vehicle collisions, overharvest, and mortality from avalanche control. Such monitoring studies could identify and remedy any site-specific issues, and could be used to inform future road building projects that potentially impact mountain goats and their habitat.

ACKNOWLEDGEMENTS

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HABITAT SELECTION, ACTIVITY AND MOVEMENT PATTERNS OF MOUNTAIN GOATS IN SOUTHEASTERN ALASKA

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Abstract: Mountain goats (*Oreamos americanus*) inhabit environments characterized by extreme topographic and climatic variability and are expected to exhibit specialized strategies designed to cope with such conditions. Within this context, demands associated with provisioning young and finding mates are likely to alter how individpers.uals respond to their environment. In this study we examined hypotheses about how mountain goat habitat selection, activity, and movement patterns varied in response to seasonal climatic conditions and reproductive constraints. In order to address our study objectives, we deployed GPS-linked radio-collars on 124 mountain goats (68 males, 56 females) in the Lynn Canal region of southeastern Alaska during 2005–2011. Mountain goat GPS location data (ca. 186,000 locations) were analyzed in a GIS framework in order to estimate daily movement rates, activity patterns (via tip-switch sensors in GPS radio-collars) and resource selection functions under different seasonal and climatic conditions for animals in different reproductive categories (i.e. males, parturient females and non-parturient females). Our findings indicated that mountain goats responded to seasonal changes in climate in distinct ways. In our coastal Alaska study site, nearly all animals conducted altitudinal migrations timed with the onset of snow accumulation and green-up; however, individual variation was evident and presumably linked to local variation in climate conditions. In addition, at a broad scale, activity and movement rates declined during winter relative to summer, yet within this framework, females and males altered behavior in predictable ways during the parturition and breeding season. Specifically, parturient females decreased movement rates during a 4-week "kidding" period, relative to non-parturient females and males. During the 5-week breeding season, or "rut", males strikingly increased movement rates and decreased activity, relative to females. Such changes in activity and movement during periods critical to reproductive success were likely driven by selection pressure exerted by predation-risk, climate, physiological constraints and social organization. Overall, these findings provided insight into behavioral strategies used by mountain goats and indicated strategies were linked to seasonal changes in climate, nutritional resources and reproductive demands.

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BIGHORN SHEEP SEASONAL MOVEMENTS AND HABITAT SELECTION IN A COAL MINING AREA

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Abstract: Rocky Mountain bighorn sheep (*Ovis canadensis canadensis*) inhabit the east side of the Elk Valley in southeastern British Columbia where 4 large, open pit coal mines were in operation. Sheep in this area generally wintered at high elevation on windswept, south facing native grasslands, with some sheep also wintering on mine properties. Expansion of coal mining was proposed in portions of the valley which may result in direct loss of high-elevation winter habitat. The primary objectives of this study were to describe winter range habitat selection, seasonal movements, and use of mine property by this population. A concurrent companion study examined winter range plant communities and production, range condition, and winter diet. We obtained ~54,000 GPS locations from 41 sheep (19 ewes, 22 rams) between March 2009 and May 2011. Winter severity differed markedly between winter 2009–10 (very low snow) and winter 2010–11 (deep snow). Survival of collared sheep dropped from 0.93 (annual rate) during the first year to 0.78 during the second, more severe winter. Winter range size did not differ between sexes, but were roughly one-third the size during winter 2010–11 (3.2 km^2) compared with winter 2009–10 (9.5 km^2). Most (79%) of the sheep monitored for a summer to winter session were migratory (non-overlapping seasonal ranges), and all non-migratory sheep – mostly ewes – were associated with the northern 2 adjacent coal operations. Fidelity to winter ranges among years was high (88%). Although differences among individuals and mine areas were apparent, use of mine property by the population varied seasonally, and showed low use (~10–15%) between November–December and April, followed by increased use which peaked at about 60–70% in September–early October. Habitat selection (resource selection function analysis) at both the winter use to home range and within-winter range scales was dominated by topographic-security variables, and less so by land cover class variables. At the winter range scale, sheep selected strongly for moderate to high elevations close to escape terrain, and weakly for higher solar incidence; females showed greater selection for higher solar incidence than males. Females exhibited higher selection for grasslands and exposed lands than males. Both sexes avoided coniferous cover in general, but made higher use of conifers during the severe winter. Use of mine property by this population was high during the growing season, which might have contributed to population increases over the past 2 decades, likely aided in large part through reclamation. High fidelity to winter ranges and the apparent influence of winter severity on survival suggested that disturbance to winter range resulting from resource extraction should be minimized where possible, with careful consideration towards management and mitigation to reduce impacts.

Key words: Ovis canadensis canadensis, Rocky Mountain Bighorn Sheep, resource selection function, mining.

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A BIOPHYSICAL DESCRIPTION AND FORAGE USE ASSESSMENT OF SELECTED BIGHORN SHEEP WINTER RANGES IN THE ELK RIVER VALLEY, BRITISH COLUMBIA

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Abstract: A study in the Elk River valley of southeastern British Columbia known for big game hunting and open pit coal mining was initiated in 2009 with the objectives of (1) classifying and describing bighorn sheep (*Ovis canadensis*) winter range plant communities, (2) measuring standing crop production, (3) mapping forage utilization and range condition, and (4) documenting winter diet composition through fecal pellet analyses. The study was a collaboration between Teck Resources, government and local stakeholders, and was linked to a concurrent bighorn sheep seasonal movements and habitat selection study.

Fifteen winter ranges were identified by examining government and industry winter aerial survey data and by consulting with knowledgeable stakeholders in the area. The winter ranges were located within the Engelmann Spruce-Subalpine Fir dry cool woodland and the Engelmann Spruce-Subalpine Fir dry cool parkland biogeoclimatic variants and were typically a complex of grasslands, shrublands, vegetated and non-vegetated rock outcrops, and cliffs. A minimum of 3 permanent multi-plots were established within each winter range. Transect sampling was conducted for herbaceous and non-vascular plants while line intercept transects were used to record shrub species cover. Site and soil data were also collected. Terrestrial Ecosystem Mapping at a scale of 1:500 m was completed at each winter range. Multi-plot (n = 5) fecal pellet sampling was conducted at each transect at 5 winter ranges in early, mid, and late winter during the winters of 2009–2010 and 2010–2011. Pellets were analyzed for percent diet composition at the Wildlife Habitat Nutrition Laboratory at Washington State University. Snow cover and depth measurements were recorded concurrent with pellet sampling. Summer field work consisted of standing crop production sampling inside and outside range production cages at all winter ranges in 2009, and in 2010 at the 5 winter ranges selected for fecal pellet sampling.

Standing crop production was highest in winter ranges with the greatest percentage cover of graminoids and where productive soils were prominent. Both the number of sheep and elk pellets varied between winter ranges; winter range use overlap was more evident at two of the winter ranges. Standing crop production ranged from 101.11 kg/ha in a heavily grazed winter range to 1751.25 kg/ha in a productive *Festuca campestris*-dominated winter range. Grazing was highest on productive sites and declined with increasing distance from escape terrain. Due to high grazing pressure, some of the winter ranges were considered to be unhealthy ecologically. Graminoids, particularly *F. campestris*, *Poa alpina*, and *Elymus trachycaulus* were the dominant forage species with small proportions of forbs and shrubs. In the relatively high snow cover winter of 2010–2011, the proportion of sedges such as *Carex albonigra* in the sheep diets increased. Snow cover and depth varied between sites and years with snow cover and snow depth greatest in the winter of 2010–2011 at all winter ranges.

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EVOLVING INFERENCES ON HABITAT SELECTION AND USE LEAD TO IMPROVING MANAGEMENT APPLICATIONS FOR MOUNTAIN GOATS IN BRITISH COLUMBIA'S SKEENA RIVER WATERSHED

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Abstract: Understanding how mountain goats (*Oreamnos americanus*) selectively use resources is important for designing wildlife management strategies. The probability that an individual uses a given resource, as characterized by environmental factors, can be quantified in terms of the Resource Selection Probability Function (RSPF). We present analyses of mountain goat habitat use data collected from helicopter survey and GPS telemetry studies over the past decade in northwest British Columbia. The presentation illustrated the evolution of the RSPF to better understand how mountain goats select environmental resources and to geo-reference the locations of mountain goat winter ranges across a broad spectrum of conditions in interior and coastal climates. Results, discussion, and management applications relevant to several forestry and helicopter tourism projects ensued.

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ARE MOUNTAIN GOATS PARTICULARLY SENSITIVE TO ANTHROPOGENIC DISTURBANCE?

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Abstract: Numerous documents allege or suggest that mountain goats *(Oreamnos americanus)* are unusually sensitive to human-caused disturbances. Based on a review of available literature, starting with the first published mention of the subject about 25 years ago, this paper assembles what we know about the nature and significance of that presumed goat sensitivity for various kinds of disturbance. My assessment distinguishes between documentation and speculation in the description of effects, and shows how careless or over-zealous literature citation has often failed to make that distinction. I also provide some published evidence on the behaviour of mountain goats as related to the habitats they occupy, suggesting that some of what we interpret as serious reaction may actually be little more than part of the daily routine. Finally, I offer my thoughts on demographic consequences, certainly the most important disturbance-related topic for future consideration. The objective is not to disclaim the potential importance of disturbance factors in mountain goat management, but rather to encourage a) more forthright expression of what we actually know, and b) more research and monitoring on what we need to know.

It's almost mantra. Goats are sensitive. Goats are sensitive. Goats are sensitive… Few papers on the species in the last two decades have failed to mention it, and I am regularly confronted with it in my deliberations as a consultant for industry in northern BC. My problem is that the mantra does not fully accord either with what I have read or with my own experience. Needing to resolve that, or at least confirm the validity of my discomfort, I decided it was time to do a thorough revisit of the literature and, having done that, I subsequently decided that there was no point in keeping the results, or my perspective, to myself. Hence, this paper.

This is not a comparative offering in the sense of assessing whether mountain goats (*Oreamnos americanus*) are more or less sensitive than other species. Although some reference to other species and to general principles as related to disturbance is also provided, the focus here is disturbance effects on goats. The primary purpose is to summarize what we actually know and to assess the transfer of knowledge on that subject.

PREMISES AND DEFINITIONS

"From a conservation perspective, human disturbance of wildlife is important only if it affects survival or fecundity and hence causes a population to decline" (Gill et al. 2001). With that point echoed in other documents (Shank 1979, Wilson and Shackleton 2001, National Research Council 2005, Goldstein et al. 2005), most researchers recognize that and, I think, aspire to take their studies to that level. Wilson and Shackleton (2001) clearly described three different levels of study applicable to their proposed research, as follows: "short-term acute behaviour (to determine whether....reactions suggest habituation or sensitization to helicopter disturbance)", "medium-term chronic behaviour (to determine whether disturbance history leads to changes in movement behaviour, or to temporary and/or permanent range abandonment)", and "long-term demographic consequences (to determine whether there are differences in key population parameters between tenure and non-tenure areas)". They note that "for management purposes, short- or medium-term responses are a

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concern only to the extent that they lead to changes in the ability of goat populations to sustain themselves in areas where they are actively disturbed." I use those three levels (short, medium, and long term, as described) in the remainder of this paper.

Whittaker and Knight (1998) recognized three categories of wildlife response to humans (attraction, avoidance, and habituation). The literature on mountain goats includes examples of all three. The most extreme examples of attraction are from national park situations, in which goats have reportedly sought out recreational campsites to exploit the mini-mineral lick potential of human urine deposits (Bansner 1976, Anunsen 1993). As will be evident in following pages, avoidance is the response that has most often been the focus for mountain goat disturbance studies to date.

Habituation, as defined by Whittaker and Knight (1998) is the "...waning of response to a repeated neutral stimulus" (i.e., learning to ignore it). It was documented experimentally for mountain goats by Penner (1988), but the best example may be the experience at the Walton mineral lick in Glacier National Park, Montana. In the mid-1970s, a new high speed highway was constructed within 50 m of the lick, with four nearby bridge and overpass structures to minimize direct road crossings by the animals accessing it. A viewing platform, providing public observation of the goats, was constructed about 60 m from the lick, with a parking lot nearby. The goats adapted to the disturbance involved, including daily passage of hundreds of vehicles on the highway, as they had to the presence of a smaller highway without crossing structures and with unregulated viewers previously (Singer and Doherty 1985a, Pedevillano and Wright 1987).

MOUNTAIN GOAT LITERATURE

The body of literature on the species is relatively small, facilitating intensive review. A check of references in the recently completed management plan for BC (Mountain Goat Management Team 2010), a very thorough document, suggests that my assessment is complete at least through that year. Note that I have not attempted to incorporate disturbance-related projects that are underway, but not yet completed.

Only 4 of 480 references listed in two bibliographic compilations for the period 1900-1978 (Foster 1977, 1979) are among the papers referenced here. From that, its absence in two major review papers (Rideout and Hoffman 1975, Wigal and Coggins 1982), and its position in a research priorities paper (a sub-topic under Priority No. 5, Eastman 1977), it is apparent that disturbance of mountain goats as a distinct issue and research subject had just started to emerge by the early 1980s. Up to that time, people who logged significant time observing goats portrayed a picture of a species that seemed to be particularly unwary, sometimes approachable to within a few metres (Brandborg 1955, Lentfer 1955, Holroyd 1967, Bansner 1976, Chadwick 1977, Thompson 1980).

The field studies that have directly and systematically recorded observations pertaining to the mountain goat disturbance issue, and therefore the apparent foundation for the "sensitive" label, are listed in Table 1. Most (6 of 8) were focused primarily on the responses of goats to helicopters. The two exceptions, both relating to noise and human presence, documented avoidance responses by some goats in some situations, but apparent habituation overall. In short, those two do not contribute to the notion that goats are particularly sensitive. Thus, the actual issue is helicopter disturbance, not disturbance *per se*, and that is confirmed by the thrust of various guidelines and position statements that have been generated in response (Denton 2000, Hurley 2004, Gordon et al. 2006, Mountain Goat Management Team 2010).

Helicopter Disturbance Studies

While Foster and Rahs (1981, 1985) get credit for the first systematic observations on this subject, the bellwether study (if I may be permitted a sheep term) is that by Joslin (1986). As the only study linking disturbance to apparent demographic effects, it gave rise to the elevated concern that has followed and no subsequent disturbance-related paper on mountain goats has failed to cite it. Unfortunately, we will never know if the author's suspicions about population and productivity effects were correct, in part because there was no post-disturbance follow-up to see if things improved, and also because of some apparent

Table 1. Field studies directly addressing disturbance effects on mountain goats.

References	Primary Subject	Focus[a]	Level of Study[b]		
			Short	Medium	Long
Foster and Rahs 1981, 1985	Hydro Exploration	H	✔	t	
Singer and Doherty 1985	Highway & Tourism	N,P	✔	✔[c]	
Joslin 1986	Seismic Exploration	H	✔	t	✔
Penner 1988	Oil/Gas Exploration	N,P	✔	t	
Cote 1996	Seismic Exploration	H	✔		
Gordon and Reynolds 2000	Goat Surveys	H	✔		
Gordon and Wilson 2004	Helicopter Logging	H	✔	t	
Goldstein 2005	Response to Helicopters	H	✔		

[a]Focus - Response to H (Helicopters), N (Noise), P (Human Presence)
[b]Level of Study: Short Term (overt) responses; Medium Term (range abandonment) responses;
   and Long Term (demographic effects). Under Medium, "t" = temporary effect.
[c]No range abandonment was noted as related to goat use of the Walton Lick.

study design issues as related to controls. The original (283 page) report may be clearer on some of these points, but it appears that the two study areas differed in overall size, in the amount of human access and activities besides the seismic work, the intensity of study (collared animals in one and not the other, and therefore possibly more sensitive to helicopter activity if they were originally captured from helicopters), and in the size and initial productivity of the goat populations in each. Further, there appears to have been no clear measure of the amount, distribution, or timing of seismic activity each sub-population was exposed to, although the total (579 km of seismic lines, requiring over 4000 km of helicopter activity over a 4-year period), was clearly extensive. Even at that, no abandonment of home ranges among the collared animals was detected, and observed displacement was local (using terrain features) and temporary, often only a matter of hours. Finally, it was not possible to completely rule out other factors, particularly disease. Joslin (1986) was up front about those matters, clearly indicating that she was reporting correlation, not cause and effect. To date, no study has actually documented disturbance-related goat population declines or reduced productivity.

The next landmark study of helicopter effects was undertaken at Caw Ridge, Alberta (Côté 1996), systematically (but opportunistically) documenting overt responses of 84 goat groups exposed to helicopter overflights. Among the findings were five cases in which groups split up while fleeing from the helicopter, prompting the following statement: "The group splinterings I observed suggest that mountain goats may be more sensitive to disturbance than other ungulates and that special care should be taken in the management of this species" While the "may be" portion of that statement is appropriate caveat, that has largely been ignored by those citing the paper, and it appears that Côté (1996) gets the credit for originating the "goats are particularly sensitive" concept.

The three remaining studies (Table 1) have provided more sophisticated and detailed observations on the short term, overt responses of mountain goats to helicopters, including video-assisted observations from inside the disturbing helicopter (Gordon and Reynolds 2000), an impressive collection of ground-based observations (Gordon and Wilson 2004), and the only study in which the monitored helicopter approaches were specified by project design rather than being observed opportunistically (Goldstein et al. 2005). It may be noteworthy that the overt responses of goats in the areas studied by Goldstein et al. (2005) were less extreme ("muted in comparison") than had been documented in other studies.

Careless Citation of Literature

To briefly summarize the preceding material, the only disturbance effects that have been documented are the short term responses of goats to helicopters. An underlying premise to the

"goats are particularly sensitive" idea is that those responses might lead to more serious longer term effects. While that may be valid as a concern, it is not supported by anything we actually know, although the implication that we <u>do</u> know is common in the applicable literature. Despite their own caveats, as described above, Joslin (1986) and Côté (1996) are regularly cited as support for statements alleging long-term population effects.

A related issue is the tendency toward what I refer to as "speculation strings". It usually takes the form of a list of potential negative effects followed by citation of multiple references. The reader assumes that the cited papers provide documentation for the stated effects when, in fact, they also say that the effects may (or can) happen, themselves citing still other papers speculating similarly. In one case among the papers I reviewed, the two introductory paragraphs cited 26 references, none of which provided clearly relevant evidence for the effects claimed. The speculation string tendency was so pervasive that the paper by Toweill et al. (2004), which described the potential long-term effects as "postulated", was particularly refreshing.

Mountain Goat Responses to Helicopters

The general interpretation is that goats are afraid (one source said "terrified") of helicopters. Except for individual animals that have had specific negative experience with helicopters (e.g., pursuit and capture, or repeated intentional "buzzing"), that is unlikely to be the case. Nevertheless, it is a well-established fact that they do indeed respond to helicopters with something that looks like fear. As described by Foster and Rahs (1981) for "severe" response cases, "Goats generally ran in panic toward dense vegetation or for escape terrain (steep rocky areas) while simultaneously aggregating. If already occupying rocky areas, they hid in rock crevices and under overhangs, behind vegetation or even other goats." Anyone who has conducted aerial surveys of goats will have seen that "hiding" behaviour. In one case I watched a billy which, having no other nearby option in the burn habitat involved, got down on its belly and shimmied under a low-hanging fallen tree.

Consistent with conclusions in Foster and Rahs (1981, 1985), Gordon and Reynolds (2000)

observed that "Goats exhibited a greater overt disturbance reaction to helicopter presence if overhead shelters such as caves, ledges, or large conifer trees with low-lying boughs were not available..." and "Higher overt disturbance levels were noted when the helicopter was above or level with the relative position of mountain goats on the hillside. Lower overt disturbance responses were noted when the helicopter was below the relative position of goats sighted."

Mountain Goat Responses to their Habitat

Geist (1978) observed that "....mountain sheep and mountain goats tend to respond to very loud noises by fleeing to the sanctuary of the cliffs. This appears to be an innate response to avalanches and rockfalls." Or, in a characteristically poetic description by Chadwick (1983) "It is a measure of the frequency of snowslides in spring that goats often cease to pay attention to the cracking and booming on all sides of them. It generally takes an overhead rockfall or avalanche sound aimed their way to produce a startled reaction. The ears go back and the tail up, and they are on their way at a gallop. If they are already on a steep section of cliffs they will seek a protective overhang. Lacking that, they pace and stamp and, as the sound rumbles closer, crouch. And then, when the ground starts to vibrate, they squeeze tightly against the uphill rock as if trying to press themselves into a crack...." Clearly, the observable responses to natural overhead sounds and to helicopters are virtually the same.

Most of the papers that have data on or something to say about natural mortality of mountain goats (Brandborg 1955; Lentfer 1955; Holroyd 1967; Chadwick 1977, 1983; Nichols 1982; Singer and Doherty 1985b; Smith 1986; K.S. White, Alaska Department of Fish and Game, pers. comm.) finger "catastrophic downslope movements of rocks, ice, and snow" (Chadwick 1983) as a regular factor. Chadwick (1983) further notes that "Such evidence as is available...points to avalanches as a major source of mortality and therefore an important selective agent in evolution of mountain goat social characteristics."

None of the sources reviewed have made a direct connection between the response to slides and response to helicopters, but Whittaker and Knight (1998) came close "....wildlife have

developed situation-specific responses because some combination of learning and genetics have made them successful...genetic and learned components may be intertwined and could have particular relevance for understanding avoidance responses. For example, bighorn sheep and mountain goats withdraw to cliffs in response to sudden, loud noises such as rockfalls....when gunshots invoke a similar response, it suggests a genetic component being reinforced through learning." It seems evident that an innate reaction to loud noises overhead would have survival value, and that we should not expect goats to refrain from reacting or habituate to them.

Sensitivity to Human Disturbance

So, are goats particularly sensitive to human disturbance? If they are, that is yet to be demonstrated. As outlined above, cases of both attraction and habituation are known and most of our examples of avoidance relate to short-term responses to helicopters. Those responses appear to be ecologically appropriate and possibly of no consequence to the animals, part of the daily routine and soon forgotten. Thus, goats may be particularly resilient rather than sensitive to such disturbances.

I mentioned earlier that a "highly sensitive" label does not accord with my own experience, which includes applicable observations both from the air and the ground over a time span of more than 30 years. During a helicopter survey in July 2010, a group of 30+ goats was encountered in and along the creek at the bottom of a canyon. They were highly agitated at our approach, scattering in several directions, and I decided not to attempt an aerial composition count. A few hours later, I was dropped off about 500 m away and made my way on foot to the canyon edge where I observed the animals for about 1.5 hours. All were within 500 m of where they had been "harassed" during the survey, and most were within 300 m. During the observation period, a few adults foraged briefly and two kids interacted in "play", but the rest of the animals remained in various positions of repose. In summary, that helicopter encounter, which elicited one of the most extreme overt reactions I have witnessed, did not cause the animals to move a significant distance from the location where they were first seen, and did not

appear to result in an enduring negative effect. The main point here is that one-time exposures to disturbance factors are not likely detrimental, and should probably be considered in separate context from the multiple exposures characteristic of some industrial and recreational activities.

There are other inconsistencies with the notion of high sensitivity, of which a major one is the extent and success of goat transplants and reintroductions. The workshop section in the 1996 NWSGC symposium proceedings (pages 145–211) identifies over 225 transplants, involving over 1600 animals, in 13 states and provinces. One of the best known of the transplant successes is that in Olympic National Park, Washington, where the primary management problem became the difficulty and expense required to either control or eliminate goats in the park. As noted by Houston et al. (1994), "Any management program selected will surely test the stamina and commitment of agency managers."

Context and Caveats

It may seem that I have gone to a lot of trouble just to question the label "Particularly Sensitive (PS)", so I need to explain why. One reason, and the simplest, is that it is not demonstrably accurate, and accuracy is what science is about. But more importantly, it complicates rather than supports management. The PS label artificially extends to goats a pseudo species-at-risk status, with all the potential for public misunderstanding, imaginary emergency, bureaucratic reaction, and the political interference that typically goes with it. Most people, including those managing land use, read science reports for information rather than for full understanding, and the thrust of current information is that we dare not do more than tiptoe through goat country. That may ultimately be counterproductive, for as outlined by Taylor and Knight (2003), "Unnecessary restrictions may actually have a negative effect on public support for and compliance with conservation-based regulations." I understand and generally support the precautionary principle, but also firmly believe that speculation should not be the foundation for management actions. That is, our professional advice should be based more on what we know than on what we fear, and researchers and managers need to be more

forthright on that distinction in reporting results and citing literature.

The likelihood that goats are responding to helicopters as part of their natural programming to loud overhead noises does not bail us out of having to further consider effects, but may help in interpretation. Meanwhile, I strongly encourage more research and monitoring on the medium- and long-term effects of disturbance, particularly for regular, intense industrial activity such as the helicopter logging studied by Gordon and Wilson (2004) and the helicopter-supported recreational activities identified by Denton (2000) and Hurley (2004). If we are going to find population level effects other than those related to provision of public access or direct removal of demonstrably important habitat, it will likely be in such situations. At the functional level, the need for careful, responsive, science-based management of goats and goat habitats is the same whether the species is particularly sensitive or not.

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A RISK-BASED APPROACH TO ASSESSING AND MANAGING DISTURBANCE EFFECTS OF HELICOPTER-LOGGING ON MOUNTAIN GOATS IN COASTAL BRITISH COLUMBIA

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Abstract: Helicopter-logging activity can affect the behaviour of mountain goats and displace them from preferred habitat; however, recommended separation distances between mountain goats and helicopters have varied between 500 m and 2000 m. We used a risk-based approach to investigate the management implications of different separation distances in the context of helicopter-logging operations on the mainland coast of British Columbia (BC). We used results from available studies and the opinion of experienced biologists to develop a risk model that related helicopter-logging to effects on mountain goats. The model indicated that different separation distances could result in similar risks to mountain goats, depending on season and snow depth. Benchmarking the risks against BC's general approach to population management of mountain goats allowed us to provide more objective recommendations for helicopter-logging activity compared to previous recommendations.

Mountain goats (*Oreamnos americanus*) are relatively common inhabitants of British Columbia's (BC) most rugged mountain habitats. Although populations in BC are considered secure, the Province has a global responsibility for their conservation because >50% of the world's mountain goats live in BC (Shackleton 1999).

Helicopter activity can alter mountain goat behaviour and displace them from habitat (Côté 1996, Harrison 1999, Gordon and Wilson 2004, Goldstein et al. 2005) but using helicopters to yard felled trees from otherwise inaccessible terrain (hereafter "helicopter-logging") is an economically important component of the forest industry in coastal BC. We used results from available studies and the opinion of experienced biologists to develop a risk model that related helicopter-logging to effects on mountain goats. Model results were used to develop legal requirements for helicopter-logging activity in a coastal timber supply area.

Fig. 1. Study area was the Sunshine Coast Timber Supply Area (TSA) in coastal British Columbia.

STUDY AREA

The risk model was developed specifically for the Sunshine Coast Timber Supply Area (TSA) of southwestern BC (Fig. 1). The TSA covered 19,359 km² of lowland coastal temperate rainforest rising to subalpine and alpine meadows, talus slopes, rock outcrops and peaks of >2000 m.

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Snow was infrequent at sea level but typically reached depths of several metres at higher elevations. Deep snow between December and March restricted mountain goats to areas under dense tree canopies that intercept snow, or to snow-shedding escape terrain. Mountain goats can use winter ranges as low as sea level during severe winter conditions (Taylor et al. 2006).

METHODS

The risk model we developed was designed to meet the following objective: to maintain the distribution and abundance of mountain goats in winter range habitats in the project area. We assumed that mountain goats select optimal habitat to meet their life requisites and that displacement from preferred habitat could result in lower fitness due to:

1. increased likelihood of accidents (e.g., falls, avalanches);
2. higher risk of predation from being displaced from escape terrain;
3. poorer body condition caused by expending energy to flee in deep snow or hazardous terrain; and/or,
4. further nutritional deprivation from subsisting in sub-optimal winter habitats with fewer available forage resources and/or poorer thermal conditions.

Research has focused on the short-term behavioural responses of mountain goats to helicopter activities but fitness consequences remain largely unstudied (Wilson and Shackleton 2001). As a result, we used the opinion of local experts and their interpretation of relevant scientific and management literature to develop an adaptive management hypothesis that could be used to inform current management and provide a rationale for future monitoring and refinement of management approaches.

Behavioural changes by mountain goats in response to helicopter activities, and their habitat use and fitness consequences, are probabilistic (i.e., the outcome of a single event cannot be reliably predicted, but different outcomes occur with predicable frequencies when many events are observed). Consequently, we modelled the system as a Bayesian Belief Network (BBN), which uses probabilities to define both input parameters and outputs (Marcot et al. 2006). BBNs have been used to model other ecological systems associated with high uncertainty (e.g., Amstrup et al. 2010). BBNs have a number of desirable characteristics for ecological modelling:

1. models are presented intuitively as a series of variables or "nodes", parameters or "states" and arrows showing the relationships among them;
2. rather than a purely conceptual model, BBNs are fully parameterized and generate quantitative predictions;
3. BBNs can accept a mix of quantitative and qualitative information, based on both existing data and on expert opinion;
4. outputs are robust to missing data;
5. models can be updated with data as they become available; and,
6. uncertainty can be accommodated explicitly by assigning ranges of probabilities to input parameters.

RESULTS

We included the following input variables in the model (Fig. 2):

1. line of sight distance - distance between helicopters and goats has been documented as an important variable influencing behaviour (Côté 1996, Wilson and Shackleton 2001, Goldstein et al. 2005). Commonly cited intervals were used as states (i.e., parameters).
2. season - we hypothesized that the consequences of behavioural changes are more severe when mountain goats are most physiologically stressed. Energy balance is negative throughout winter because access to preferred forage is limited (Fox and Smith 1988) and moving through snow is energetically costly (Dailey and Hobbs 1989). Lower survival, at least for juvenile mountain goats, is correlated with winter severity (Côté and Festa-Bianchet 2003). The consequences of negative energy balance are likely to increase as the winter progresses.
3. snow depth - snow conditions can differ significantly in different parts of a winter range (i.e., under canopy or at different elevations and aspects), but from an energetic perspective, mountain goats begin to suffer a significant metabolic cost when sinking depths exceed brisket height (Dailey and Hobbs 1989). We
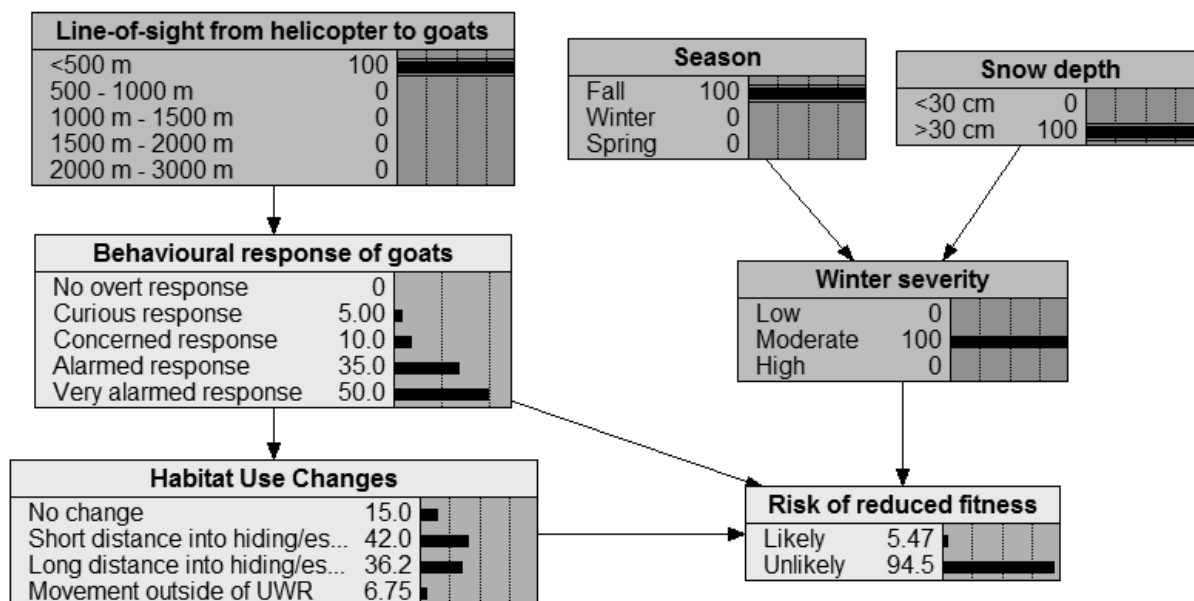
Fig. 2. Bayesian Belief Network developed to describe the hypothesized relationships among helicopter-logging activity, the behavioural responses of mountain goats, and the risk of reduced fitness. In this example output, a distance of <500 m between a helicopter and mountain goats during the fall season with snow >30 cm results in half of the mountain goats exhibiting a "very alarmed response", resulting in a hypothesized 5% risk of reduced fitness.

used >30 cm as the snow depth at which metabolic cost begins to increase. This was based on literature that identified 25 cm as the critical depth for black-tailed deer and the fact that mountain goats are slightly taller than deer (Bunnell 1990). Where 30 cm is the minimum snow depth found on a winter range, mountain goats are unlikely to be able to avoid increased mobility costs, except where snow conditions (e.g., crusting, compaction) enable greater mobility; however, these characteristics are difficult to measure consistently and objectively and were not considered.

Other important variables were considered constants:

4. intensity of helicopter-logging activity - although the frequency of helicopter activity could influence reactions by mountain goats, helicopter-logging activity is an intensive activity in general, requiring helicopter approaches every few minutes. We assumed that effects would saturate quickly; therefore, intensity was considered a constant.

5. duration of helicopter-logging activity - longer exposure to helicopter activity might result in stronger reactions by mountain goats. We parameterized the model assuming an average

duration of helicopter-logging operations of 1–2 weeks. Although the maximum behavioural response by mountain goats likely occurs within 1–2 days, the consequences of the response likely increases with duration for the strongest behavioural responses (e.g., movements into sub-optimal habitat). Chronic exposure (i.e., repeated disturbances over several weeks or months) associated with consistent habitat use changes could make permanent abandonment of a winter range more likely. There is also the possibility that individuals could habituate to the activity (Stankowich 2008). This was not considered in the model, which was focused on short-term responses.

6. size of helicopter - the model specifically addressed the use of large helicopters associated with the yarding phase of logging activities (i.e., removing logs from the site with heavy lift helicopters). Some smaller helicopters are also used to support logging operations but we assumed the marginal effect of additional, smaller machines would be minor.

7. relative position of the helicopter - approach angles can influence the reactions of mountain

Table 1. Relative winter severity index, as estimated by season and snow depth in the risk management model for mountain goats.

Season	Snow depth (cm)	Winter severity
Fall	<30	Low
Fall	>30	Moderate
Winter	<30	Moderate
Winter	>30	High
Spring	<30	Moderate
Spring	>30	High

goats and other Capridae to helicopters (Krausman and Hervert 1983, Côté 1996, Frid 2003); however, helicopter-logging generally occurs below the location of mountain goats and helicopter position was therefore considered a constant.

Season and snow depth were summarized in a node called winter severity, which estimated the combined, relative effect of the variables on mountain goat susceptibility to consequences arising from behaviour and habitat changes (Table 1). Winter severity was considered highest for deep snow late in the season when mountain goats are stressed by months of limited mobility and nutritional deprivation.

We estimated the relationship between distance from helicopter-logging activity and mountain goats behavioural changes according to Penner's (1988) classification of responses and available literature (e.g., Côté 1996, Goldstein et al. 2005; Table 2). Expected habitat use changes resulting from behavioural changes by mountain goats were based largely on expert opinion (Table 3).

The risk of reduced fitness was hypothesized to be a function of both the behavioural responses of mountain goats (i.e., risk increases with stronger initial reaction to helicopter-logging activity) and resulting habitat use changes (i.e., the farther animals travel from preferred habitat, the higher the risk), as well as winter severity (i.e., travelling long distances in deep snow in poor condition poses the greatest risk). There was little available literature or experience to quantify these relationships. Our estimates were informed by experience but should be considered hypotheses (Table 4).

The risk of mountain goats moving off a winter range as a result of helicopter activity was hypothesized to be low for all approach distances (Fig. 3), but there was an inflection in the model results at 1000–1500 m. At this distance the probability of mountain goats moving long distances or moving off a winter range was estimated to be 11%. This probability increased to 43% at <500 m.

Risk of reduced fitness was considered acceptably low when <1% (green) and unacceptably high when >4% (red). These limits were inferred from provincial harvest guidelines (BC Ministry of Environment 2010) and reflect that mountain goat populations are very sensitive to mortality (Hamel et al. 2006) and that even small reductions in fitness (from either direct mortality or an increased likelihood of reproductive failure) are likely to have negative population consequences. The risk of reduced fitness was hypothesized to be unacceptably high population consequences. The risk of reduced fitness was hypothesized to be unacceptably high when helicopter-logging activity occurs <1000 m from mountain goats in severe winter conditions,

Table 2. Estimated relationship between separation distances and subsequent behavioural responses, following Penner (1988).

Distance from helicopter-logging to goats (m)	No overt response (%)	Curious response (%)	Concerned response (%)	Alarmed response (%)	Very alarmed response (%)
<500	0	5	10	35	50
500-1000	0	5	15	50	30
1000-1500	10	25	40	15	10
1500-2000	30	40	15	10	5
2000-3000	60	35	5	0	0

Table 3. Hypothesized relationship between behavioural responses of mountain goats to helicopter-logging activity and the relative distance moved by goats. Short and long distances were not defined because of the variation in size of winter ranges.

Behavioural response of goat	No change	Short distance into hiding/escape terrain	Long distance into hiding/escape terrain	Movement outside of winter range
No overt response	100	-	-	-
Curious response	100	-	-	-
Concerned response	100	-	-	-
Alarmed response	-	70	25	5
Very alarmed response	-	35	55	10

Table 4. Hypothesized risk of reduced fitness in the risk management model, based on winter severity, behavioural response of mountain goats, and habitat use changes.

Winter severity	Behavioural responses of goats	Habitat use changes	Unlikely	Likely
Low	No overt response	No change	100	0
Low	Curious response	No change	100	0
Low	Concerned response	No change	100	0
Low	Alarmed response	Short distance into hiding/escape terrain	99.9	0.1
Low	Alarmed response	Long distance into hiding/escape terrain	99.8	0.2
Low	Alarmed response	Movement outside of UWR	99.5	0.5
Low	Very alarmed response	Short distance into hiding/escape terrain	99	1
Low	Very alarmed response	Long distance into hiding/escape terrain	98	2
Low	Very alarmed response	Movement outside of UWR	98	2
Moderate	No overt response	No change	100	0
Moderate	Curious response	No change	100	0
Moderate	Concerned response	No change	100	0
Moderate	Alarmed response	Short distance into hiding/escape terrain	99	1
Moderate	Alarmed response	Long distance into hiding/escape terrain	98	2
Moderate	Alarmed response	Movement outside of UWR	90	10
Moderate	Very alarmed response	Short distance into hiding/escape terrain	95	5
Moderate	Very alarmed response	Long distance into hiding/escape terrain	90	10
Moderate	Very alarmed response	Movement outside of UWR	75	25
High	No overt response	No change	100	0
High	Curious response	No change	100	0
High	Concerned response	No change	100	0
High	Alarmed response	Short distance into hiding/escape terrain	98	2
High	Alarmed response	Long distance into hiding/escape terrain	96	4
High	Alarmed response	Movement outside of UWR	80	20
High	Very alarmed response	Short distance into hiding/escape terrain	90	10
High	Very alarmed response	Long distance into hiding/escape terrain	80	20
High	Very alarmed response	Movement outside of UWR	70	30

and <500 m in moderate winter conditions (Table 5).

DISCUSSION

One reason recommended separation distances between helicopters and mountain goats have varied is because recommendations are often provided without reference to the objective the recommendation is intended to achieve, and/or the degree of precaution applied. For example, an objective to completely prevent changes in mountain goat behaviour resulting from helicopter
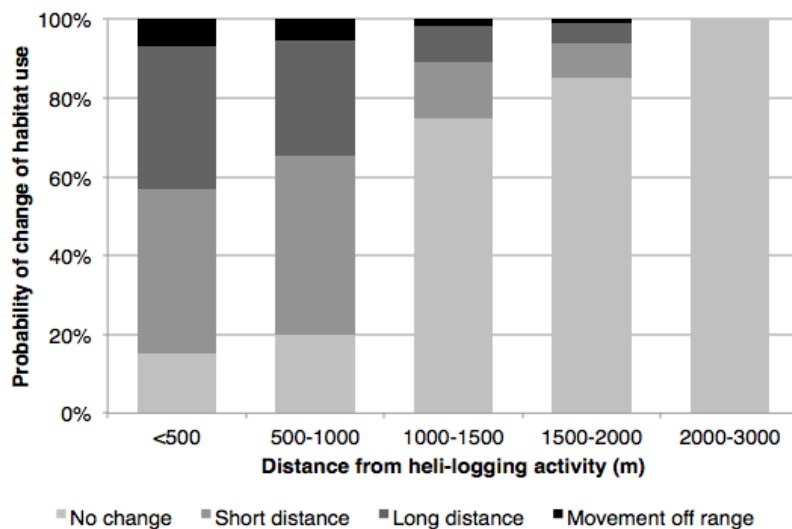
Fig. 3. Relationship between separation distances and the estimated likelihood of changes in habitat use, based on the risk management model.

confidence of management decisions. We suggest that the best approach in these circumstances is to develop a working hypothesis in the form of a quantitative model that explicitly documents assumptions and uncertainties. The model can then be used to predict the outcomes of different policy options. These predictions can serve as the basis for adaptive management trials, the results of which can be used to explicitly update the model to ensure that management is always based on the best available information.

Our study represents the first attempt to assess the risk of helicopter-logging to the fitness of mountain goats. We suggest that risk is associated not only with the approach distance of helicopters but also with the severity of winter conditions, which might increase the fitness implications of behavioural changes caused by helicopters. We further suggest that some published separation distances pose a very low risk to the fitness of mountain goats. Although rarely stated, the objective of published recommendations appears to be to minimize the likelihood of behavioural reactions by mountain goats in response to helicopters. This may or may not align with the policy objectives of wildlife agencies.

Because of our reliance on expert opinion, our results are best considered hypotheses to guide current management under uncertainty, and to guide future monitoring and adaptive management.

activity requires a much more precautionary separation distance than an objective that accepts some risk to mountain goats. Without reference to objectives or precaution, recommendations confound the positive (i.e., "what is") elements of the management problem with the normative (i.e., "what ought to be"). In contrast, our method focused on characterizing the risk to mountain goats associated with different management policies and separating the technical issue (i.e., risk of reduced fitness) from the policy decision (i.e., what level of reduced fitness is acceptable?).

Wildlife managers are often faced with the challenge of managing systems with a high degree of uncertainty. Gaps in the scientific and management literature, as well as limited resources for monitoring and adaptive management trials, necessarily limits the

Table 5. Risk of reduced fitness, based on distance from helicopter-logging activity and winter severity. Risk of <1% was considered acceptably low and >4% unacceptably high.

Winter severity	Line-of-sight distance from helicopter-logging activity to mountain goats (m)				
	<500	500-1000	1000-1500	1500-2000	2000-3000
Low	0.88	0.57	0.19	0.10	0
Moderate	5.47	3.78	1.23	0.66	0
High	9.94	6.95	2.26	1.21	0

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IMPACT OF HUMAN RECREATION NEAR BIGHORN SHEEP LAMBING AREA

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Abstract: Bighorn sheep (*Ovis canadensis*) occupy low elevation habitat in western North Dakota and persist within small, fragmented sub-populations. From 2001 to 2011, we monitored habitat use by bighorn ewes (n = 143) to identify core-use areas. We documented abandonment of lambing habitat used by the Chateau herd that was associated with a recreational hiking trail. The Chateau herd's fidelity to lambing areas was 54.6% (SE = 15.8, P = 0.016) compared to 100% for all other sub-populations (n = 14). Chateau ewes travelled a greater maximum distance between patches of lambing habitat (6.6 km) than the mean (4.1 km); however, it was not the maximum distance observed (8.3 km). Although lamb recruitment by Chateau ewes was lower ($\bar{x}$ = 0.21, SE = 0.06) than herds with 100% fidelity to lambing areas ($\bar{x}$ = 0.30, SE = 0.02), it was not significant (P = 0.156). Bighorn are sensitive to human disturbance, particularly during the lambing season. Therefore, minimizing human disturbance near lambing areas is essential to preventing habitat abandonment and consequent lower lamb survival. Human disturbance near lambing areas likely has a greater impact on small metapopulations due to a limited quantity of suitable lambing habitat.

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EXAMINING MOVEMENTS AND RESOURCE SELECTION OF MOUNTAIN GOATS IN RELATION TO HELI-SKIING ACTIVITY

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Abstract: Helicopter-based recreation is increasing rapidly in many areas used by mountain goats (*Oreamnos americanus*). Although the immediate, acute responses of mountain goats to helicopters have been well studied, longer-term effects are unclear. There is concern that disturbance caused by helicopter activity may result in heightened energetic expenditures and displacement from preferred habitats; impacts that could have important implications during the winter season when habitat requirements are highly specific and animals are subject to significant nutritional and energetic stress. From 2007–2010, location data from 11 GPS-collared female mountain goats inhabiting a gradient of heliskiing activity (no use to high intensity) were collected as well as detailed GPS-helicopter tracks obtained in cooperation with Last Frontier Heliskiing. We reviewed how we examined whether heli-skiing activity affected the medium-term movements and range use of mountain goats within a commercial heli-skiing tenure in northwest British Columbia. We discussed how we were examining this unique dataset within a 3D-GIS framework to define proximity and visibility of heliskiing activity to animals, both spatially and temporally. We then explained the methods we were utilizing to relate these point-specific measures of heliskiing activity to a range of movement metrics including medium-term range size and displacement, average movement rates, and distinct anomalous extra-home range movements. To further explore range use, we illustrated how we were examining the relative importance of heliskiing-related covariates to selection strategies through logistic regression and the information-theoretic approach.

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STATUS OF MOUNTAIN GOATS IN WASHINGTON

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Abstract: Based on aerial surveys (2004–2007, adjusted for sightability) and subjective estimates for unsurveyed areas, I developed an estimate of the total number of mountain goats (*Oreamnos americanus*) in Washington State, USA. Mountain goat populations were estimated for 56 units, 40 areas, and 21 zones, yielding a total 2,815 (2,401–3,184) mountain goats. Of the units/areas/zones identified, about 60% have been monitored with aerial surveys. For the remaining areas, the estimate for Lake Chelan was based on ground counts and the rest subjectively estimated. Additional aerial surveys around Mount Adams, for Mount Rainier National Park, the North Wenatchee Mountains, and the Chiwawa River area would enhance our knowledge of mountain goat populations in Washington.

This is the first estimate of mountain goat (*Oreamnos americanus*) populations for the entire state of Washington. The most recent prior attempt to produce such an estimate was in 1961 (Wadkins 1962). His total of 8,555 did not include the Olympic Mountains, Mount Rainier National Park, or mountain goats on Yakama Indian lands, and was based on the extrapolation of ground counts. Although the Washington Department of Fish and Wildlife (WDFW) has conducted helicopter surveys of mountain goats for a number of years, between 2004–2007 they developed a sightability model for mountain goats that has facilitated consistent estimation of mountain goat populations (Rice et al. 2009). These surveys, combined with those conducted in the Olympic Mountains (Happe et al. 2004), provided the foundation for the current estimate. Nevertheless, WDFW surveys are typically limited to mountain goat populations in areas where hunting is permitted and substantial amounts of mountain goat habitat were not surveyed. In unsurveyed areas, I relied on expert opinion for estimating mountain goat numbers.

STUDY AREA

I estimated mountain goat numbers in the Cascade and Olympic Mountains within Washington State. Occasionally, mountain goats have been reported in the northeastern (Selkirk) and southeastern (Blue Mountains) portions of the state, but these areas were not included in this estimate.

METHODS

I developed an estimate of the number of mountain goats in Washington based on a combination of aerial surveys conducted during July and September of 2004–2007 and expert opinion for those areas not surveyed. To determine geographic units for estimation I started with 2007 WDFW hunting units, added areas not covered in 2007 units from 2002 units (which were more numerous and extensive), and then added ad hoc polygons for areas not included by either. For surveys, I adjusted counts and calculated 90% confidence intervals based on our sightability model (Rice et al. 2009) and averaged across years for units with multiple surveys. For non-surveyed locales, I solicited expert opinion as to best subjective estimate, likely minimum and likely maximum for designated ad hoc units.

In some cases units were partially surveyed. In these cases, I generally added the survey estimates and the expert opinion estimates for the remaining portions of those units. However, sometimes the expert opinion estimates included the areas surveyed, and I used the expert opinion estimates for each unit instead. For the total estimate ranges, I took the simple expedient of adding the upper and lower confidence bounds from the surveys to

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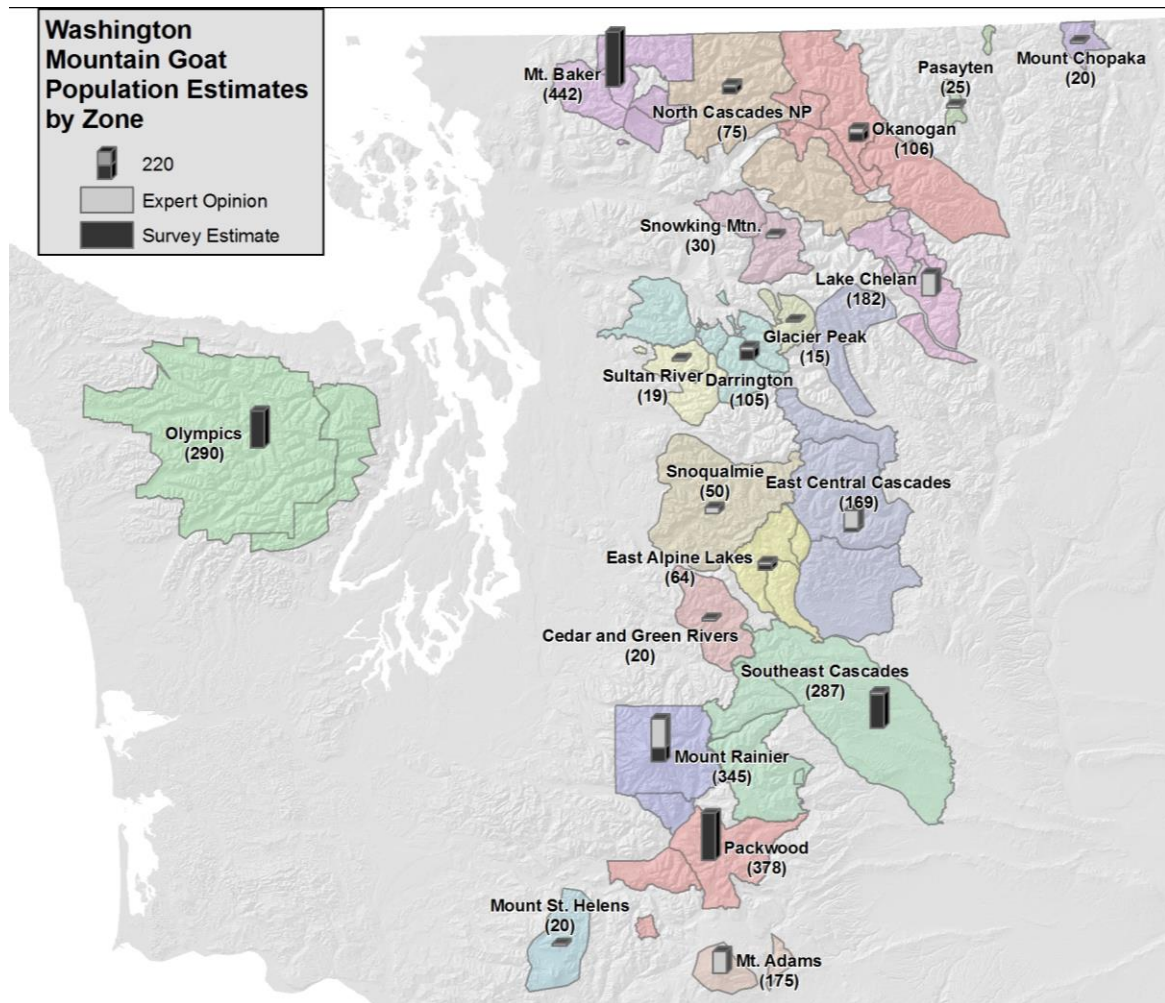
Fig. 1. Estimated number of mountain goats in Washington by Zone. The legend shows the height of an estimate of 220, with the proportion of each estimate that is based on expert opinion in light gray and that based on surveys in dark gray.

the likely minimum and likely maximum expert opinion estimates.

I summarized unit level estimates by two hierarchical groupings: Area and Zone. Survey estimates and expert opinion estimates were added separately within each Area and Zone. For surveys, I summed the variances (Pitman 1993:193) and recalculated confidence intervals based on the total variance. For expert opinion estimates, I summed the expert opinions for minimum and maximum. Hence, relative precision increased with broad scale estimates for surveys, but not for expert opinion estimates.

Special Cases

Lake Chelan

WDFW's few surveys of Lake Chelan were limited in scope, few, and lower than the Chelan Public Utility District (PUD) estimates. For the North and South shores of Lake Chelan I took the 2004–2006 PUD estimates, assigned the minimum to the likely minimum expert opinion, the maximum to the likely maximum expert opinion and the intermediate PUD estimate to the best guess.

Olympics

Olympic National Park staff estimated the mountain goat population for the Olympic Peninsula from random stratified surveys in 2004

(Happe et al. 2004). Based on a few observations, I estimated that 17 (13–25) of these were in the Olympic National Forest.

Okanogan

Mountain goats visiting Hancock Ridge (Methow unit) appeared to spend the majority of their time on Mount Ballard and Majestic Mountain (East Ross Lake unit). Consequently, I used survey results from Hancock Ridge as a basis for the estimate for East Ross Lake. I also included peripheral areas surveyed with the Methow unit (near Washington Pass) in the Methow estimate.

Glacier Peak

Mountain goats visiting Gamma Ridge all appeared to be from the east side of the Cascades coming to visit the mineral licks on Gamma Ridge (Rice 2010). Therefore I used the Gamma Ridge surveys as a basis for estimation in the Chiwawa River ad hoc unit, and used expert opinion for the number of residents in the rest of the Glacier Peak unit.

RESULTS

Estimates for surveyed areas were based on a total of 1,139 goat groups containing 4,799 individuals that were observed over 4 years (2004–2007).

Mountain goat populations were estimated for 56 units, 40 areas, and 21 zones (Table 1, Figs. 1 and 2), yielding an estimated total of 2,815 (2,401–3,184) mountain goats for Washington.

Of the total units/areas/zones, about 60% were monitored with aerial surveys; the estimate of goat numbers for other areas was based on expert opinion, with the exception of Lake Chelan where routine ground counts were performed. About 25% of Washington's mountain goats were in National Parks. About 35% of Washington mountain goats were in the seven units for which hunting permits were issued in 2009. Overall, 47% of mountain goats outside of national parks were in areas for which goat hunting permits were issued from 2004–2007.

DISCUSSION

Aerial survey coverage of Mt. Adams (primarily on Yakama tribal lands), Mount Rainier National Park, the North Wenatchee Mountains, and the Chiwawa River area would improve our knowledge of the status of mountain goats in Washington. Subsequent to this report, the Muckleshoot Tribe surveyed most of the Snoqualmie area, resulting in an estimated population of 49 mountain goats (Vales 2009), compared with my subjective estimate of 50.

There is a large degree of uncertainty about mountain goat populations in unsurveyed areas (total 703–1,402 goats). However, the costs of completely surveying all these areas would be prohibitive. A random stratified survey design (e.g., Happe et al. 2004) would probably be called for should this be attempted.

My total estimate of 2,815 mountain goats in Washington was substantially less than the estimate of 8,555 goats from 1961. My estimate for the areas included for the 1961 estimate was 2,007 goats. It is difficult to say how much of this difference is due to declines in mountain goat populations, and how much is due to differing methods. It is clear that there have been large declines in some areas. For instance, the Snoqualmie area was thought to contain 450 mountain goats in 1961 (Wadkins 1962), while the current estimate was 50. Similarly the Bumping River area population was estimated at 475 in 1961 and my estimate was 67. Excessive harvest is thought to be the primary cause of such declines (Rice and Gay 2010). In contrast, Mount Rainier National Park was thought to hold 374–500 mountain goats in 1983 (Michalovic 1984), which was similar to my current estimate of 231–385. Similarly, the Packwood area population was estimated at 450 in 1961, compared to the current estimate of 378. Clearly, declines have been uneven across the landscape.

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STATUS OF MOUNTAIN GOATS IN WASHINGTON • *Rice*

Table 1. Estimated number of mountain goats by Zone, Area, and Unit, based on survey, expert opinion, and combined with 90% confidence intervals (CI) and estimate range. MGU = mountain goat unit (2002 and 2007). Table continued on next page.

Zone	Area	Unit	MGU	Survey		Expert opinion		Combined	
				Est	CI	Est	Range	Est	Range
Mt Baker	Ruth Creek	Ruth Creek	4-1	58	50-66			58	50-66
	Mt Baker	Lincoln Creek	4-4	53	49-56			53	49-56
		Chowder Ridge	4-3	97	92-103			97	92-103
		Avalanche Gorge	4-7	222	207-237			222	207-237
		Dillard Creek	4-6			0	0-0	0	0-0
		All		372	356-388	0	0-0	372	356-388
	Loomis Mtn	Loomis Mtn		12	9-15			12	9-15
	All			442	424-461	0	0-0	442	424-461
North Cascades NP	North Cascades NP	North Cascades NP		50	41-59	25	20-40	75	61-99
Okanogan	East Ross Lake	East Ross Lake	4-8			30	25-35	30	25-35
	Jack Mtn	Jack Mtn	4-9			10	5-15	10	5-15
	Majestic Mtn	Majestic Mtn	4-10			0	0-0	0	0-0
	Okanogan	Methow	2-2	66	61-70			66	61-70
	All			66	61-70	40	30-50	106	91-120
Pasayten	Eastern Pasayten	Central Pasayten				10	5-15	10	5-15
		Eastern Pasayten				15	11-20	15	11-20
		All				25	16-35	25	16-35
Mt Chopaka	Mt Chopaka	Mt Chopaka	2-1			20	10-30	20	10-30
Linton Mtn	Linton Mtn	Linton Mtn				0	0-0	0	0-0
Snowking Mtn	Mt Tommy Thompson	Mt Tommy Thompson	4-12			5	0-10	5	0-10
	Mt Buckindy	Mt Buckindy	4-14			25	20-30	25	20-30
	All					30	20-40	30	20-40
Darrington	Boulder River	Liberty Mtn	4-21	55	47-63			55	47-63
		North Lake		0	0-0			0	0-0
		Twin Peak	4-23	8	5-11			8	5-11
		All		63	54-71			63	54-71
	E of Sauk R	White Chuck		7	5-10			7	5-10
		Mt Pugh		0	0-1			0	0-1
		Sauk River	4-18	2	1-3			2	1-3
		Sloan Peak	4-24	2	1-3	30	20-50	30	20-50
		All		10	7-13	30	20-50	40	27-63
	All			75	66-84	30	20-50	105	86-134
Glacier Peak	Glacier Peak	Glacier Peak	4-16	53	44-62	10	0-20	10	0-20
		Lime Ridge				5	0-10	5	0-10
		All				15	0-30	15	0-30
East Central Cascades	Chiwawa River	Chiwawa River				75	50-100	75	50-100
	Nason Ridge	East Stevens Pass	3-1	24	15-34			24	15-34
	Wenatchee Mts	North Wenatchee Mts	3-2			60	50-75	60	50-75
		Cle Elum	3-5			10	5-15	10	5-15
		All				70	55-90	70	55-90
	All			24	15-34	145	105-190	169	120-224
Lake Chelan	Stehekin	Stehekin				20	15-30	20	15-30
	East Sawtooth Ridge	East Sawtooth Ridge				15	10-20	15	10-20
	Chelan North	Chelan North	2-1	41	35-47	90	75-115	90	75-115
	Chelan South	Chelan South		21	17-25	57	50-100	57	50-100
	All					182	150-265	182	150-265

Continued next page

| Zone	Area	Unit	MGU	Survey Est	Survey CI	Expert opinion Est	Expert opinion Range	Combined Est	Combined Range
Table 1 continued from previous page									
	Sultan River	Mt Pilchuck				6	8-10	6	8-10
		Vesper Peak	4-25			10	5-25	10	5-25
		Mt Stickney				3	1-5	3	1-5
		All				19	14-40	19	14-40
Olympics	Olympic NP	Olympic NP				273	251-291	273	251-291
	East Olympics	East Olympics				17	13-25	17	13-25
		All		290	264-316			290	264-316
Snoqualmie	Snoqualmie	Snoqualmie				50	24-75	50	24-75
East Alpine Lakes	Kachess Ridge	Chikamin Ridge				10	5-15	10	5-15
		Goat & Davis Mts	3-3			15	10-20	15	10-20
		Kachess Ridge	3-11	39	33-46			39	33-46
		All		39	33-46	25	15-35	64	48-81
Cedar & Green Rivers	Cedar & Green Rivers	Cedar & Green Rivers				20	16-28	20	16-28
Southeast Cascades	Blazed Ridge	Blazed Ridge	3-10	92	84-99			92	84-99
	Naches Pass	Naches/Corral Passes	3-6	101	91-112			101	91-112
	Bumping River	Bumping River	3-7	67	63-71			67	63-71
		Timberwolf Mtn		8	5-10	20	8-25	20	8-25
		All		72	64-81	20	8-25	87	71-96
	All			267	254-281	20	8-25	287	262-306
Mt Rainier	Mt Rainier NP	Mt Rainier NP		111	101-121	224	130-164	335	231-285
	Tatoosh	Tatoosh	5-2			10	5-15	10	5-15
		All		111	101-121	234	135-179	345	236-300
Packwood	Goat Rocks	Goat Rocks/ Tieton R	5-4	282	273-292			282	273-292
	Smith Creek	Smith Creek	5-3	32	25-38			32	25-38
	Dark Divide	Dark Divide		64	56-71			64	56-71
		All		378	364-391			378	364-391
Mt St Helens	Mt St Helens	Mt St Helens				20	15-25	20	15-25
Mt Adams	Mt Adams	Mt Adams				150	90-225	150	90-225
	Klickitat River	Klickitat River				25	15-40	25	15-40
		All				175	105-265	175	105-265
All				1740	1698-1782	1075	703-1402	2815	2401-3184
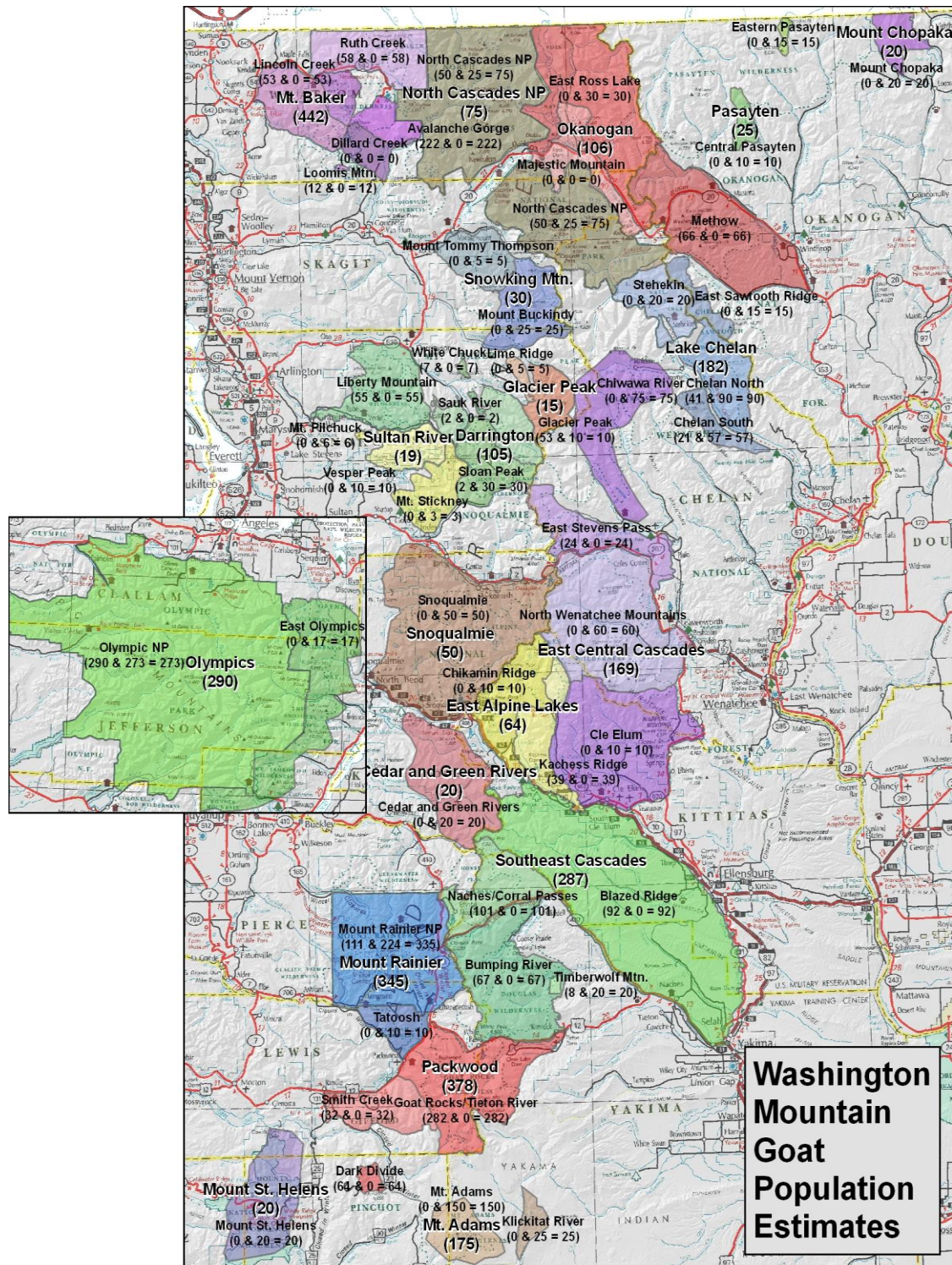
Fig. 2. Estimated number of mountain goats in Washington. Large font labels are for Zones with the combined estimates in parentheses. Smaller font labels are for units, with the survey estimate, expert opinion estimate, and combined estimate in parenthesis.

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EFFECTS OF DELAYED SPRING GREENUP ON BIGHORN SHEEP OF THE LUSCAR AND GREGG RIVER MINES, ALBERTA

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Abstract: In 2011, spring greenup was delayed 3 weeks by unusual deep and persistent snow on the Luscar and Gregg River reclaimed mines in Alberta, resulting in higher than usual ungulate mortality. These mines are located on the east slopes of the Northern Rocky Mountains where Chinook winds typically clear winter ranges of snow throughout the winter providing excellent winter range for bighorn sheep (*Ovis canadensis*) and other ungulates. Sheep using these areas are under high predation pressure from numerous large carnivores. Records of bighorn sheep mortality for the spring of 2011 were obtained from systematic ground surveys conducted by mines personnel and from incident records provided by Alberta Environment and Sustainable Resource Development. Known mortality and causes are summarized, and compared to fall survey results. As expected, winter mortality was highest in the oldest ram classes, and the 2011 lamb crop did poorly (30 lambs:100 ewes in fall 2011). Ewe numbers in the fall of 2011 were similar to those in 2010 and annual survival of lambs born in 2010 was good (55% measured in the fall of 2011).

In west-central Alberta, the spring of 2011 was characterized by a more than usual persistent snow pack which delayed spring greenup by 3 weeks into the end of April. This is an area where the Chinook wind normally ablates the snow pack and makes forage easily available to grazing ungulates throughout the winter; greenup usually begins on south-facing slopes and valley bottoms in early April. The effect of this delayed greenup on mortality of various age classes of bighorn sheep was examined. A similar but less intense event occurred in the spring of 2002 which resulted in high mortality of older bighorn (*Ovis canadensis*) rams, and in poor survival of lambs born in 2002.

Weather is often cited as contributing to ungulate mortality, especially affecting juvenile survival in dense populations (Portier et al. 1998) and adult survival in exceptional circumstances (Rughetti et al. 2011). Bighorn sheep are not well adapted to deep and crusted snow and are found on south-facing or windblown slopes next to escape terrain in winter. Bighorn sheep exhibit strong sexual dimorphism. Males have higher energy requirements and adopt riskier reproductive strategies than females to achieve high dominance rank to achieve reproductive success. Rams enter the winter period in a weakened state due to the rut as compared to ewes. It is therefore expected that harsh winter and spring weather would affect mature or older rams more than females. Rughetti et al. (2011) documented elevated mortality in adult chamois of both sexes in response to harsh winter conditions. Higher ewe mortality was not expected for the Luscar and Gregg River mine population of bighorn sheep. It is thought that ewes experiencing nutritional stress at critical times of year will redirect resources from the lamb therefore a low survival of lambs born in the spring of 2011 was expected through incomplete gestation or high neonatal mortality.

STUDY AREA
Climate and Physical Characteristics
Bighorn sheep have colonized reclaimed lands associated with two open pit coal mines in west-central Alberta in an area known as the Coalbranch. The reclaimed mines (Teck Coal Corporation, Cardinal River Operations, Luscar Mine and Coal Valley Resources Ltd. Gregg River Mine) are located in the Subalpine Natural SubRegion in the Front Ranges of the Canadian Rocky Mountains. Climate is characterized by

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cool, wet and short summers and long, cold winters with heavy snows. Precipitation tends to be greater and winter temperatures more moderate in the Central Ranges than along the eastern slopes of the Front Ranges where the Luscar and Gregg River mines are located (Natural Regions Committee 2006:57). Elevation varies from 1680 m to 1860 m (5512–6102 ft). Topography is rugged, with slopes of varying aspect and angles. Benched high walls, an artifact of open pit mining, have been maintained in strategic areas to provide escape terrain for bighorn sheep in proximity to reclaimed grasslands (MacCallum and Geist 1992). Other design features have been incorporated into the landscape to achieve the end land use goal of providing wildlife habitat. In most years, snow cover is present from November through to April. This study area is located in a major wind corridor (Natural Regions Committee 2006:20) and is characterized by the Chinook; a dry warming wind descending on the east side of the Rocky Mountains primarily in Alberta and Montana. The Chinook can occur year round but its effects are most pronounced in winter when temperature increases of 25^0 C or more within a few hours are possible. The Chinook winds frequently remove snow cover thus ameliorating winter's effects by providing easy access to forage throughout the winter for grazing animals. Spring greenup normally begins in April on south-facing slopes and valley bottoms.

Population

Bighorn sheep on the Luscar and Gregg River mines have been monitored since 1985 and 1989 respectively (MacCallum 2006). These sheep are characterized by large body size, good lamb:ewe ratios, and high density (MacCallum 2006). The maximum fall count on the two mines for the 10 years between 1992 and 2001 varied between 390 and 808 bighorn sheep. Between 2002 and 2011 maximum fall count varied between 798 and 1,065 bighorn sheep (Teck Coal Ltd., Cardinal River Operations annual reports). In the last 20 years, annual population growth rates have varied from a 6.6%–9.7% gain per year for the 10 year period from 1992 to 2001, and a 5.8%–7.3% gain per year in the 10 years between 2002 and 2011. Variable rates of reclamation, an increasing elk (*Cervus elaphus*) population, continuing predation

pressure, stochastic weather events, and other factors influence population growth rates on the two mines.

METHODS

Weather Data

Weather data were obtained from Alberta Agriculture and Rural Development long-term climate records available on the web. Maps of snow pack accumulation in stubble fields relative to long term normals were obtained from: agriculture.alberta.ca/acis/Alberta-climate-maps.jsp). Long-term and accumulated precipitation (mm) and long-term and average temperature (at 2m ^{0}C) were obtained from 4 stations located nearest the eastern slope of the Rocky Mountains (http://agriculture.alberta.ca/acis/alberta-weather-data-viewer.jsp). Stations were Hendrickson Creek, Jasper Warden Station, Southesk and Job Creek.

Mortality

Population parameters for the bighorn populations on the Luscar and Gregg River mines were generated annually by means of systematic visual ground surveys carried out throughout the year. Mortality records were used to correct the fall count to generate demographic statistics. Fall was used rather than spring as bighorns were more dispersed in the spring and the highest counts occurred in the fall. Mortality records were collected by mine staff, contractors, and Alberta Justice and Solicitor General officers for various purposes. Alberta Justice and Solicitor General collected the heads of the larger rams and registered them. Mortality records included information on species, age, location, date of death, and cause of death: (unknown; natural - including winter kill; predation by grizzly (*Ursus arctos*), wolf (*Canis lupus*), coyote (*C. latrans*), cougar (*Puma concolor*); unknown predation; vehicle collision with train; vehicle collision with heavy or light vehicle; capture for export; capture for Fish and Wildlife purposes – research and collection; accident – miscellaneous human caused death; and illegal). Mortality records were as complete as observation and collection allowed but represented only known mortality; mortality

was underestimated, particularly for smaller bodied sheep.

RESULTS

Snow Pack

Snow pack accumulations in stubble fields relative to long term normals indicated that very high to extremely high snow pack conditions begin late January 2011 in Yellowhead County where the mines are located (Fig. 1). This condition persisted locally in Alberta through February and March but in April 2011 (Fig. 2) expanded to include the whole of the eastern slope from the Montana border to the northern extent of the Rockies in Alberta. By April 20, 2011 when the rest of the province showed near normal snow pack accumulation, the east slope was characterized by very high and extremely high snow conditions.

Precipitation

Accumulated precipitation for the four weather stations indicated that precipitation between November 2010 and April 2011 was near normal when compared to long term normals for the Hendickson Creek and Job Creek stations (Fig. 3).

Air Temperature

Air temperatures in the early part of winter 2010–2011 were normal for the four weather stations but plunged below normal in mid February 2011 and stayed low throughout March and April, 2011 (Fig. 4). The Chinook winds, which are accompanied by a rise in temperature, did not occur and the accumulated snow pack persisted through most of April delaying greenup until the very end of April and early May.

Mortality

Twenty-seven mortality records were collected for bighorn sheep on the Luscar and Gregg River mines between January 1, 2011 and April 30, 2011 (Fig. 5). Cause of death in 2011 was cougar (44%), natural (22%) unknown (15%), wolf (11%), unknown predation (4%), and train (4%). Seventy-8% of these mortalities were older rams (Class III and IV), 7% Class II rams, 7% unclassified rams, 4% ewes and 4% lambs. Highest mortality occurred in the first two weeks of February and

again in the first two weeks of April (Fig. 6 - two mortalities occurred in January, eight in February, six in March and eleven in April). Total mortality from January to April 2011 represented 2.5% of the 2010 total fall population, older ram mortality represented 7.9% of the Class II-IV fall count, and nursery herd mortality represented 0.32% of the fall nursery herd (Table 1). Annual survival of lambs (measured from fall 2010 to fall of 2011) was 55% indicating good survival through the winter of 2011. The number of ewes in the fall of 2011 (384) was similar to the fall of 2010 (391). The lamb:ewe ratio in the fall of 2011 representing those lambs born immediately after the prolonged spring of 2011 was 30:100. This was the lowest lamb:ewe ratio reported since surveys began in 1985; the fall lamb:100 ewe ratio for the 10 years previous to 2011 (2001–2010) was 49:100. The severe winter of 2010–2011 was not confined to the Alberta east slopes. Populations of pronghorn (*Antilocapra americana*) and deer in southeastern Alberta (*Odocoileus hemionus* and *O. virginianus*) were also affected by cold temperatures and persistent snow pack (Figs. 1 and 2). As a result, harvest goals for pronghorn and deer in most prairie Wildlife Management Units were adjusted downward for fall 2011 (D. Eslinger, Alberta Fish and Wildlife, personal communication). High levels of mortality were also reported for pronghorn, elk, and deer in pockets of Montana, Wyoming and Idaho during the winter of 2010–2011 (Long 2011, Zuckerman 2011).

DISCUSSION

The absence of the Chinook and persistent cool temperatures in the winter and spring of 2011 resulted in limited access to forage for bighorn sheep on the Luscar and Gregg River mines at this critical time of the year. Even though the timing of mortality through the winter of 2011 was similar to that through the winters of 1992–2010, a higher proportion of older rams relative to the numbers of rams present in the fall died during the winter and spring of 2011 than in previous years. Ewe numbers in the fall of 2011 were similar to those in the fall of 2010. Lambs born in the spring of 2010 survived the winter reasonably well as indicated by an annual survival rate of 55% measured in the fall of 2011. The lamb:ewe ratio in the fall of 2011 was the lowest in 20 years

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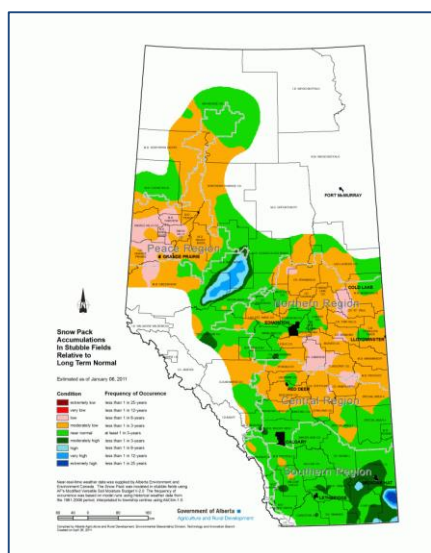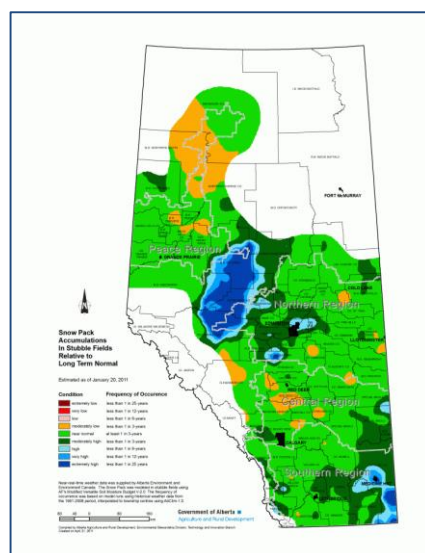
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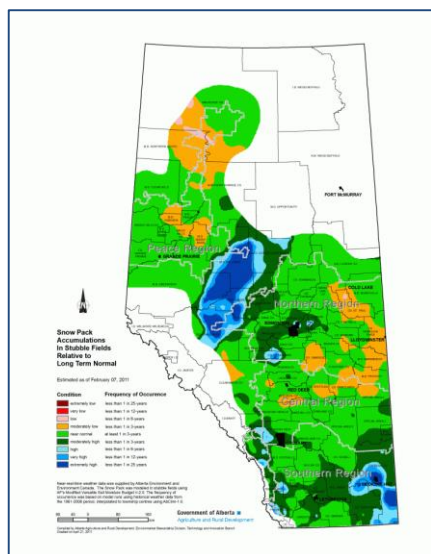
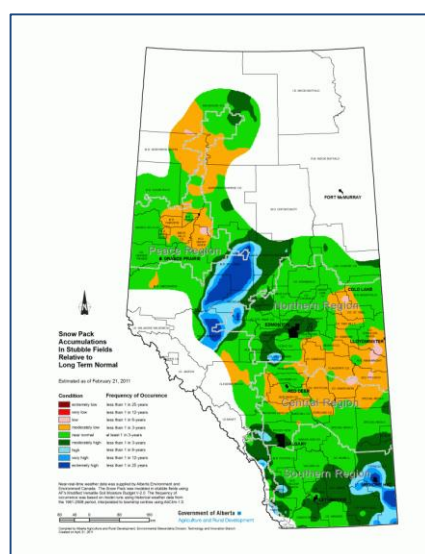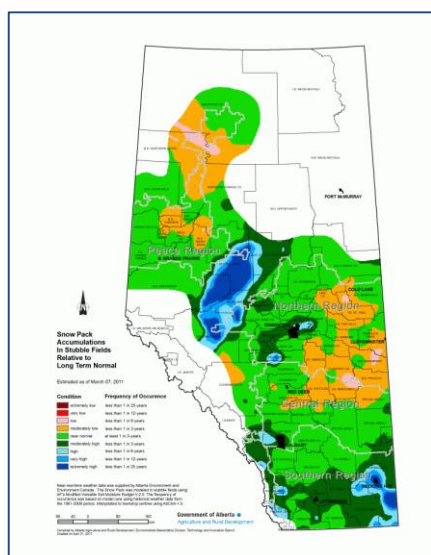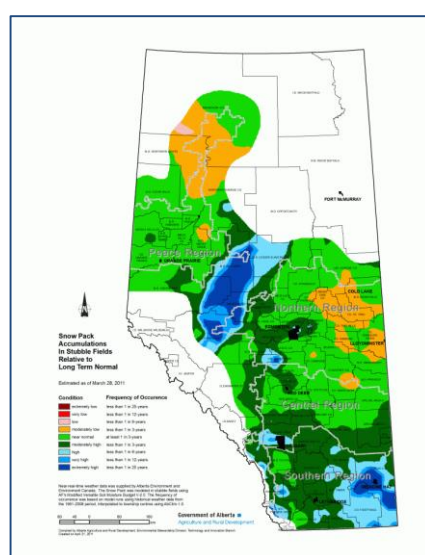

January 20

February 7

February 21

March 7

March 28

Fig. 1. Snow pack accumulations in stubble fields relative to long-term normals (low – red to high – blue) in Alberta, January through March 2011.

April 5

April 11

April 18

April 20

April 26

Fig. 2. Snow pack accumulations in stubble fields relative to long-term normals (low – red to high – blue) in Alberta, April 2011.
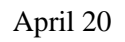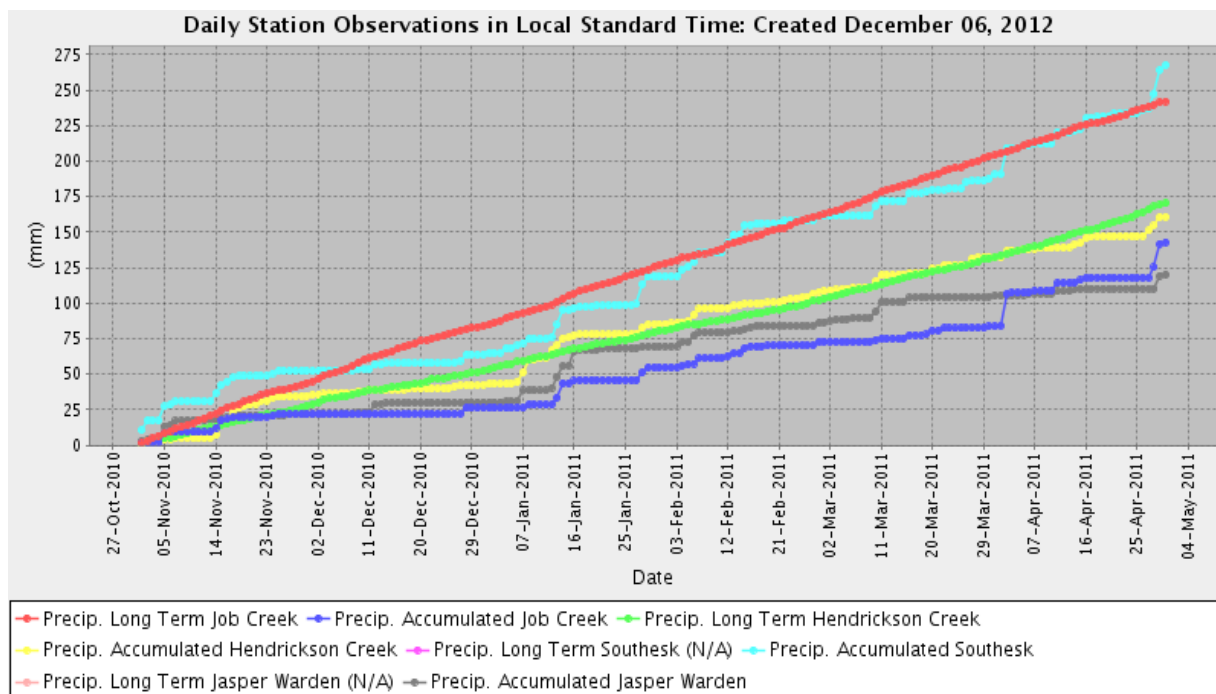
Fig. 3. Long term and accumulated precipitation for 4 stations in the northern Alberta Rocky Mountains, October 27, 2010 to May 4, 2011.
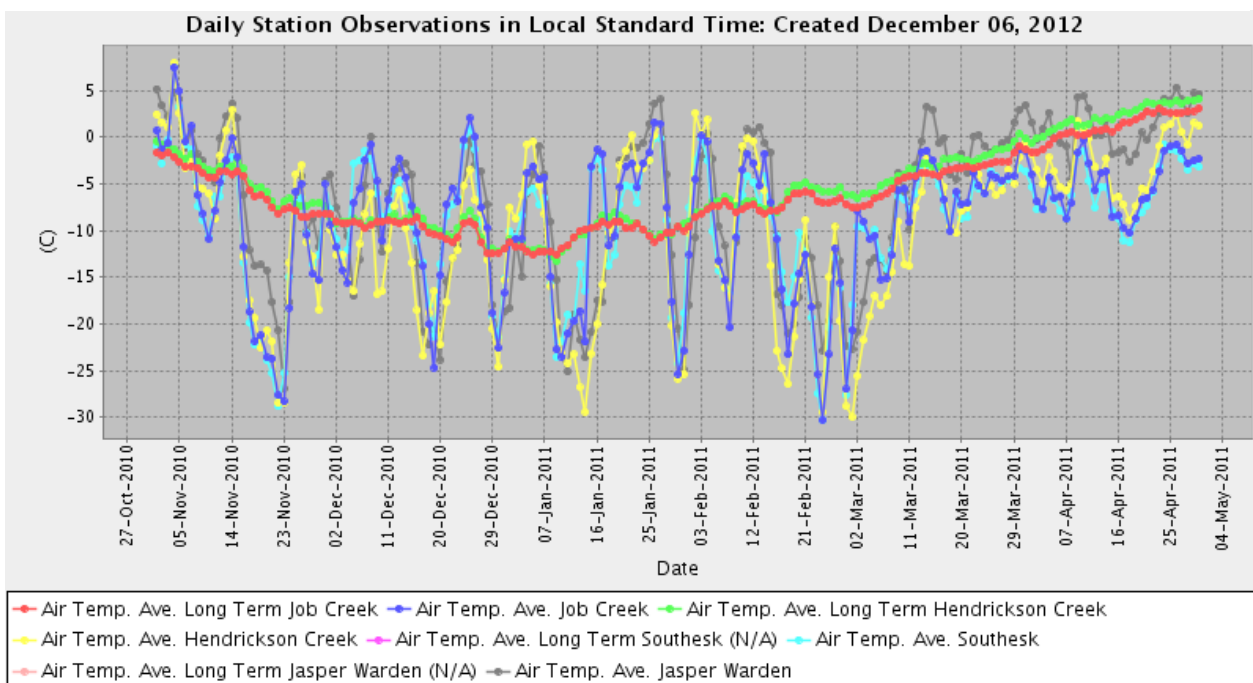
Fig. 4. Long term and average air temperature for 4 stations in the northern Alberta Rocky Mountains, October 27, 2010 to May 4, 2011.

indicating poor survival of lambs born in the spring of 2011 following the hard winter and prolonged spring.

A similar weather event occurred in the winter of 2002 with similar results, i.e., a higher proportion of rams dying than previous years, good lamb survival through the winter but poor lamb:ewe ratios the following fall (Bighorn 2003).

Conditions in 2002 were described as "snow and cool weather continued through March, April,
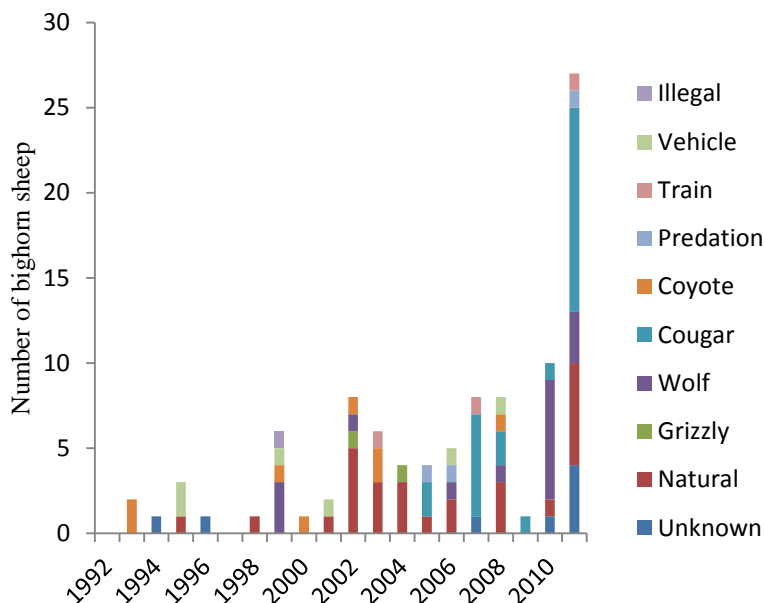
Fig. 5. Total bighorn sheep mortality and causes between January 1 and April 30, 1992–2011, Luscar and Gregg River mines.

and well into May. Both the March 8 and April 12 surveys were conducted in deep snow condition. Sheep appeared to be confined to favoured slopes and were not able to use greenup in the valley bottoms that usually becomes available in April".

These observations support predictions of higher mortality of older age rams in response to a prolonged winter, and highlight the importance of spring weather on the survival of lambs in a northern climate, as has been identified by Portier (1998) and others.

Fig. 6. Bighorn sheep biweekly mortality as a percentage of total winter (January 1 to April 30) mortality, Luscar and Gregg River mines.

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Table 3. Percent bighorn sheep winter mortality (January to April) of the previous fall population. Mortality is from all causes except for translocation and collection removals. The category Ram includes Class II, III, and IV sheep; Nursery includes ewe, lamb, yearling, and Class I ram.

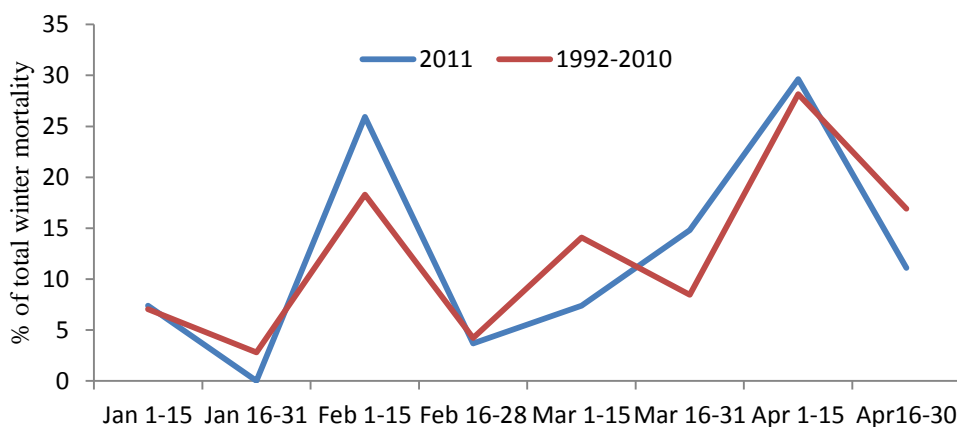| Year	% All Mortality: Fall Population	% Ram Mortality: Fall Rams	% Nursery Mortality: Fall Nursery
1992	0.00	0.00	0.00
1993	0.51	0.00	0.56
1994	0.21	0.00	0.27
1995	0.54	1.05	0.25
1996	0.17	0.00	0.29
1997	0.00	0.00	0.00
1998	0.16	0.38	0.00
1999	0.75	1.36	0.41
2000	0.13	0.00	0.22
2001	0.27	0.34	0.19
2002	0.99	2.39	0.20
2003	0.75	0.64	0.68
2004	0.44	0.91	0.20
2005	0.48	1.21	0.00
2006	0.51	1.25	0.13
2007	0.75	2.11	0.16
2008	0.83	1.95	0.14
2009	0.09	0.25	0.00
2010	0.89	2.51	0.14
2011	2.54	7.86	0.32
ALL	0.63	1.38	0.20

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Photo: JP Lemivaara

Photo: JP Lemivaara

Photo: Mari Wood

Several sheep ranges and many California bighorn sheep were
seen by Symposium participants during the field trip.
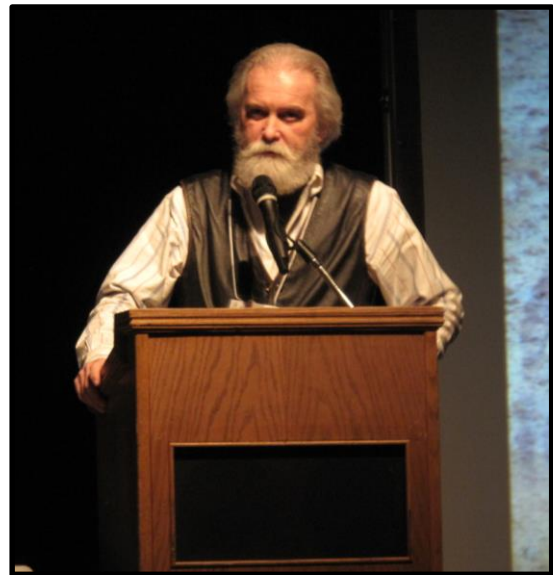
Keynote speakers Gray Thornton (left), and Shane Mahoney (right) shared their
insights with delegates at the end of the Symposium.

Photo: Steve Wilson

The Tk'emlups Indian Band hosted the group on their lands which offered an opportunity to view the local sheep range and listen to speakers (left). Symposium delegates listening to forestry consultant Bruce Morrow, RPF, describe burning a sheep range (right).

Photo: Aaron Reid

Conference participants "trapped" inside a sheep corral trap at Sun Rivers.

Photo: Roma Allen

Photo: Roma Allen

The field trip culminated with a wild game barbeque at the Dewdrop sheep range hosted by volunteers from the Kamloops Fish and Game Association, and sponsored by the Tk'emlups Indian Band, Sikanni River Outfitters, and Kamloops Brewery.

SULPHUR/ 8MILE STONE'S SHEEP PRE-TENURE PLAN REVIEW; THE APPLICATION OF THE SULPHUR/8MILE STONE'S SHEEP PROJECT TO OIL AND GAS PRE-TENURE PLAN FOR THE MUSKWA-KECHIKA MANAGEMENT AREA

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Abstract: With the completion of the Sulphur/8 Mile Stone's Sheep Research, the Stone's Sheep Steering and Science Committees provided a recommendations report on land use options to the Muskwa-Kechika Advisory Board and the BC Ministry of Forests, Lands and Natural Resource Operations. I provide an overview of that report and the committee's recommendation for the identification of a Stone's Sheep Special Zone which excludes industrial tenures to protect the majority of the area identified as critical. The boundaries of a portion of the High Elevation Zone of the Sulphur/8mile pre-tenure plan, where oil and gas tenures and other industrial tenures should be excluded, are identified. Implementation and monitoring recommendations are also included.

STUDY AREA

The Muskwa-Kechika Management Area (M-KMA) is intended to establish a world standard for environmental sustainability and economic stability, serving as a model that balances human activities such as resource extraction and tourism with conserving environmental values and a wilderness state over time.

This goal is supported by the Muskwa-Kechika Management Area Act (M-KMAA) that is intended to: *"Maintain in perpetuity the wilderness quality, and the diversity and abundance of wildlife and the ecosystems on which it depends, while allowing resource development and use in parts of the M-KMAA designated for those purposes, including recreation, hunting, trapping, timber harvesting, mineral exploration and mining, and oil and gas exploration and development."*

Achieving the goal of the M-KMA is accomplished through a variety of planning tools deployed in areas where development potential is elevated. Managers must look at the economic values, not in isolation of one another or of their surrounding environment, but rather as part of an integrated whole. All of the values must be managed together to achieve a sustainable future for all of the values in the M-KMA. Pre-tenure consultation in 2003 identified a concern over potential oil and gas tenures in the Sulphur/8Mile Resource Management Zone (RMZ) of the M-KMA. The Muskwa-Kechika Advisory Board worked with the Ministry of Energy, Mines, and Petroleum Resources (MEMPR) to identify the areas of high oil and gas potential. The Muskwa-Kechika Management Area has considerable undeveloped oil and gas resource potential (Fig. 1).

Sulphur/8 mile is a Resource Management Zone within the Muskwa-Kechika Management Area and created under the M-KMAA in 1998. The M-KMAA regulation states that resource management is to be conducted in accordance with the pre-tenure plan which serves as the oil and gas local strategic plan. Due to concerns about the potential impacts of development on Stone's Sheep (*Ovis dalli stonei*) expressed during the pre-tenure consultations on the Sulphur / 8 mile pre-tenure plan area (S/8MPTP), and specifically the Sulphur/8 Mile High Elevation Zone, MEMPR authorized an agreement stipulating that oil and gas tenures would not be sold in the higher elevation zone of the Sulphur/8 Mile High Elevation Zone until more information about Stone's Sheep was available to inform decisions. In May 2004, the
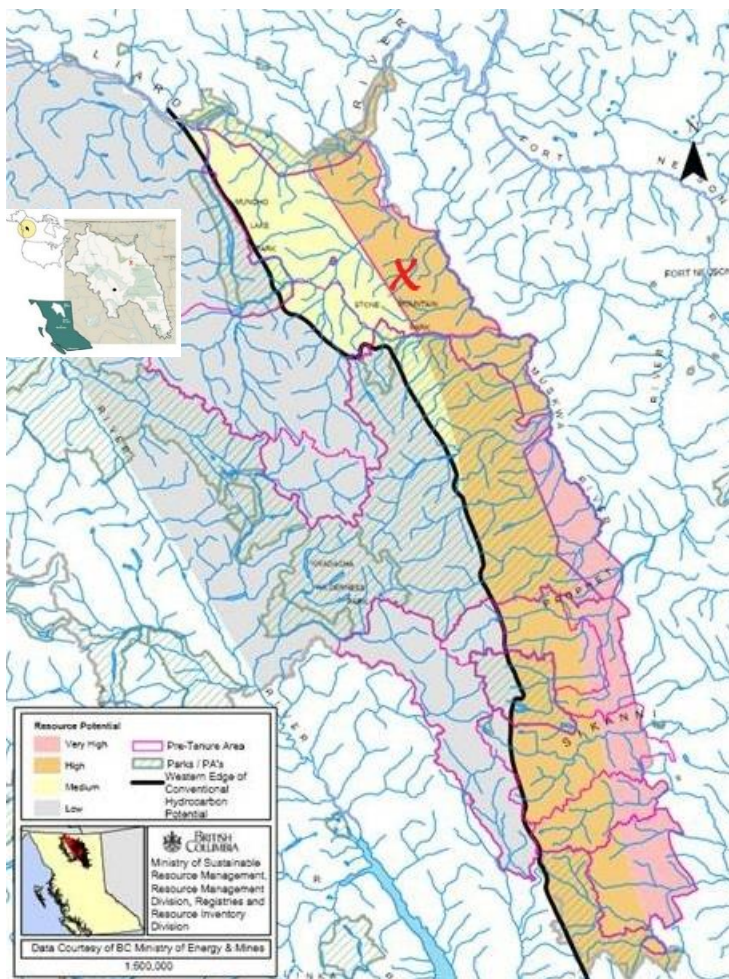
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Fig. 1. M-KMAA High Oil and Gas Potential Zone.

pre-tenure plan for oil and gas development in the Muskwa-Kechika Management Area was approved and identified the need to undertake Stone's Sheep research in response to concerns expressed by the pre-tenure advisory group (BC Ministry of Sustainable Resource Management 2004; Appendix A).

The North Peace Stone's Sheep Sustainability Steering Committee ("Steering Committee") was formed to oversee research, raise funds, and support the development of advice for the government to consider when providing management direction to guide the management of Stone's Sheep within the S/8MPTP.

Stone's Sheep studies were initiated in 2005. With the conclusion of the project in 2012, four reports are now available (Scientific and Community Environmental Knowledge Fund 2012). With the increased understanding of the status and needs of Stone's Sheep, the Steering

Committee commissioned a project to explore how the scientific findings might be applied for development planning under the pre-tenure plan for the high-elevation zone. Stone's Sheep studies were initiated in 2004 with a problem analysis (Axys Environmental 2005). Funding issues delayed initiation of field work until 2006 when Pamela Hengeveld, R.P.Bio. and Clint Cubberley, R.P.Bio.) were contracted to undertake field studies on behalf of the Steering Committee. Synergy ecology's project reports (Hengeveld and Cubberley 2012a, b) verified many of the issues identified by the Public Advisory Group (PAG) with one exception: the study found no evidence, current or historical, of sheep populations in the High Elevation Zone north of the Toad River.

METHODS

Hengeveld and Cubberley's work had four components:
1. Prepare a summary of the research components and their potential application;
2. Prepare a suite of proposed guidelines with all potential topic areas and issues to be addressed in a tentative format, with options;
3. Conduct a workshop with the oil and gas industry and other stakeholders to review and brainstorm the topic areas, issues and guideline format and make recommendations on changes/inclusions to the guidelines (Tassell and Churchill 2012);
4. Draft a report with final recommendations for the Steering Committee to forward to the Muskwa-Kechika Board and the Ministry of Forests, Lands and Natural Resource Operations (MFLNRO) for consideration of incorporation in pre-tenure plans use by MEMPR and Industry.

I provide an overview of a recommendations report by the Stone's Sheep Steering and Science Committees provided to The Muskwa Kechika Advisory Board and The Ministry of Forest Lands And Natural Resource Operations. This report reviewed the results-based methodology utilized in pre-tenure plans, along with recommendations of the Synergy ecology reports, and further examined existing PTP spatial biophysical mapping (BC
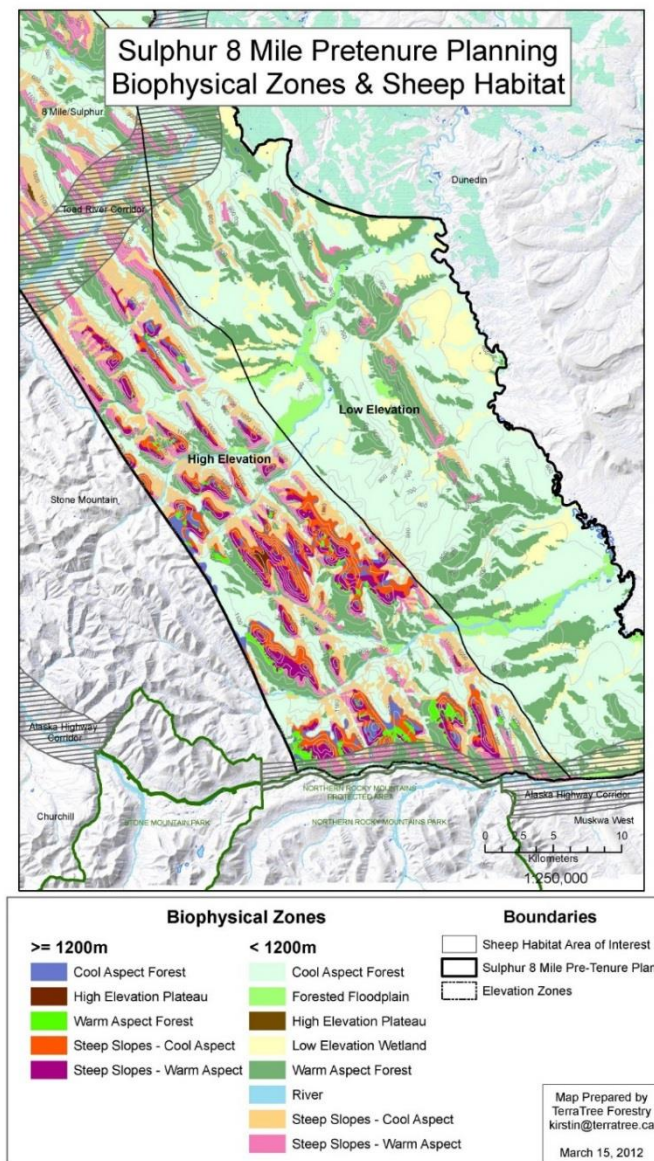
Fig. 2. Biophysical zones of the Sulphur/8Mile High Elevation Zone.

Ministry of Sustainable Resource Management 2004; Fig. 2) to create options to evaluate within the results-based methodology framework identified for pre-tenure plans (BC Ministry of Sustainable Resource Management 2004). I deferred to recommendations from workshop participants in the original consultation group (Scientific and Community Environmental Knowledge Fund 2012) which assessed the implications of the inputs mentioned above, and recommended a Special Stone's Sheep Zone.

RESULTS

From Hengeveld and Cubberley (2012a):

North of the Toad River

No sheep were found in this northern area during capture efforts (winters 2004/2005–2008/2009), except one group of 4 sheep, including a collared female transplanted to the area by the Ministry of Environment in March 2005; these four sheep were observed during the December 2006 and March 2007 censuses.

Reconnaissance flights in November 2007 and July 2008 did not detect any sheep.

A First Nations local knowledge study and a community knowledge study failed to identify historical sheep use in this area.

Sheep absence from alpine ranges is consistent with BC government sheep harvest records.

During this study, GPS-collared sheep in the entire S/8M area did not move beyond the areas of winter census observations and there is no other source of sheep that could utilize this northern area of the high-elevation zone.

South of the Toad River

All age-sex groups use ranges in the S/8M PTP High Elevation Zone south of the Toad River. Core sheep ranges were found on Ram Mountain and other alpine complexes, with female nursery groups residing there year-round.

Density on winter ranges at the Ram Mountain complex in the south S/8MPTP High Elevation Zone was roughly 3.5–4 sheep/km^2.

Males, particularly young males, use the High Elevation Zone more extensively than females do. This was reflected in higher ratio of males to females in the High Elevation Zone than average across the Stone Mountain range. For the six GPS collared males 86.7% of locations in the High Elevation Zone were above 1,200 m elevation.

During winter census, the ratio of lambs to females was higher in the S/8MPTP High Elevation Zone (55%) than the average for all Stone's Sheep populations (37%).

Only a small group (possibly the result of a sheep translocation done by BC Ministry of Environment in 1996) utilized the S/8MPTP High Elevation Zone area south of the Dunedin River to the Alaska Highway and the North Tetsa River.

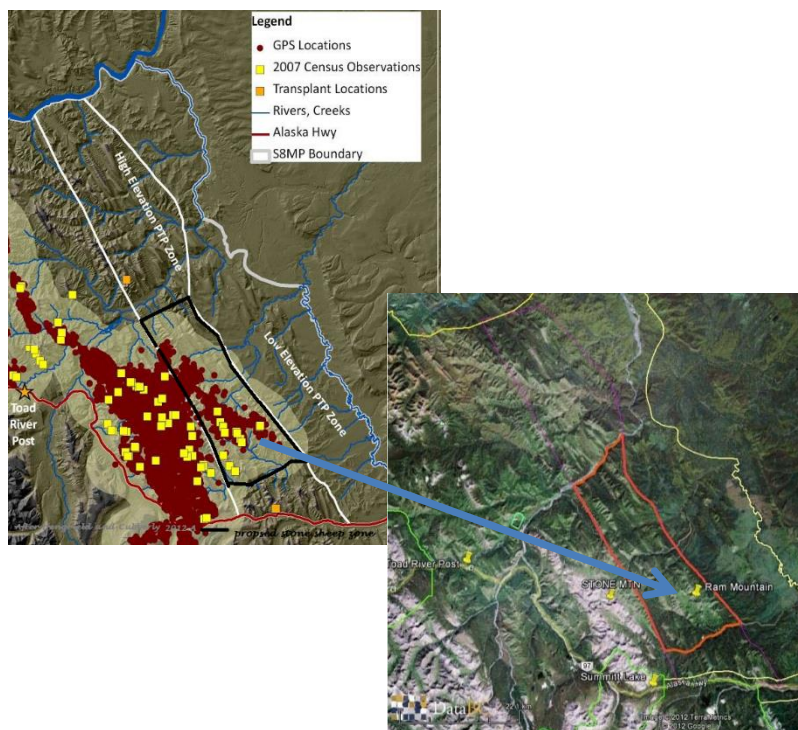Fig. 3. Special Sheep Zone recommended by Hengeveld and Cubberley (2012a) with overlay of exclusion zone recommended by Stone's Sheep Committee.

The management recommendations identified a Special Stone's Sheep Zone for wildlife sustainability management.

MANAGEMENT IMPLICATIONS

Following consideration of the risk to Stone's Sheep populations, the Steering Committee submitted the following recommendations to the Muskwa-Kechika Board and the Ministry of Forests, Lands and Natural Resource Operations:

1. Divide the High Elevation Zone.
2. For the portion of the High Elevation Zone North of the Toad River implement the pre-tenure directions that are already in place as general measures for Stone's Sheep in the Muskwa-Kechika Pre-Tenure Plan.
3. Muskwa–West (north) Pre-Tenure Planning Zone: implement the same existing direction for Muskwa–West (north) Pre-Tenure Planning Zone.
4. The portion of the High Elevation Zone South of the Toad River: exclude Southern High Elevation Zone from oil and gas tenure (Fig. 3; Table 1).

5.   Provide long-term sheep population protection for the southern High Elevation Zone through special designation by either: changing the approved boundaries of the Muskwa-Kechika Pre-tenure Area to exclude this area or create a "no disposition notation order" under the Petroleum and Natural Gas Act.

Additionally the Steering Committee would like to bring to the attention of the Muskwa-Kechika Advisory Board and the Ministry of Forests, Lands and Natural Resource Operations that the restrictions to oil and gas development to sustain Stone's Sheep, if accepted, should apply to all other forms of surface development that may result in similar impacts. Stone's Sheep warrant this level of protection, and require exclusion for other conflicting activities. Options should include a full suite of regulatory or legislative actions.

To facilitate the implementation of these recommendations, the following changes to the Muskwa-Kechika Pre-Tenure Plan are recommended:

1. A GIS file of the boundaries of the Stone's Sheep Zone has been included with this report.
2. The Muskwa-Kechika Pre-Tenure Plan for oil and gas has been constructed in a loose leaf format to accommodate changes.
3. Change maps (their Figs. 7-1 and 7-2) on pages 7-2 and 7-4.
4. Changes to text of Element 1.1 on pages 7-9 and 7-10.
5. Changes to text on pages 5-9. The resultant text would be:

Stone's Sheep are the rarest of North American wild sheep and the plan area encompasses a sizeable area of critical Stone's Sheep winter habitat. Considerations for Stone's Sheep include: avoidance of sheep winter habitat, minimize stressors in late winter, monitor for sheep trails at any elevation and manage so that wildlife use is not disrupted or impeded, monitor and mitigate

Table 1. Biophysical size comparisons of proposed a) "Stone's Sheep Zone" and b) Sulphur / 8 mile pre-tenure plan area zone/subzones.

a)

Biophysical zone	S/8M Pre-Tenure zone (ha)	Low Elevation Zone (ha)	High Elevation Zone (ha)	Sheep Zone (ha)	Sheep Zone % OF S/8M Pre-Tenure zone
Low Elevation Wetland	9,668	9,213	455		
Warm Aspect Forest (<45%)	41,830	24,052	17,778		
Cool Aspect Forested (<45%)	91,575	58,473	33,102		
River	1,937	790	1,147		
Forested Floodplain	3,253	2,752	501		
High Elevation Plateau	382	0	382		
Steep Slope - Cool Aspect (>45%)	29,468	2,253	27,215		
Steep Slope - Warm Aspect (>45%)	19,815	1,214	18,601		
Totals	197,928	98,747	99,181	39,760	20.08%

b)

Biophysical zone	High elevation zone (ha)	Sheep Zone %
High Elevation Plateau	382	28.88%
Steep Slope - Cool Aspect (>45%)	27,215	42.01%
Steep Slope - Warm Aspect (>45%)	18,601	42.14%
Totals	46,198	41.95%

vehicle-related mortalities, limit dust and artificial mineral sources.

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APPENDIX A

Agreement Regarding Stone's Sheep Studies Sulphur / 8 Mile Pre-Tenure Plan Area of the Muskwa-Kechika Management Area.

Due to concerns about impacts on Stone's Sheep expressed in the Pre-Tenure Consultations in Sulphur / 8 Mile Pre-Tenure Plan Area, MEMPR authorized an agreement that would see deferral of Sulphur/8 Mile High Elevation Zone (S/8M-HEZ) from inclusion in the Pre-Tenure planning document (BC Ministry of Sustainable Resource Development 2004) until more information on Stone's Sheep was available.

Agreement Regarding Stone's Sheep Studies Sulphur/8 Mile Pre-Tenure Plan Area

The following outlines a consensus agreement of the Public Advisory Group regarding the High Elevation Zone of the Sulphur / 8 Mile pre-tenure plan area (maps 7-1 and 7-2 of the M-KMA Pre-Tenure Plan show the location of the High Elevation Zone).

There are two components to this agreement:
1. Stone's sheep studies and pre-tenure plan management direction.
2. Geophysical activities.

1. Stone's sheep studies and pre-tenure plan management direction:

Whereas the High Elevation Zone contains critical Stone's sheep habitat; and

Whereas there is a need to undertake research and activities to re-build Stone's sheep populations and to take a cautious, scientific approach to the potential for impacts on Stone's sheep; and

Whereas taking reasonable time to collect information and develop appropriate management direction is expected to have little if any negative economic impact;

The pre-tenure plan Public Advisory Group agrees that, for the High Elevation Zone:
1. Coordinated[20] information / research studies should be initiated immediately on Stone's sheep populations and habitat.
2. Management direction to guide oil and gas activities, incorporating the Stone's sheep research, should be written and approved in the pre-tenure plan by December 2009.
3. Opportunities for oil and gas tenure sales should take effect upon approval of the management direction.

Related Agreement:

A small portion of high elevation terrain, similar to that in the Sulphur / 8 Mile area occurs in the northwest corner of the Muskwa-West pre-tenure plan area. The above agreement will not apply to the Muskwa-West area, but it is expected that the management direction developed and approved by December 2009 will be applied to this high elevation portion of the Muskwa-West area.

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[20] "Coordinated" studies includes multi-interest input and participation in the development and oversight of the information / research program.

POPULATION AND HARVEST TRENDS OF MOUNTAIN SHEEP AND MOUNTAIN GOATS IN BRITISH COLUMBIA

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Abstract: We present provincial population and harvest trends for mountain sheep and mountain goats in British Columbia (BC). Population size was estimated every 3–5 years from 1987–2011 by regional biologists and compiled for provincial totals. Over this time, Stone's Sheep (*Ovis dalli stonei*) numbers in northern BC were generally consistent at between 9,900–15,000 animals (x̄ = 12,250). The estimated number of Dall's sheep (*O. d. dalli*) was 400–600 in the extreme northwest of the province. All bighorn sheep in BC are classified as *Ovis canadensis* but are separated into Rocky Mountain and California bighorn sheep ecotypes for management purposes. Total bighorn sheep numbers peaked in the early to mid-1990s with estimates of 2,750–3,250 Rocky Mountain bighorn sheep and 3,100–3,900 California bighorn sheep. The estimated number of mountain goats (*Oreamnos americanus*) appeared stable over time (x̄= 52,200) but this may be due to a lack of inventory data that would enable detection of population change. Mountain sheep and mountain goats have high value to both resident and non-resident hunters as well as for wildlife viewing. Annual hunting licence sales for the 23 years 1989–2011 for mountain sheep and mountain goat ranged from 2,024–3,091 (x̄ = 2,564) and 2,404–3,415 (x̄ = 2,946), respectively. Compulsory inspection and reporting of horns from harvested mountain sheep and mountain goats was initiated in 1976. This information was used to determine trends in resident and non-resident harvest over 36 years (1976–2011). Annual harvest of Stone's sheep ranged from 254–515 (x̄ = 357) and from 0–16 (x̄ = 9) for Dall's sheep. Bighorn sheep harvest peaked in the mid-1990's with Rocky Mountain bighorn sheep harvest from 21–106 (x̄ = 57) and 31–145 (x̄ = 74) for California bighorn sheep. Annual harvest of mountain goats ranged between 599 and 1,163 (x̄ = 846). Key concerns are discussed to outline the need for increased inventory and applied research dedicated to mountain sheep and mountain goats.

Key words: bighorn sheep, British Columbia, harvest, Dall's sheep, mountain goat, Stone's sheep, thinhorn sheep.

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Mountain sheep and mountain goats are important species in BC for a variety of reasons that include food, culture, visual appreciation and trophy values. They are considered iconic both regionally and provincially. There are four types of mountain sheep in the province (Fig. 1); two subspecies of thinhorn sheep, and two ecotypes of bighorn sheep. Approximately 80% of the global population of Stone's sheep (*Ovis dalli stonei*) occurs in northern British Columbia and a small population of Dall's sheep (*O. d. dalli*) is found in the extreme northwest corner of the province. Rocky Mountain bighorn sheep are native in the mountain ranges of east-central and southeast BC and there are two introduced populations in the southern interior. California bighorn sheep are primarily at lower elevation in drier habitats along river drainages in the southern interior part of the province (Blood 1961). Rocky Mountain and California bighorn sheep were originally considered separate subspecies (Shackleton 1999) but in 2001 they were classified as one species (*Ovis canadensis*) following Wehausen and Ramey (2000; BC Conservation Data Centre, 2012). Since then, bighorn sheep have been managed as two separate ecotypes and California bighorns are further divided into four metapopulations (Demarchi et al 2000b; Fig. 1). There is likely some low degree of mixing between the ecotypes on adjacent ranges. There is no overall management plan for mountain sheep in BC but in the Thompson Okanagan Region three regional plans have been developed for California and Rocky Mountain Bighorn Sheep (Harper et al. 2002, Fraser River Bighorn Sheep Advisory Committee 2004, South Thompson Bighorn Sheep Management Committee 2005). Status Reports have been developed for Rocky Mountain bighorn
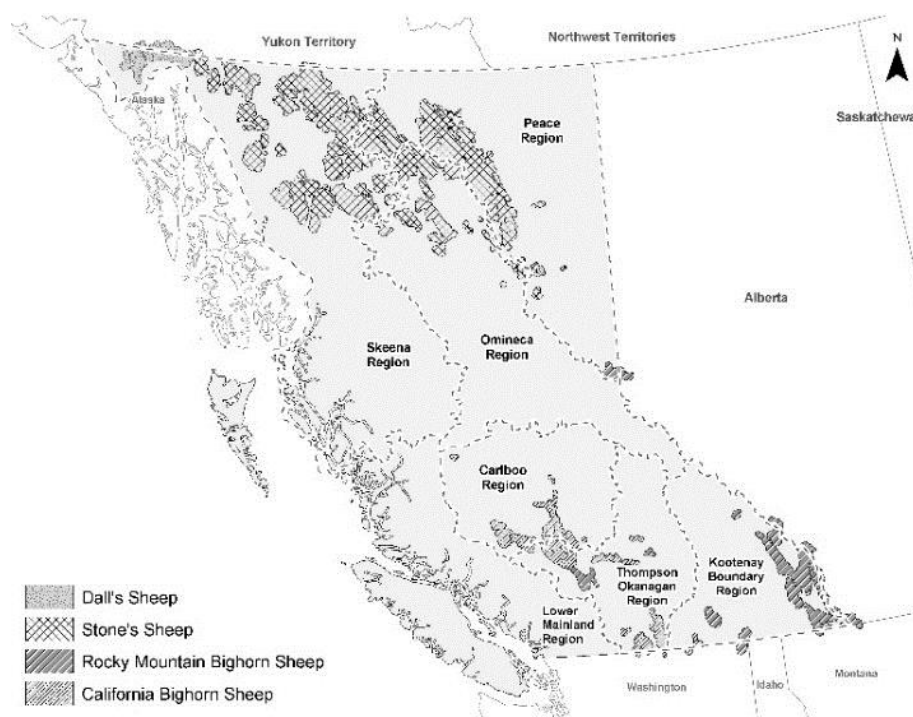
Fig. 1. Distribution of mountain sheep in British Columbia.

sheep (Demarchi et al. 2000a), California bighorn sheep (Demarchi et al. 2000b) and thinhorn sheep (Demarchi and Hartwig 2004).

British Columbia is home to approximately half of the world's mountain goats (Fig. 2); therefore, the province has a global responsibility for mountain goat conservation and management. Relative to other ungulate species, mountain goats have low reproductive rates and can be sensitive to human disturbance, so conservative management is advised (Festa-Bianchet and Côté 2008). In 2010, the BC Ministry of Environment released the *Management Plan for the Mountain Goat* (*Oreamnos americanus*) *in British Columbia* which contains detailed population and harvest information and provides recommendations for improved population monitoring and maintaining sustainable harvest (Mountain Goat Management Team 2010). This paper provides a long-term assessment of population and harvest trends of mountain sheep and mountain goats in BC.

METHODS

Population estimates were determined by regional biologists every 3 to 5 years from 1987 to 2011 using aerial survey data in combination with expert opinion. These regional estimates were then compiled for provincial totals. Rocky Mountain
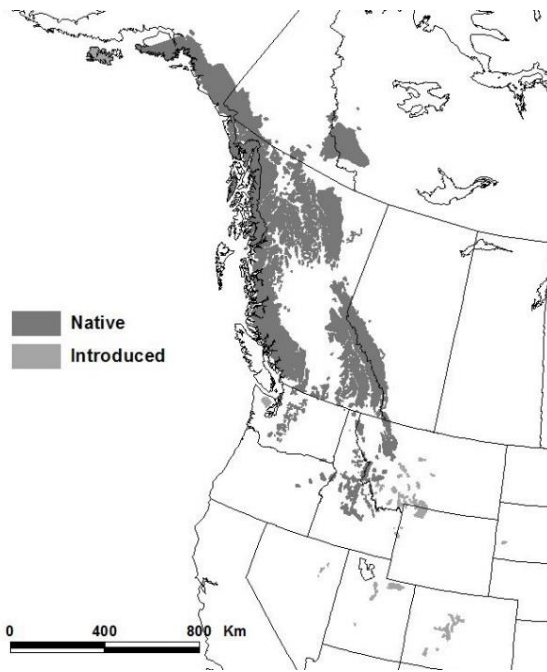
Fig. 2. Distribution of mountain goats in North America depicting the large range encompassed within British Columbia (map courtesy BC Ministry of Environment 2010).

and California bighorn sheep data were pooled from 1987 to 1994 but have been recorded separately since 1997. To better reflect uncertainty of estimates, ranges were produced from 2000 to 2011

Harvest data were gathered for 36 consecutive years (1976–2011) through the Ministry's Compulsory Inspection and Reporting (CI) program which requires that all successful
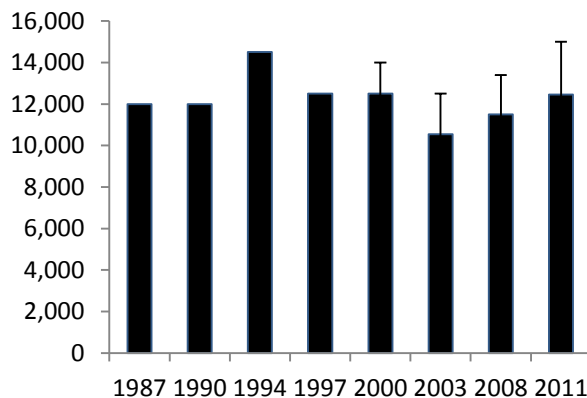
Fig. 3. Population estimates of thinhorn sheep in BC.

licensed hunters submit horns and heads from harvested mountain sheep and mountain goats in order to legally possess and transport them. Inspection and reporting process is standardized to include: estimation of age using horn growth annuli, recording inter-annulus length measurements, total horn lengths, estimated horn broomed length, and horn base circumferences. Because reporting is mandatory, these data are not presented with estimates of error. As a specific regional project, CI data for thinhorn sheep from the Skeena Region were screened for reporting bias for 1996–2011 and these data were incorporated into this analysis (Jex 2011).

RESULTS AND DISCUSSION

Thinhorn Sheep

Skeena-Omineca-Peace Regions

Populations of the two subspecies of thinhorn sheep, Stone's sheep and Dall's sheep (Fig. 1), in British Columbia appear to be generally stable at between 9,900 and 15,000 animals since 1987 ($\bar{x}$= 12,250). Early estimates were primarily informed by expert opinion and limited fixed-wing aircraft survey data. Since 2000, population estimates were produced as ranges and are more refined as helicopter-based inventories were used (Fig. 3). Licensed harvest of Stone's sheep has ranged from 254 to 515 ($\bar{x}$ = 357) annually since 1976, with fluctuations occurring in the mid-1980s and early 1990s (Fig. 4) that are consistent with population abundance patterns in other thinhorn populations (Hik and Carey 2000, Alaska Department of Fish and Game 2008). Possible causes of fluctuations in harvest include: changes in weather patterns that affect winter and spring severity subsequently resulting in a negative effect on lamb survival and abundance; anthropogenic disturbances and increased levels of access that alienate habitats and alter habitat use; as well as economic drivers and hunting conditions that affect the numbers and timing and success of hunters. Harvest of Dall's sheep during this time ranged from 0 to 16 ($\bar{x}$ = 9) annually and is recently trending down (Fig. 5), most likely due to the small portion of the province that Dall's sheep occupy and the amplified effect
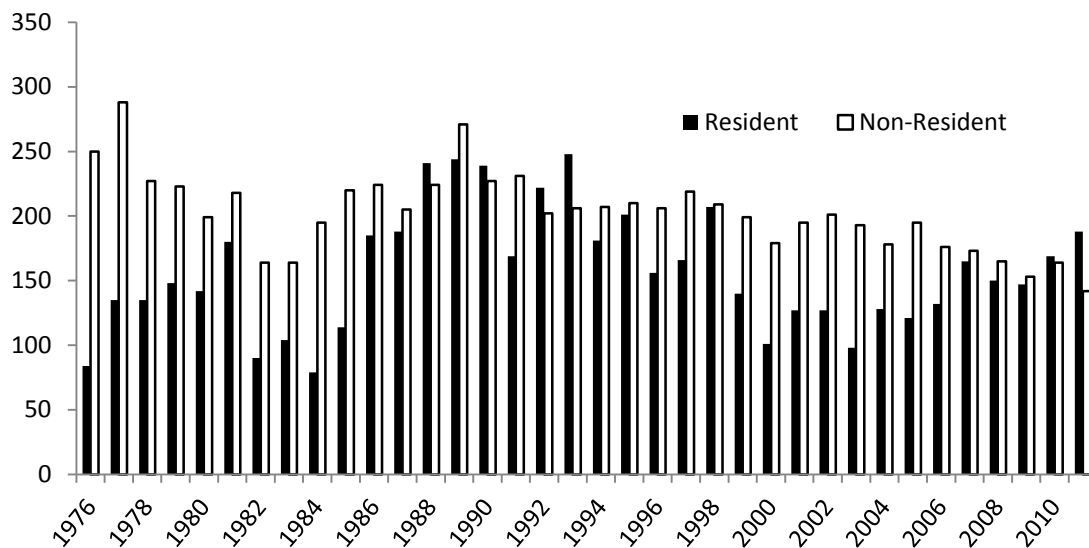
Fig. 4. Annual harvest of Stone's sheep in BC from 1976-2011.
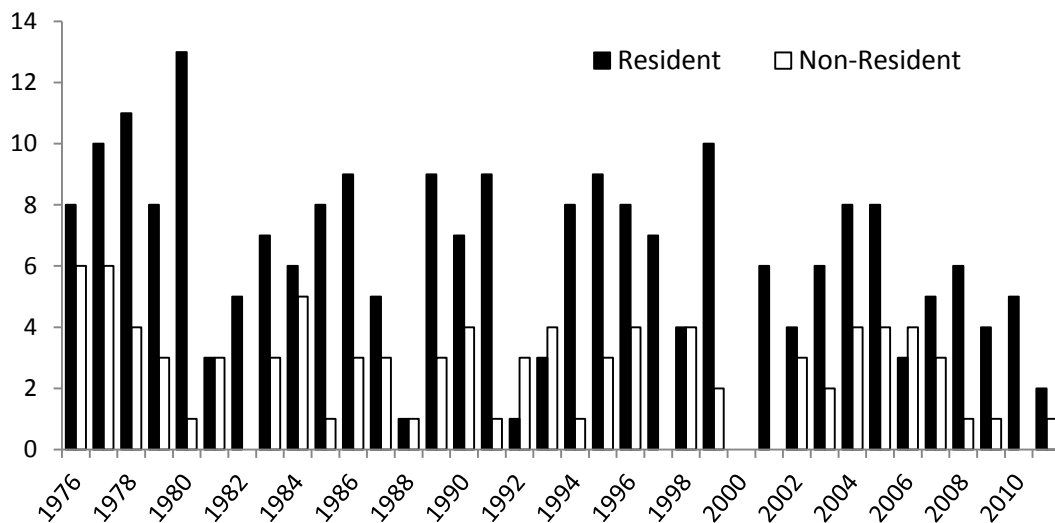
Fig. 5. Annual harvest of Dall's sheep in BC from 1976-2011.

that the previously noted impacts have on the low annual harvest. Increases in exploration activities, resource development and anthropogenic disturbances since 2005 may have affected the availability of Dall's sheep to licensed hunters as some rams may move into the Yukon when disturbed (Jack Goodwin[2] pers. comm.). Anecdotal information on the level of success in the resident and non-resident harvest (Fig. 5) supports the disturbance proposition.

Rocky Mountain Bighorn Sheep

Kootenay/Boundary Region

Fluctuations in provincial numbers of Rocky Mountain bighorn sheep (Figs. 6 and 7) and harvest (Fig. 8) are best explained by examining factors affecting the bighorns within the Kootenay/Boundary Region (Fig. 1). Population estimates have been between 1900 and 2400 sheep since the mid-1980s (Fig. 6) and herds are

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[2] Jack Goodwin is a guide outfitter based in Atlin, BC. His operating area covers Wildlife Management Units

6-29 & 6-28, and is the only area where Dall's sheep occurs in BC.
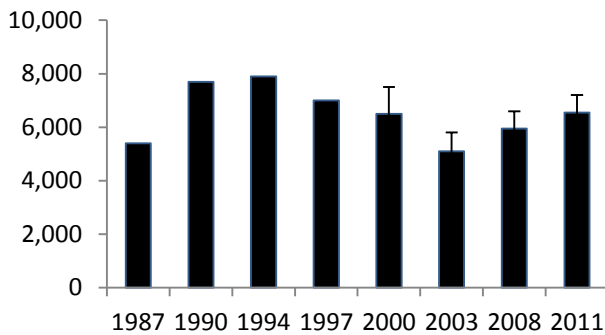
Fig. 6. Population estimates of bighorn sheep (Rocky Mountain and California bighorns combined) in BC.
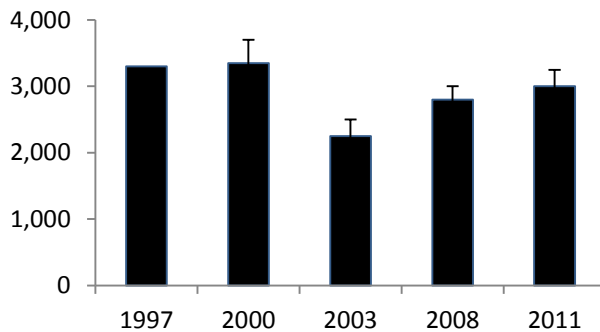
Fig. 7. Population estimates of Rocky Mountain bighorn sheep in BC.

generally divided into those that use lower elevation winter ranges within the Rocky Mountain Trench and those that use higher-elevation winter ranges. Some seasonal movement occurs between BC and Alberta. An all-age respiratory disease die-off occurred in the early 1980s in some herds in the region while other herds were not affected. This occurrence of disease followed a pattern seen at least twice before with reports of similar die-offs in the 1940s and 1960s (Schwantje 1988). Since the 1980s, most herds have either increased or remained stable; however, there are some smaller herds whose numbers have either never recovered or have declined. Predation, reduced access to quality habitat including conifer in-growth, and site specific adverse weather conditions (e.g. high snowfall winters in 1996/97 and 1997/98) may be factors associated with the reduced survival in these herds. No disease outbreaks have been reported since the 1980s die-off.

Annual harvest of Rocky Mountain Bighorn sheep has ranged from 21 to 106 ($\bar{x}$ = 57) from

1976 to 2011. Prior to 1977, harvest strategies in the eastern part of the region included a 7/8 curl or minimum 8-year-old ram season which was changed to a full curl regulation in 1978. Between 1985 and 2002 there was a resident Limited Entry Hunt (LEH) ewe season to reduce specific herd densities. Currently, only full-curl ram seasons are available. Harvest peaked in the late 1980s and early 1990s with an average of 55 rams and 42 ewes annually (Fig. 8). Harvest levels declined after the two severe winters to a low of 20 rams in 2000, increasing since 2005 with an average of 41 rams per year (Fig. 8).

Peace Region

The Narraway herd, in the southern reaches of the Peace Region is North America's most northerly bighorn sheep population. Currently this herd is estimated to be less than 200 individuals. Surveys have been sporadic and it is only recently that Alberta and BC have collaborated on surveys so trend information is lacking. Seasonal migrations to the east occur in winter, with movements back to the west in summer. The extent (spatial and numerical) of seasonal migration is unknown and likely dependent on winter severity. The most recent survey (2009) enumerated 177 sheep, of which 54 were in BC. The herd appears to be stable, as there is no indication from previous surveys of large fluctuations in population size.

Harvest of this herd is managed with a full curl regulation in BC and trophy sheep regulation in Alberta. From 1983 to 2009 the average annual combined harvest from BC and Alberta was 5 sheep (range 1–11). BC harvest during that time period averaged 2 rams/year (range 0–9) and Alberta harvest was 3 rams/year (range 0–9). There were no apparent trends in harvest through time. BC and Alberta will continue to collaborate on management of this herd.

Thompson/Okanagan Region

Two introduced herds (Spences Bridge and Chase herds) of non-migratory Rocky Mountain bighorn sheep exist in the Thompson/Okanagan Region. Populations are thought to be stable and number approximately 500 and 40 sheep respectively. Only the Spences Bridge herd is currently hunted. Harvest in the last 5 years
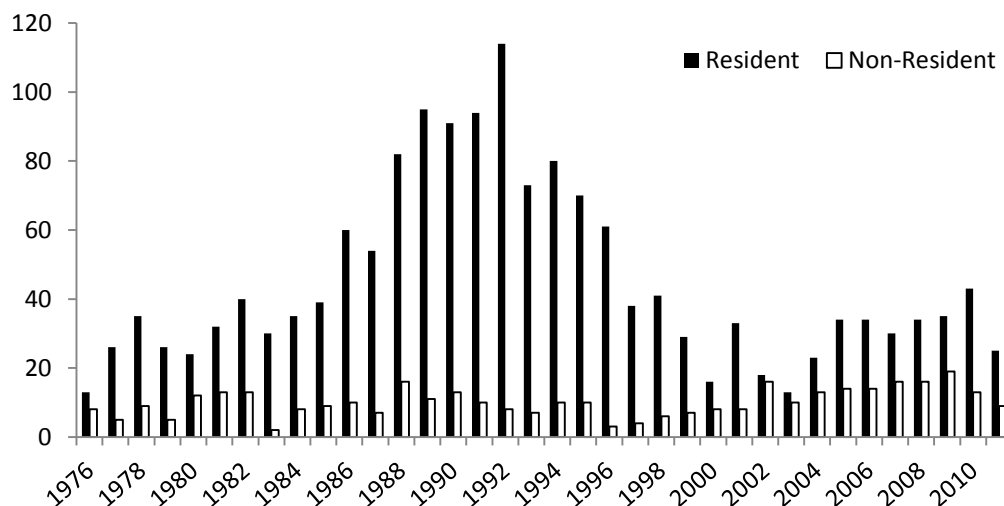
Fig. 8. Annual harvest of Rocky Mountain bighorn sheep in BC from 1976-2011.

averaged approximately 7 rams per year (range 5–10) under a horn curl restricted General Open Season (GOS). Harvest regulation changes in 1999 were designed to reduce ram harvest and focus on older sheep resulting in lower harvest. In years prior to 1999, harvest was managed under a full curl regulation and the number of rams taken was high, averaging 17 per year (range 11–22). Due to rapid horn growth, most of these were young rams. In 1999, a more restrictive horn curl regulation was implemented and harvest has since averaged 5 rams per year (range 0–10).
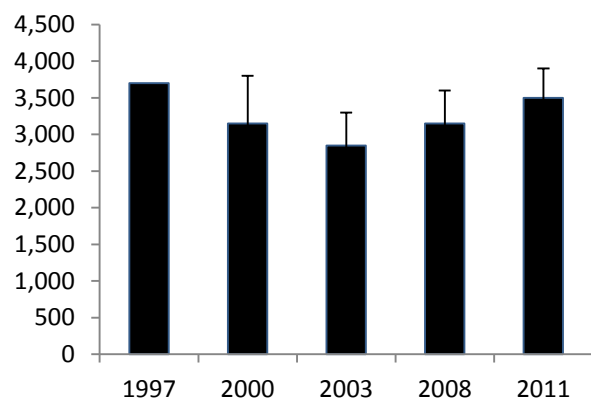
Fig. 9. Population estimates of California bighorn sheep in BC.

California Bighorn Sheep

Total numbers of California bighorns in BC peaked in the early to mid-1990s and then declined through 2003 (Figs. 6 and 9). Since 2003 there has been recovery provincially however some populations remain depressed. Some herds have recently expanded into previously unoccupied habitats and these contribute to the more recent increase in 2008 and 2011 estimates.

Annual harvest ranged from 31-145 ($\bar{x}$ = 74). Harvest increased from 1980 through 1995, declined through to 2000 and has been stable to slightly increasing since (Fig. 10). The harvest decline since the mid-1990s was largely due to the decline in the Fraser River metapopulation and associated changes to hunting regulations during that time which are detailed below.

Fraser Metapopulation

The current population estimate for the Fraser metapopulation is approximately 1,600 California bighorn sheep. The highest density and largest of these herds have historically been the low-elevation resident and migratory herds along major river basins. Through the 1980's and early 1990's, the Fraser metapopulation was estimated at between 2,800 and 2,900 sheep. Beginning in 1995, many herds experienced substantial declines, dropping to an estimated low of approximately 1,200 by 2005–2007 (Fig. 9).
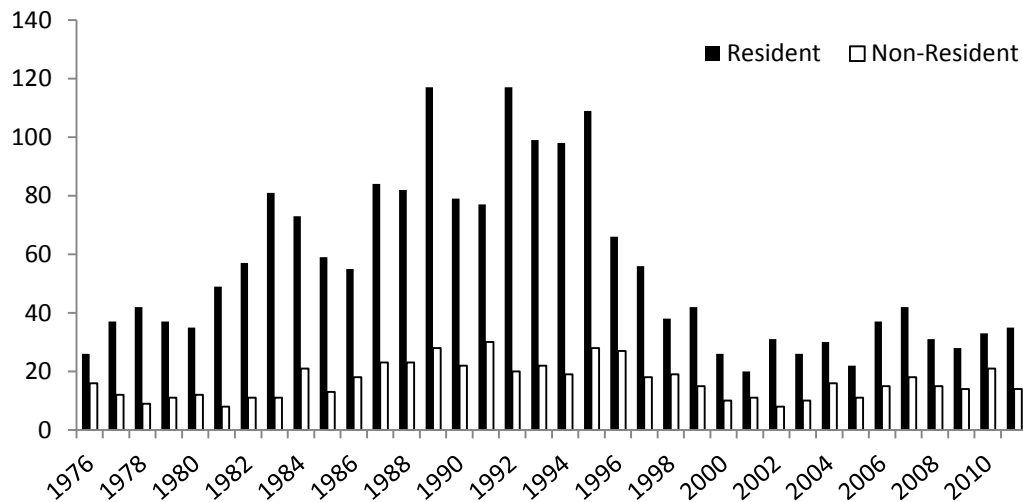
Fig. 10. Annual harvest of California bighorn sheep in BC from 1976-2011.

Extremely low lamb recruitment in some herds over long periods combined with high predation rates by coyotes and cougars are believed to be primary factors (Hebert and Harrison 1988, Harrison and Hebert 1988). In addition, a significant number of ewes were removed from specific herds for translocation to the United States for conservation purposes over several decades (Table 1), and range quality has suffered from livestock use and conifer in-growth. Since 2005, a few herds have increased; however, the majority of herds remain at relatively low numbers with several herds with chronic low lamb recruitment (<10% in two cases). A recently-initiated research project has identified *Mycoplasma ovipneumoniae* in clinically ill young lambs in one of these herds.

Prior to 1996, harvest for this metapopulation was managed under ¾ and full curl GOS regulations. In 1996, a LEH for ¾ curl rams in combination with a GOS for full curl rams was implemented in much of the area to significantly reduce ram harvest. Ram harvests since 1996 have averaged 14 per year. The declines in harvest are attributed to an overall population decline which resulted in more restrictive regulation regimes (such as conversion to full curl) and closure of some GOS hunting seasons (Fig. 10).

Thompson Metapopulation

The current population estimate for the Thompson metapopulation is approximately 1,000 California bighorn sheep. There are five herds of California bighorn sheep within this metapopulation and all but one have increased significantly since the late 1980s. Two herds (Battle Creek and Chasm Creek) are new and naturally established, and combined have increased to approximately 180 animals since the early 1990s and early 2000s, respectively. Overall numbers in the South Thompson and Kamloops Lake herds increased from approximately 175 in the late 1980s to approximately 750. One herd (Skwaam Bay) introduced to suboptimal habitat in the early 1990s has not fared as well and has been stable at approximately 30 animals.

The Thompson metapopulation of sheep has one herd (Kamloops Lake) that has had consistent hunting regulations; only a portion of the herd is hunted and harvest has been minimal, averaging 2 rams per year. A hunt was established for the South Thompson herd from 2006–10 and a total of 11 rams were harvested. Because a significant portion of this herd ranges on private lands, the hunt was instituted as part of a pilot landowner enfranchisement project. This program is now in review therefore the season is currently closed pending outcomes of the review. A LEH hunt has been established for the Chasm Creek herd

beginning in the 2012 season and if current trends observed in the other expanding herd (Battle Creek) continue, a hunt on that herd may be expected in the near future.

Okanagan-Similkameen Metapopulation

The current population estimate for the Okanagan–Similkameen metapopulation totals approximately 1,015 sheep with about 615 in the Okanagan herd and 400 in the Similkameen herd. The Okanagan herd suffered an all-age respiratory disease-related die-off in 1999–2000, where approximately 65% of an estimated 430+ bighorns died. There was a significant reduction in lamb recruitment post die-off, a typical pattern following all-age die-offs in bighorn sheep (University of California-Davis 2007, Wehausen et al. 2011). However, within two years the recruitment had returned to pre-die-off levels and by 2011, the Okanagan bighorns recovered to pre-die-off numbers. As part of a recovery plan (Harper et al. 2002), California bighorn sheep were translocated into vacant habitat at the northern extent of this sheep range in 2007 and 2009 (Table 1). The translocation has contributed approximately 100 additional bighorns to this metapopulation. Harvest for the Okanagan and Similkameen herds are under any ram and ¾ curl LEH seasons, respectively. Since 2004, the average annual harvest has been 21.

Kettle-Granby Metapopulation

This is the easternmost metapopulation of California bighorn sheep in BC and occurs in the Kootenay/Boundary Region (Fig. 1). This herd was translocated into the area in the 1980s from the south Okanagan (Table 1) and has grown to approximately 200 animals. These sheep are limited to mid- to low-elevation slopes due to high crown closure forest on the upper slopes. The majority of the population occur along the south and east aspects of major river drainages within the area. Currently, this metapopulation has hunting seasons for any ram under an LEH, with an average annual harvest of 4.

Mountain Goats

The estimated provincial population of mountain goats has remained relatively stable from 1987 to 2011 at about 50,000 animals (Fig.

11). There is a lack of current and repeated inventories such that while a large portion of the province has been surveyed for mountain goats, many surveys have occurred only once, resulting in a poor understanding of population trends (Mountain Goat Management Team 2010). Visibility bias during mountain goat surveys has been a confounding factor in determining population estimates in BC (Cichowski et al. 1994, Poole 2007), especially for coastal populations living largely in or near forested habitats (Mountain Goat Management Team 2010). A new technique for estimating mountain goat abundance using fecal DNA shows promise for addressing this visibility bias (Poole et al. 2011).

Mountain goats are managed under both either sex GOS and LEH seasons. In 2010, a provincial regulation was implemented to minimise harvest of females and an outreach program was initiated to train hunters online. The annual harvest of mountain goats has ranged from 599 to 1,163 ($\bar{x}$ = 846; Fig. 12). There were some years in the late 1980s and early 1990s where harvest exceeded 1000 mountain goats per year yet there was no associated increase in licence sales. In some years non-resident harvest exceeded resident harvest highlighting the importance of mountain goats to the guide/outfitting industry (Fig. 11).

The northern portion of the province (Omineca, Peace and Skeena Regions) contains approximately 65% of the provincial mountain goat population. The number appears stable; however, in recent years resource development projects and backcountry recreation expansion
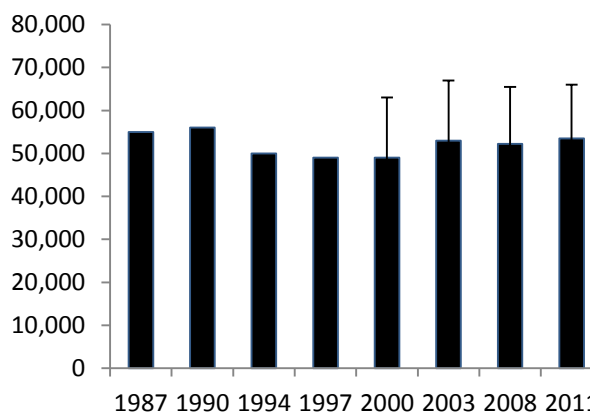
Fig. 11. Population estimates of mountain goats in BC.
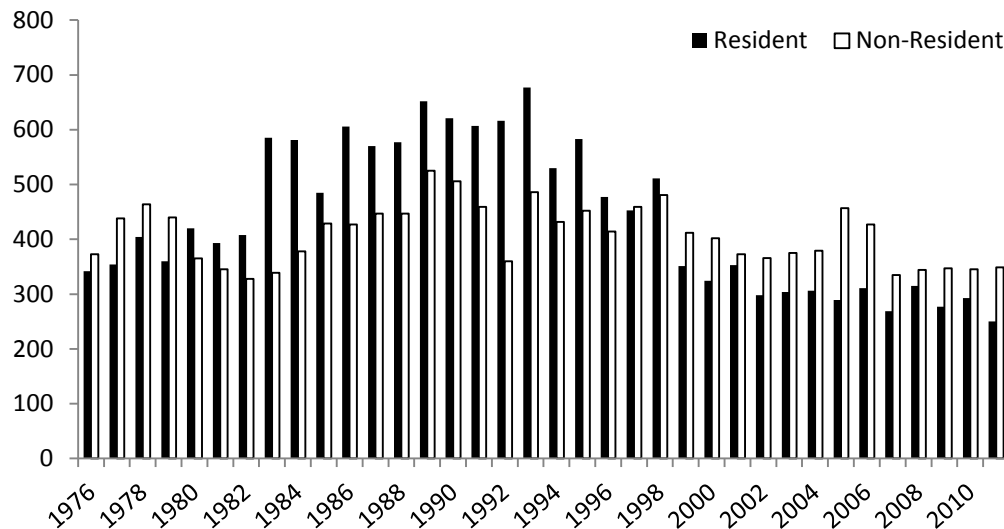
Fig. 12. Annual harvest of mountain goats in BC from 1976-2011.

have been associated with habitat alienation and habitat loss. Large-scale mountain goat population declines resulting from disease and parasites have not been identified in BC (Jenkins et al. 2004), although it is suggested anecdotally that the occurrence of contagious ecthyma in a herd in the extreme northwest of the province has affected its viability. Within the last decade, observations and reports of animals affected by the virus in this herd have declined (Jack Goodwin, pers. comm.). In the north, mountain goats are predominantly managed through a combination of GOS and LEH opportunities where high levels of easy access could increase the risk of localized overharvest. The main harvest management concern is the proportion of female mountain goats taken. For example, resident hunters usually harvest a higher proportion of female mountain goats than do non-resident hunters. Since 1976, the average composition of the harvest for resident hunters in the north is 34% female versus 66% male; for non-resident hunters the composition is 22% female versus 78% male. Since 2000, average composition of harvest for resident hunters in the north is 25% female versus 75% male; for non-resident hunters the composition is 16% female compared to 84% male. This change is assumed to be the result of the hunter education program

aimed specifically at improving gender identification of mountain goats.

In the southern portion of the province, the Kootenay/Boundary region has the highest numbers of mountain goats and numbers there are currently stable. In other areas, particularly the Coast mountain ranges and some interior mountain ranges, mountain goat population trends have been variable. Some populations appeared to peak in the mid-1990s and have since declined by as much as 50%, while other interior and south coastal populations appear to have slowly declined over the last 2 decades. In contrast to these more widespread declines, some populations have been stable and other populations have re-established themselves in a number of mountain complexes formerly extirpated of mountain goats. Some stable populations have also shifted range use and changed distribution within ranges (Mountain Goat Management Team 2010). The reduction in mountain goat harvest (Fig. 12) likely reflects some of the broader population declines in the central interior portion of the province and subsequent regulation changes. About 30% of the provincial harvest of mountain goats occurs in the Kootenay/Boundary region (Mountain Goat Management Team 2010) where there have been changes in hunter opportunity from 1979–1984 when LEH authorizations were increased from
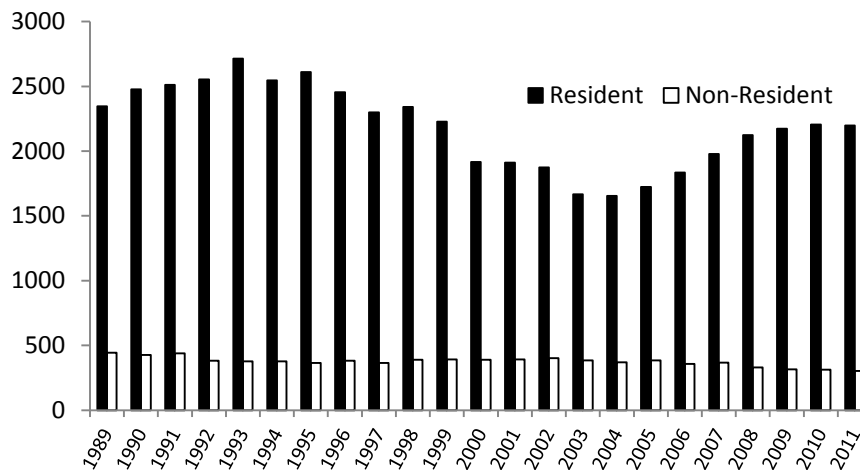
Fig. 13. Licence sales for mountain sheep in BC.
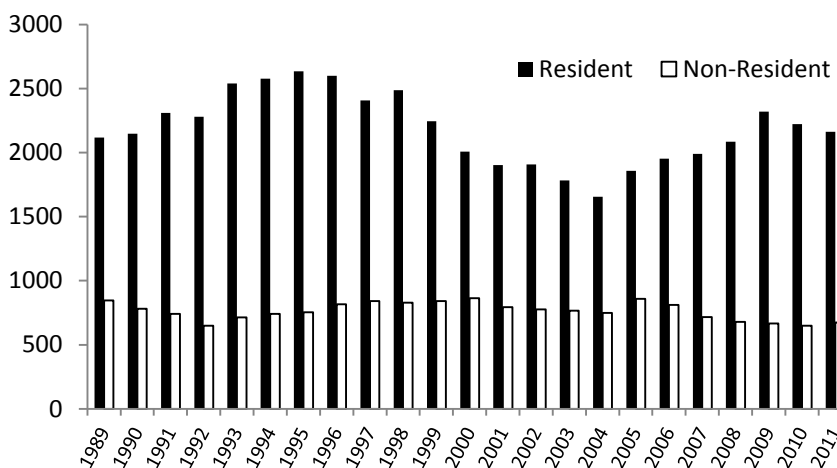
Fig. 14. Licence sales for mountain goats in BC.

about 100 to over 1,100 authorizations per year. Annual resident harvest increased during this time from about 75 to 450 mountain goats. There was another increase in LEH authorizations between the mid-1990s and mid-2000s yet harvest declined, probably due to reduced hunter interest as hunter numbers also declined from 700–850 to 400–500 during this time (Mountain Goat Management Team 2010).

Licence Sales for Mountain Sheep and Mountain Goats

Mountain sheep and mountain goats are valued by both resident and non-resident hunters. Annual hunting licence sales for 23 years (1989 to 2011) ranged from 2,024 to 3,091 ($\bar{x}$ = 2,564) for mountain sheep and 2,404 to 3,415 ($\bar{x}$ = 2,946) for mountain goat (Figs. 13 and 14). Resident hunter licence sales for both mountain sheep and goats peaked in the early to mid-1990s and fell to a low in 2004 and then showed a steady increase to 2010. This same trend is reflected in the provincial general resident hunter licence sales for all species. Annual non-resident harvest for both mountain sheep and mountain goats is limited by guide outfitter quotas, however licence sales are not. Non-resident license sales in BC during this same timeframe have remained relatively stable, and on average made up 18% of the total mountain sheep licence sales and 36% of the total mountain goat licence sales.

Translocations

Translocations can reflect population trends of mountain sheep (Tables 1 and 2). The luxury of robust bighorn populations with few recognized conflicts and good quality range in previous decades resulted in BC providing bighorn stock for many successful recovery programs in the United States, particularly from 1954 to 2000. After the identification of Bovine Spongiform Encephalopathy in Canadian cattle in the late 1990s, the US closed the border to ruminant imports and has allowed only one importation of bighorn sheep from Alberta in the winter of 2011.

BC has provided a total of 568 animals (primarily reproductive age females) to the western US for reintroductions or herd augmentations (Table 2). In addition, a total of 850 animals were moved between herds within BC (Table 1). In early years in BC the purpose of

Table 1. Translocation of bighorn sheep within BC (1933-2012).

Year	Source	Region[a]	Destination	Region	No. Translocated	Ecotype
1933	Squilax	TOR	Skwaam Bay (Adams Lk.)	TOR	20	Rocky Mountain
1955	Junction	CR	Bluff Lake	CR	9	California
1955	Junction	CR	Vaseux	KBR	4	California
1955	Junction	CR	Whitewater	CR	2	California
1956	Junction	CR	U.B.C.	LMR	4	California
1956	Junction	CR	Dog Creek	CR	8	California
1956	Junction	CR	Gang Ranch	CR	6	California
1957	Junction	CR	U.B.C.	LMR	4	California
1957	Junction	CR	Vaseux	TOR	10	California
1966	Junction	CR	Kamloops Lake	TOR	11	California
1977	Vaseux	TOR	Okanagan Game Farm	TOR	20	California
1981	Kamloops	TOR	Harper Ranch	TOR	1	California
1982	Wigwam Flats	KBR	Bull River	KBR	16	Rocky Mountain
1984	Columbia Lake	KBR	Lizard Range	KBR	28	Rocky Mountain
1984	Columbia Lake	KBR	McGuire Creek	KBR	7	Rocky Mountain
1984	Vaseux	TOR	Grand Forks	TOR	20	California
1985	Columbia Lake	KBR	Tulip Creek	KBR	20	Rocky Mountain
1985	Columbia Lake	KBR	McGuire Creek	KBR	10	Rocky Mountain
1985	Junction	CR	Harper Ranch	TOR	6	California
1985	Junction	CR	Dog Creek	CR	12	California
1985	Vaseux	TOR	Grand Forks	TOR	12	California
1986	Columbia Lake	KBR	Lizard Range	KBR	11	Rocky Mountain
1986	Stoddart Creek	KBR	Wigwam Flats	KBR	47	Rocky Mountain
1986	Columbia Lake	KBR	Wildhorse R.	KBR	5	Rocky Mountain
1986	Junction	CR	Dog Creek	CR	13	California
1986	Vaseux	TOR	Grand Forks	TOR	13	California
1987	Stoddart Creek	KBR	Arrow Lakes	KBR	18	Rocky Mountain
1987	Columbia Lake	KBR	Wildhorse R.	KBR	12	Rocky Mountain
1987	Columbia Lake	KBR	Lakit Lake	KBR	11	Rocky Mountain
1987	Columbia Lake	KBR	Mause Creek	KBR	17	Rocky Mountain
1987	Junction	CR	Word Creek	CR	7	California
1987	Deer Park Ranch	CR	Skwaam Bay	TOR	1	California
1988	Deer Park Ranch	CR	Skwaam Bay	TOR	12	California
1989	Radium	KBR	Wigwam Flats	KBR	20	Rocky Mountain
1988	Deer Park Ranch	CR	Word Creek	CR	12	California
1989	Stoddart Creek	KBR	McGuire Creek	KBR	19	Rocky Mountain
1990	Spences Bridge	TOR	Squilax Creek (Chase)	TOR	4	Rocky Mountain
1990	Junction	CR	Chilko Lake	CR	11	California
1992	Stoddart Creek	KBR	Ram Creek	KBR	22	Rocky Mountain
1993	Ewin Ridge	KBR	Bingay Creek	KBR	7	Rocky Mountain
1993	Thomas Ranch (South OK)	TOR	Penticton Creek	TOR	12	California
1994	Big Bar	TOR	Seton Lake	TOR	23	California
1993	Radium	KBR	Ram Creek	KBR	27	Rocky Mountain
1994	Radium	KBR	Ewin Ridge	KBR	10	Rocky Mountain
1994	Junction	CR	Taseko Mtn.& Tosh Creek	CR	32	California
1998	S. Thompson (Harper Ranch)	TOR	Penticton Creek	TOR	14	California
1997	S. Thompson (Harper Ranch)	TOR	Seton Lake	TOR	2	California
1997	Kamloops Lake (Tranquille)	TOR	Seton Lake	TOR	1	California
2004	Harper Ranch	TOR	Shorts Creek	TOR	12	California
2005	Radium	KBR	Wasa Creek	KBR	25	Rocky Mountain
2007	Keremeos	TOR	Ok Mtn.	TOR	34	California
2007	Golden	KBR	Whiteswan Lake area	KBR	19	Rocky Mountain
2008	S. Thompson (Mt. Paul/Sun Rivers)	TOR	Alkali Ranch	CR	26	California
2009	Golden	KBR	Grundy Creek	KBR	13	Rocky Mountain
2009	Kamloops Lake (Tranquille)	TOR	Ok Mtn.	TOR	15	California
2009	Kamloops Lake (Tranquille)	TOR	Big Bar (OK Ranch)	TOR	42	California
2012	S. Thompson (Mt. Paul/Sun Rivers)	TOR	Fraser River (Mackay Creek)	TOR	36	California
2012	S. Thompson (Mt. Paul/Sun Rivers)	TOR	Fraser River (Mackay Creek)	TOR	15	California
Total translocations within BC					**850**	

[a] CR - Cariboo Region, TOR - Thompson/Okanagan Region, KBR - Kootenay/Boundary Region, LMR - Lower Mainland Region

translocations was primarily to establish new herds, but since 1980 the purpose was mostly as a management tool to reduce herd density as a disease mitigation measure. There have been 58 translocations, ranging from 1 to 47 individuals, within BC from 1933–2012. Two translocations (Spences Bridge and Chase), totalling 99 bighorn sheep, moved bighorns into BC from Banff

Table 2. Translocation of bighorn sheep into BC (1927) and translocation of bighorn sheep from BC (1954-2000).

Year	Source	Region[a]	Destination	Region	No. Translocated	Ecotype
1927	Alberta (Banff)	-	Spences Bridge	TOR	49	Rocky Mountain
1927	Alberta (Banff)	-	Squilax (Chase)	TOR	50	Rocky Mountain
Total translocations into BC					**99**	
1954	Junction	CR	Oregon	-	20	California
1956	Junction	CR	N. Dakota	-	18	California
1957	Junction	CR	Washington	-	18	California
1963	Junction	CR	Idaho	-	19	California
1965	Junction	CR	Idaho	-	9	California
1966	Junction	CR	Idaho	-	10	California
1967	Junction	CR	Idaho	-	12	California
1971	Junction	CR	California	-	10	California
1978	Vaseux	TOR	Nevada	-	12	California
1983	Junction	CR	Nevada	-	19	California
1984	Junction	CR	Nevada	-	12	California
1985	Junction	CR	Nevada	-	20	California
1988	Junction	CR	Idaho	-	14	California
1989	Junction	CR	N. Dakota	-	10	California
1989	Junction	CR	Nevada	-	33	California
1989	Keremeos	TOR	Nevada	-	20	California
1990	Junction	CR	Nevada	-	15	California
1990	Columbia Lake	KBR	Colorado	-	34	Rocky Mountain
1990	Junction	CR	Oregon	-	15	California
1993	Keremeos	TOR	Nevada	-	26	California
1995	Big Bar	TOR	Nevada	-	42	California
1996	Kamloops Lake [Tranquille]	TOR	Washington	-	25	California
1996	South Thompson [Harper Ranch]	TOR	Washington	-	7	California
1996	Big Bar	TOR	N. Dakota	-	21	California
1996	Big Bar	TOR	Nevada	-	20	California
1997	South Thompson [Harper Ranch]	TOR	Utah	-	11	California
1997	Kamloops Lake	TOR	Utah	-	12	California
1997	Spences Bridge	TOR	Snake River/Oregon, Idaho, WA	-	40	Rocky Mountain
1999	South Thompson [Harper Ranch]	TOR	Nevada	-	18	California
1999	Kamloops Lake [Tranquille]	TOR	Nevada	-	5	California
2000	South Thompson [Harper] (11)	TOR	Washington/Lake Chalan	-	11	California
2000	South Thompson [Mt. Paul] (10)	TOR	Washington/Lake Chalan	-	10	California
Total translocations out of BC					**568**	

[*] CR - Cariboo Region, TOR - Thompson/Okanagan Region, KBR - Kootenay/Boundary Region, LMR - Lower Mainland Region

National Park, Alberta in 1927. These animals were released into traditional California bighorn habitat and herds have persisted and expanded their range. There have been 32 translocations during 1954–2000, totalling 568 bighorn sheep (range 5–42), where sheep were moved out of BC. Sixty Stone's sheep were moved in 2 translocations from 1990–1996 within BC (Hatter and Blower 1996). From 1924–1999 there were 151 mountain goats moved within the province and 93 animals from the province (Hatter and Blower 1996; Mountain Goat Management Team 2010).

CONCLUSION

Most populations of mountain sheep and mountain goats in BC are considered relatively stable with some localised declines in bighorns and interior and coastal populations of mountain goats. Large-scale population declines in bighorn mountain sheep in BC have historically been related to respiratory disease outbreaks that occurred after contact with domestic sheep. This issue continues to be a priority concern on privately owned land in BC (Appendix 1). In general, harvest trends do follow population levels and this is especially apparent in Rocky Mountain and California bighorn sheep. Harvest appears to be proportional to population size, where Stone's sheep have a greater population size (9,900–15,000) and average annual harvest ($\bar{x} = 357$) relative to Rocky Mountain bighorn sheep population size (2,750–3,250) and harvest ($\bar{x} = 57$) and California bighorn sheep (3,100–3,900) ($\bar{x} = 74$).

A better understanding of the basic ecology of mountain goats is needed in BC, especially in coastal habitats where limited inventory and

anecdotal reports suggest numbers may be declining (Mountain Goat Management Team 2010). Mountain goats are sensitive to helicopter disturbance (Côté 1996, Festa-Bianchet and Côté 2008) and there are real challenges managing both mountain goats and mountain sheep in balance with socio-economic pressures of industrial and recreational development. Some research has recently been published on the impacts on mountain goats (Cadsand et al. 2012) but further investigation is warranted with the increase in resource extraction and recreational industries working in mountain goat and mountain sheep habitat.

Research on mountain sheep has largely focused on the habitat use of California bighorn sheep (Blood, 1961, Demarchi 1965, Demarchi and Mitchell 1973, Wikeem 1984), Rocky Mountain bighorn sheep (Hebert 1973, Poole 2012) and Stone's sheep (Seip and Bunnell 1985, Walker et al. 2007, Churchill and Glaholt 2012) with only limited work on factors that may affect populations (Harper 1984, Milakovic and Parker 2011) including disease (Schwantje 1988). Recent research on harvest management examining bighorn horn growth data in relation to age of harvest determined that rams which grew horns at a faster rate were harvested at a younger age (Hengeveld and Festa-Bianchet 2011), but there is still a lack of research focused on linking harvest and populations. A new collaborative project with Dr. Marco Festa-Bianchet (University of Sherbrooke) is using Stone's sheep CI horn data to analyse ecological variables that may affect survival, growth, and vulnerability of Stone's Sheep to harvest. Additional work is required focussing on the factors involved in poor bighorn lamb recruitment and other health-related issues of mountain sheep and mountain goats. New research should be focused wherever possible on applied population and harvest management issues and produce recommendations to enhance and maintain sustainable populations and harvest of mountain sheep and mountain goats in BC.

ACKNOWLEDGEMENTS

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Appendix 1. Matrix of issues/topics for mountain sheep in British Columbia originally developed for the Western Association of Fish and Wildlife Agencies Wild Sheep Working Group. Ranked 1 (highest) to 10 (lowest) priority.

ISSUE/ MANAGEMENT TOPIC	Thompson[a]/ Okanagan	Kootenay/ Boundary	Cariboo	Skeena	Omineca	Peace	Thompson/ Okanagan[a]
WS Habitat Quality	5	2	5	7	3	8	4
WS Habitat Quantity	8	2	8	8	8	7	4
Habitat Fragmentation	5	4	7	4	7	7	7
Vegetative Succession	4	2	8	8	5	4	3
Water Availability	8	5	8	10	2	10	6
Wilderness Designations	10	7	7	8	3	5	8
Restrictions due to Wilderness Designation	10	7	9	10	8	10	9
WS Habitat on Private/Deeded Lands	3	5	3	10	1	10	3
Recreational Impacts	7	3	3	5	3	7	6
ATV/OHV	3	2	2	5	8	9	5
Human Expansion	4	3	8	10	8	10	2
Energy Development	3	1	3	10	9	2	6
Livestock Grazing	2	2	2	7	9	9	2
Restrictive Fences	9	5	9	10	9	10	7
Wild Horses	5	10	10	7	9	9	3
Forage Competition	9	3	4	9	7	5	7
Poaching/Illegal Take	5	8	5	3	9	5	9
Anti-Hunting NGOs	None	8	9	8	8	9	9
P/A of Advocacy NGO	Y	Y	Y	Y	Y	Y	Y
Adequacy of Funding	1	4	6	3	8	3	4
Dedicated Personnel for WS Management	3	4	7	7	9	1	5
Lack of Management Plan	8	7	5	5	None	3	5
Too Little Access for Hunting/Management	7	5	10	8	5	5	9
Too Much Access	7	5	7	5	5	6	2
Shared WS Management with Tribal/First Nation	No	5	5	5	No	1	5
Predation – wolves	5	5	6	7	5	2	9
Predation – cougars	3	5	10	10	9	10	3
Predation – coyotes	5	6	7	8	7	6	3
Predation on WS (avian)	5	?	5	7	?	8	?
Predation on WS	4	4	8	7	5	4	5
Ability to Influence Predation Levels on WS	5	6	8	8	No	5	5
Disease Issues with WS	1	2	1	7	No	4	2
Disease Issues (other than w/ Domestics)	4	6	7	7	No	9	4
Viability of Populations	4	7	7	7	8	6	7
T&E Listing Status	10		10	10	No	9	7
Connectivity between WS Meta-Population	9	5	5	7	8	8	5
Impediments/Barriers	5	5	10	8	8	8	7
Mining Developments	5	6	6	3		1	5
Helicopter Disturbance	8	6	7	3		7	9

[a] Indicates subregion
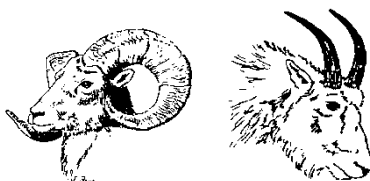
ARE ALBERTA'S TROPHY RAMS DECLINING IN QUALITY AND QUANTITY?

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Abstract: In Alberta, hunting of trophy sheep by provincial residents has been conducted since 1968 on an unlimited entry basis using 4/5th curl to define a legal ram. Under such a regime, rams with rapidly growing horns and the potential to reach a large size can be harvested as young as 4–5 years of age, before they achieve the high breeding success facilitated by large horns. Artificial selection pressure against fast-growing and larger rams has been reported in the Ram Mountain population where trophy hunting was associated with declines in both body mass and horn length over a 30 year period. It is unknown whether other populations may be similarly affected. Following concerns expressed by hunting organizations over a decline in availability of large rams, we analyzed data from 7,054 trophy rams harvested over 36 years (1974–2009). We used linear and linear mixed-effect models to look for temporal changes in horn length, basal circumference, and harvest age at the provincial level and in 8 Sheep Management Areas (SMAs) considered separate metapopulations. Provincially, annual ram harvests have declined since the 1990's while at the SMA scale, harvests in 5 of 8 SMAs have declined with 3 remaining stable. Average ram age at harvest increased provincially from 6.7 to 7.5 years, as a result of a decline in the proportion of young (4–5 years) rams in the harvest, indicating that rams now need to be older to reach legal size. Horn length increased with age at both scales of analysis. Surprisingly, base circumference declined with harvest age, likely because larger rams are shot at younger ages, while smaller rams survive. Over time, horn length and circumference decreased provincially when controlling for age, but temporal trends varied amongst SMAs. Declining growth rates in some areas reduced the number of rams available for harvest and rams of harvestable size are now smaller. Fast-growing rams are shot when young and removed from the population before prime breeding age. Alternate hunting strategies are required to protect fast-growing young rams if provincial objectives of maximizing the production of trophy rams are to be achieved. Habitat factors may also have to be manipulated if environmental influences also are contributing to declines in horn growth.

Trophy bighorn sheep in Alberta are managed to maximize production of trophy rams and to maximize opportunities to hunt (Environmental Protection 1993). Although the provincial harvest of trophy sheep and provincial population estimates have remained relatively stable over the past 35 years, concerns have been expressed over the size and number of trophy rams. A detailed study of one intensively monitored population at Ram Mountain has provided strong evidence of artificial selection through unrestricted trophy hunting by Alberta residents (Bonenfant et al. 2009; Coltman et al. 2003; Coltman et al. 2005).

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The same study has shown that although ram horn size has a strong hereditary component, it is also affected by environmental conditions including population density (Coltman et al. 2005; Festa-Bianchet et al. 2004; Jorgenson et al. 1998). Declines in horn size in trophy hunted populations of bighorn sheep and other mountain ungulates have now been reported by several other studies (Garel et al. 2007; Hengeveld and Festa-Bianchet 2011; Pérez et al. 2011), although in the absence of control data from unhunted populations it is difficult to quantify how much of these temporal declines may be due to artificial selective pressures and how much to possible changing environmental conditions. In addition, trophy hunting is likely to have a strong effect on male age structure (Milner et al. 2007). Bighorn ram mating success increases with age (Coltman et al 2002), thus hunting may have substantial effects on the distribution of male mating success, although no study has been able to quantify these effects.

The possible effects of artificial selection on horn size in wild sheep remain controversial and are likely affected by many natural and management-affected variables, such as changes in population density and plant productivity, harvest intensity, level of selectivity and the presence of harvest refugia (Festa-Bianchet and Lee 2009). Although harvest records have several inherent limitations (Pelletier et al. 2012), they provide a potentially useful opportunity to examine long-term trends in the age and size of harvested rams. We analyzed harvest records from trophy sheep in Alberta to determine whether the age, horn length and basal circumference of rams, and harvest rates, have changed over time at a provincial scale and within sheep management areas.

STUDY AREAS

Bighorn sheep in Alberta are distributed across the contiguous Rocky Mountain Range and in isolated mountain complexes of Ram Mountain and Shunda. Protected Areas, including both national and provincial parks, border or encompass much of the sheep range. DNA analyses of horn core samples from bighorn rams were used to divide the provincial sheep population into eight genetically identifiable subpopulations, or sheep management areas (SMAs; Fig. 1).
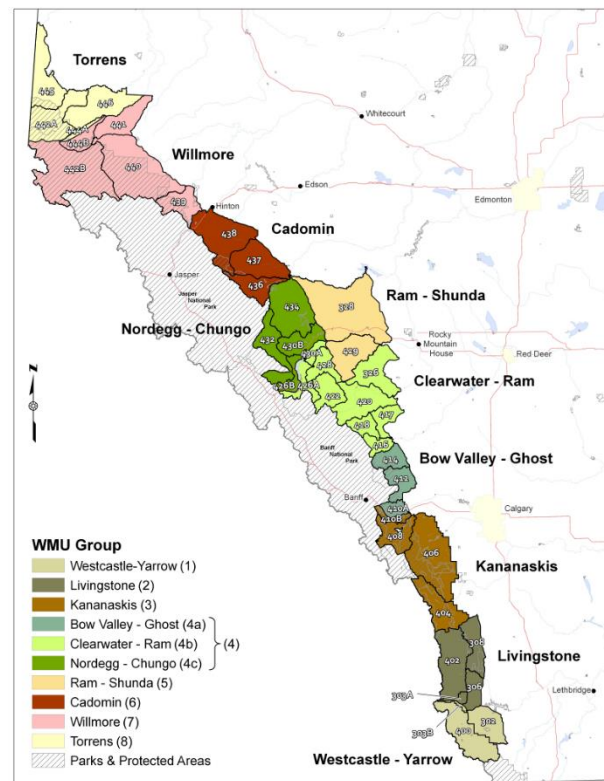
Fig. 1. Sheep Management Areas (SMAs) in Alberta, Canada. Numbers in brackets refer to the eight SMAs.

METHODS

We analyzed age and horn data from 7,054 trophy rams harvested over 36 years (1974–2009). Age was estimated based on horn annuli (Geist 1966), and measurements included base circumference and total length. For those SMAs where the definition of 'legal' ram was changed from 4/5-curl to Full-curl in 1996 (Westcastle-Yarrow and Ram-Shunda), only data up to 1995 were analyzed. While it would be useful to analyze registration data collected post implementation of the full curl requirement, the sample size available at present was too low for meaningful evaluation. Measurements from 116 illegally-harvested rams (including 51 that were less than 4/5 curl) were included in the analyses.

Linear models were used to examine temporal trends in horn size and age of harvested rams at both the provincial scale and then for each SMA (Fig. 1). In all cases, we also tested for possible nonlinear effects of either ram age or harvest year by including a quadratic term. Province-wide analyses were conducted using linear mixed effect models and accounted for possible regional

differences by including the SMA where each ram was harvested as a random effect. Inclusion of SMA as a random effect means that data for rams from SMAs that typically produce larger horns were adjusted for a SMA-specific effect before being included in the analysis. That step prevents, among other things, spurious results that may be caused by annual differences in the distribution of the harvest among SMAs with different characteristics. All statistical analyses were conducted using R version 2.10. The 'lme4' package was used to fit mixed effects models (Bates et al. 2008).

RESULTS

Age of Harvested Rams

Provincially, the average age of harvested rams increased from 6.7 to 7.5 years between 1974 and 2009 (Fig. 2a; t-value = 6.994, $P < 0.001$). This increase was mostly due to a gradual decline of the proportion of rams aged 4 or 5 years in the harvest (Fig. 2b; $r^2 = 0.31$, slope ± SE: $0.003 ± 0.0008$, $P < 0.001$). From 1974 to 1990, 20–30% of rams harvested in 12 of 17 years were aged 4 or 5 years. In 2005–2009, these young rams made up less than 15% of the harvest.

Analyses of age at harvest in different SMAs broadly confirmed the overall increasing trend detected at the provincial level (Fig. 3). Within each SMA, the increase in age of harvested rams over time appeared due primarily to a decrease in the proportion of rams aged 4 or 5 years in the harvest.

Horn Length and Basal Circumference

Provincially, the average horn length and base circumference of harvested rams showed a significant quadratic trend, with an apparent increase from 1975 to about 1990, followed by a decline (Table 1). These temporal changes were only evident when the age of each animal harvested was accounted for.

Temporal trends in horn length and basal circumference of harvested rams varied among SMAs. SMAs showing a decline in horn length or basal circumference over time (linear or quadratic) accounted for 77% or 91% of the total harvest from 1974–2009, respectively. Only SMAs 6 and 8 showed a significant increase in horn length over
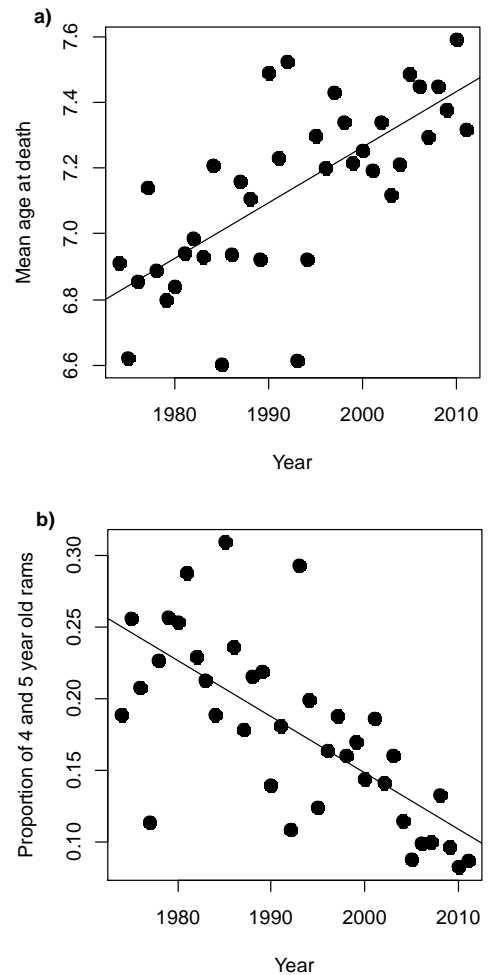
Fig. 2. Data from bighorn rams harvested in Alberta from 1974 to 2009 showing a) the average age and b) the proportion of rams aged 4 or 5 years.

time, while no SMAs showed an increasing trend in base circumference.

Horn length of harvested rams increased with age at both the provincial and SMA scales (Fig. 4a). With the exception of SMA 8, where horn length appeared to increase linearly with age, the effect of age on horn length was usually quadratic. In contrast, basal circumference surprisingly declined with age for rams aged 6 years and older at both the provincial and SMA scales (Fig. 4b).

DISCUSSION

In Alberta, the age of harvested rams increased from 1974–2009, while horn size decreased slightly during this 36-year period. Provincially, the average age of harvested rams rose by almost a year during this time, as a result of a 10% decline in the proportion of young (4–5 years) rams in the
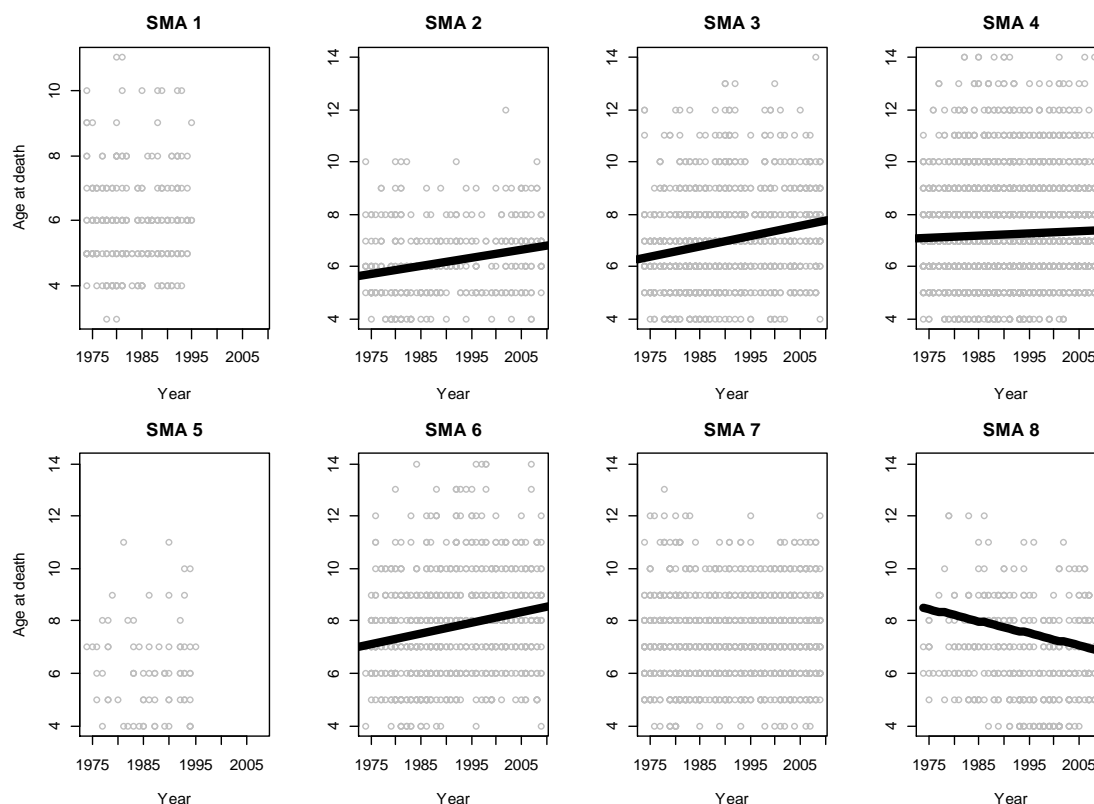
Fig. 3. Relationship between the year of harvest and age for bighorn sheep rams harvested in each Sheep Management Area (SMA) in Alberta. Black lines show significant temporal trends.

harvest. Since 1990, the average horn length and basal circumference of harvested rams in the province decreased when ram age was controlled for in analyses. These trends towards increasing ram age, decreasing proportion of young rams in the harvest and declining horn size over time were evident also for most sheep management areas in Alberta, although results varied among SMAs. Noteworthy too is that basal circumference declined slightly with age for rams aged 6 years or older, contrary to expectations. Together, these results suggest that rams in recent years need to be older to reach legal size than previously, and that fast-growing, larger rams are shot at younger ages than slow growing rams. These conclusions are consistent with research findings from bighorn sheep populations in British Columbia (Hengeveld and Festa-Bianchet 2011) and Spanish Ibex (*Capra hispanica*; Perez et al. 2011).

Since horn growth is a highly heritable trait, the loss of fast-growing rams before they can contribute to recruitment could result in artificial selection

Table 1. Effect of year and age at harvest on a) horn length and b) horn base circumference (cm) estimated using linear mixed effect models accounting for sheep management area for bighorn ram in Alberta, 1974-2009.

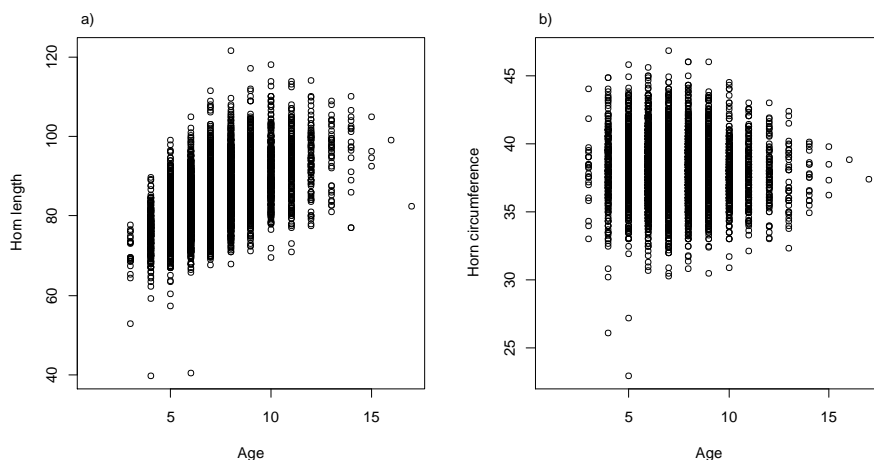|	Variables	Coefficient	SE	P-value	N
a) Horn Length					6938
	Harvest year	17.594	3.0954	<0.001	
	Harvest year^2	-0.004	0.0008	<0.001	
	Age	4.787	0.2182	<0.001	
	Age^2	-0.163	0.0138	<0.001	
b) Horn Base					6933
	Harvest year	6.672	1.0322	<0.001	
	Harvest year^2	-0.002	0.0003	<0.001	
	Age	0.120	0.0727	0.098	
	Age^2	-0.010	0.0046	0.022	

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Fig. 4. Data from bighorn rams harvested in Alberta from 1974 to 2009 showing a) total horn length and b) base circumference in cm.

due to environmental changes (Rughetti and Festa-Bianchet 2012). Other factors that may contribute to a decline in horn growth over time include climatic conditions and habitat quality associated with sheep densities (Jorgenson et al. 1998; Rominger and Goldstein 2006; Wishart 2006). At the provincial scale, however, declines in horn size are unlikely to be due to an increase in sheep density, as the Alberta sheep population has remained relatively stable for the last few decades (Jorgenson 2008). To more conclusively attribute changes in horn growth and horn size to various environmental influences or hunting pressure, annuli or increments should be measured in both hunted (provincial) and protected populations (e.g. National Parks).

Alternate hunting strategies are required to protect fast-growing young rams if provincial objectives of maximizing the production of trophy rams are to be achieved. Harvest options that are being discussed include limited entry hunts, full curl restrictions and shortened hunting seasons, among others. Prescribed burns and access management are continuing to occur across sheep range to address environmental influences that may also be contributing to declines in horn growth.

against large horns (Coltman et al. 2003). To achieve high breeding success, bighorn sheep must have large horns and survive to 7 years or older (Coltman et al. 2002). In Alberta, however, under the current unlimited entry hunt with 4/5-curl restriction, fast-growing rams may reach trophy size and be harvested at 4 or 5 years old. High harvest pressure could result in removal of most fast-growing rams and in turn, favor the reproduction of small, slow-growing rams. While the ram harvest rate of the sheep population is low (2–3%), the harvest rate of the trophy ram population is high (40–60%). During winter surveys conducted post-hunt, trophy rams across all SMAs comprise on average 4.8% (range 1.6–13.3%) of the sheep classified (unpublished data). In some SMAs in the province, it is estimated that more than 90% of rams are apparently harvested in the year they attain legal status. Such high harvest levels may result in strong artificial selection against large rams. Artificial selection has been reported in sheep populations at Ram Mountain (Coltman et al. 2003) and in British Columbia (Hengeveld and Festa-Bianchet 2011). Currently, we know little about the possible role of protected areas as refugia against selective harvest. It is known that rams may migrate to hunted areas from protected areas for the rut, after the hunting season (Hogg 2000).

Although the decrease in bighorn sheep horn size in Alberta over the past 35 years may be attributable to artificial selection through selective hunting (Coltman et al. 2003), it may also be partly

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BIGHORN SHEEP, MOUNTAIN GOATS, AND WILDLIFE CROSSINGS ON THE TRANS-CANADA HIGHWAY IN BANFF NATIONAL PARK, ALBERTA

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Abstract: Since 1982 the Trans-Canada Highway in Banff National Park has been upgraded in four major phases to a 4-lane, divided highway with continuous wildlife exclusionary fencing for 77 km. A system of underpasses and overpasses provides crossing opportunities for wildlife. In November 1996 we began monitoring wildlife use of these structures on the first three phases, and in December 2007 began monitoring the fourth phase. As of 2012 we detected nearly 200,000 crossings by 11 species of large mammals at 28 structures, including 4,750 crossings by bighorn sheep (*Ovis canadensis*) at 15 different structures. No crossings by mountain goats (*Oreamnos americanus*) were detected, despite mountain goats occurring at high elevation on opposite sides of the highway. Opportunities to provide for mountain goat passage across the highway might be better in adjacent Yoho National Park where goat habitat extends downslope close to the Trans-Canada Highway. Although habitat connectivity along the upgraded highway is largely restored for species resident in valley bottom habitat, effects on alpine-dwelling species are poorly understood and require further investigation. We discussed how an assessment of the genetic structure and health of the mountain goat meta-population within the mountain national parks will improve understanding of the influence of landscape features on gene flow and exchange of individuals among populations.

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EVIDENCE FOR MYCOPLASMA OVIPNEUMONIAE AS THE PRIMARY CAUSE OF EPIZOOTIC PNEUMONIA IN BIGHORN SHEEP (*OVIS CANADENSIS*) - AND WHY IT MATTERS

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*Abstract***:** Pneumonia is an important, population-limiting disease of bighorn sheep (*Ovis canadensis*) that typically occurs in the form of epizootics. Several species of bacteria are frequently isolated from lung tissues of affected animals of which *Mannheimia haemolytica* has received the most research attention. However, *M. haemolytica* fails to meet several expectations of a common epizootic agent, including prevalence in affected animals and evidence of epizootic transmission. *Mycoplasma ovipneumonia* has also been proposed as a primary agent of bighorn sheep pneumonia. In this presentation we showed that *M. ovipneumoniae* better meets epizootic agent expectations, including very high prevalence in affected animals within outbreaks, very high prevalence across outbreaks, existence of single strain types within outbreaks, and absence from most non-pneumonic populations. In addition, *M. ovipneumoniae* is clearly involved in experimental disease transmission from domestic sheep to bighorn sheep. Accurate identification of the epidemic infectious agent is critical to understanding the sources and reservoirs, transmission dynamics, and eventually effective management and control measures for this devastating disease. These results suggest that *M. ovipneumoniae* should be the focus of research efforts towards this end.

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THE SHORT AND LONG OF IT: PNEUMONIA IN A BIGHORN SHEEP METAPOPULATION

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Abstract: We analyzed patterns of pneumonia in 14 of 16 bighorn sheep (*Ovis canadensis*) populations that comprised the Hells Canyon bighorn sheep metapopulation in Idaho, Oregon, and Washington, 1997–2010. During this period, pneumonia-caused mortalities were confirmed in 53 of 447 radio-collared sheep, 12 unmarked dead adult sheep, and 92 lambs. We identified at least 3 classes of pneumonia in populations: all-age, lamb only, and adult only. These classes differed in duration and effects on population dynamics, but also showed a high degree of variability within type. We detected weak synchrony in adult and all-age pneumonia between neighboring populations, but no spatial correlation in lamb-only pneumonia. Once a population experienced pneumonia there was a 60% or greater probability of pneumonia every year afterward. Pneumonia mortality in lambs increased over time in 3 populations monitored for the duration of the study. Pneumonia is both an acute and chronic disease that through persistence in populations, repeated introductions, or both, is having a long term impact on this bighorn sheep metapopulation.

Key words: Ovis canadensis, bighorn sheep, pneumonia, Hells Canyon metapopulation, Idaho, Oregon, Washington.

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USING STRUCTURED DECISION-MAKING TO MANAGE DISEASE RISK FOR MONTANA WILDLIFE

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Abstract: We used structured decision-making to develop a 2-part framework to assist managers in the proactive management of disease outbreaks in Montana. The first part of the framework was a model to estimate the probability of disease outbreak given field observations available to managers. The second part of the framework was a decision analysis that evaluated likely outcomes of management alternatives based on the estimated probability of disease outbreak, and applied manager's values for different objectives to indicate a preferred management strategy. We used pneumonia in bighorn sheep (*Ovis canadensis*) as a case study for our approach, applying it to 2 populations in Montana that differed in their likelihood of a pneumonia outbreak. The framework provided credible predictions of both probability of disease outbreaks as well as biological and monetary consequences of management actions. The structured decision-making approach to this problem was valuable for defining the challenges of disease management in a decentralized agency where decisions were generally made at the local level in cooperation with stakeholders. Our approach provides local managers with the ability to tailor management planning for disease outbreaks to local conditions. Further work is needed to refine our disease risk models and decision analysis, including robust prediction of disease outbreaks and improved assessment of management alternatives.

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INFECTION AND IMMUNITY IN A BIGHORN SHEEP METAPOPULATION

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Abstract: We hypothesized that the temporal dynamics of pneumonia in bighorn sheep (*Ovis canadensis*) can be explained by the development of herd immunity within populations. To account for the pneumonia dynamics observed in Hells Canyon bighorn sheep, we examined the probability of surviving a bighorn sheep pneumonia epidemic given past exposure(s) to pneumonia, for 512 radio-collared bighorn sheep in 14 demographically independent populations in Hells Canyon where 36 pneumonia epidemics had been recorded over the 14 year study period. To understand the role of maternal immunity in lamb epidemics, we examined lamb survival, given dam exposure history, for 370 ewe-lamb pairs. In ewes, exposure to pneumonia induced short-lived protective immunity to pneumonia that lasted 1 to 2 years. An individual ewe's probability of surviving an epidemic improved with cumulative exposure events experienced over its lifetime. Translocation was a significant predictor of survival, with translocated ewes having 3.4 to 4.5 times the hazard of dying of pneumonia than resident sheep. Translocation was the only significant predictor of ram survival through pneumonia epidemics, with translocated rams being 5 times more likely to die of pneumonia than resident sheep. Lambs' hazard of dying increased, paradoxically, with the number of times their dam had been exposed to pneumonia. Our results suggest an interaction between resistance to infection and resistance to disease in this bighorn sheep metapopulation, where resistant individuals interact with carriers to produce the pneumonia dynamics observed in Hells Canyon. Some simple mathematical models of the patterns observed in our data confirm that a small proportion of carriers must be responsible for long-term persistence of pneumonia.

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A CALIFORNIA BIGHORN SHEEP LAMB MORTALITY INVESTIGATION IN AN EAST FRASER RIVER HERD, BC, CANADA

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Abstract: Chronic poor recruitment and lamb mortality were investigated in a California bighorn sheep (*Ovis canadensis californiana*) herd from British Columbia's (Canada) interior in the summer of 2011. Daily monitoring of a band of sheep from mid-June to mid-July identified coughing and diarrhea in lambs which increased in prevalence over time until 32–39% of lambs were affected near the end of the study period. Two euthanized sick lambs and one lamb found dead had severe bronchopneumonia. *Mycoplasma ovipneumoniae* was determined to be a significant pathogen in the lung based on characteristic histological lesions and its identification using polymerase chain reaction. Other bacteria isolated from the lungs and the tympanic bullae include: *Bibersteinia trehalosi*, *Pasteurella* spp., *Mannheimia haemolytica*, and *Streptococcus suis*. Although lungworm (*Protostrongylus* spp.) was initially suspected to be a contributing cause of pneumonia, compatible histological lesions were not evident and only one adult nematode was found in lungs at autopsy. Low counts of lungworm larvae in feces of lamb and adult sheep collected during the summer supported this result. Our findings suggest *Mycoplasma ovipneumoniae* was a major cause of morbidity in these lambs and we hypothesize additional factors, such as secondary bacteria, inclement weather, and predation of sick lambs that result in high lamb losses in some years. Further research is required to confirm these findings and to determine the relative importance of additional factors on poor recruitment in this herd.

Bighorn sheep (*Ovis canadensis)* populations throughout western North America have experienced high losses due to infectious disease (Besser et al. 2008, 2012). California bighorn sheep (*O. c. californiana*) in British Columbia (BC, Canada) are no exception and several herds have experienced population declines thought to be related to disease. The Fraser River Valley metapopulation of California bighorn sheep, which comprises 60% of the total Canadian population of this subspecies, reportedly declined 25% in 1984, and 38% in 1995 (Fraser River California Bighorn Sheep Advisory Committee 2004). More recently, the number of animals of the East Fraser population, a constituent of the Fraser metapopulation, declined from 850 animals in 1993 to 350 in 2007, and is currently estimated at 450; 41% of this increase being a result of a sheep translocation performed in 2009 (C. Procter and D. Jury, Ministry of Forests, Lands, and Natural Resource Operations, unpublished data).

Within this population, it appears that herds east of the Fraser River (Lillooet to Canoe Creek) are recovering, with the exception of a band of bighorn sheep within the Kelly Creek-Canoe Creek (KCCC) herd and a band within the

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Lillooet-Kelly Creek (LKC) herd. For example, the KCCC band had a lamb:ewe ratio of 11% in August of 2010 and the LKC band had a lamb:ewe ratio of 5% in November of 2009 (C. Procter and D. Jury, unpublished data). These herds were previously identified in a 2004 management plan as being at high risk of population declines due to the presence of multiple threats, including: disease/parasites, predation, livestock disturbance, and forage competition. The report further speculated that persistently low herd numbers were attributable to high lamb mortality in some years (Fraser River California Bighorn Sheep Advisory Committee 2004).

Autopsies performed on two lambs (6 weeks and 8 weeks of age) from the Pavilion band of the LKC herd in 2005 revealed emaciation and polymicrobial bronchopneumonia with pleuritis. Despite numerous tests for known sheep pathogens, a consistent infectious etiology was not identified. At autopsy, pneumonia was found to be the primary cause of death which correlated with annual observations of lambs from both bands showing lethargy, poor body condition, and respiratory distress.

Based on these findings and the localized nature of the poor recruitment, an investigation of the causes of poor lamb recruitment in a band of sheep from the KCCC herd was initiated in the summer of 2011. A 4 week field program was organized to confirm and characterize lamb morbidity, attempt to collect dead lambs for examination, and identify disease-causing agents responsible for poor lamb survival. In accordance with previous autopsy results and lamb morbidity observations, investigators hypothesized that infectious respiratory disease was an important problem, but all causes of morbidity and mortality were investigated.

METHODS

Study Site

The range of the KCCC herd extended from Canoe Creek to Kelly Creek on the east side of the Fraser River. The band under study used the eastern banks of the Fraser River, southwest of Big Bar Mountain, and northeast of the Fraser River Big Bar Ferry crossing, the latter 72 km from Clinton, British Columbia, Canada. This area includes Big Bar Creek and is a constituent of British Columbia's Lillooet land district (approximate UTM coordinates N560689 E5676150). Although some sheep of the KCCC herd may migrate to alpine summer range, the band of this study were considered non-migratory and known to make extensive use of irrigated alfalfa hayfields located at the southern aspect of their range.

The study area spanned approximately 7 km by 1.5 km and was accessed by an all-terrain vehicle trail snaking through its center, or by roads running adjacent to the hayfields.

The altitude ranged from 330 m to 1100 m and the landscape was composed of variable terrain: vertical rock face cliffs, sparsely treed bluffs, sloped outcrops, and deep carved valleys separated by intermittent steppes. Tree density intensified with increasing distance from the Fraser River and at an altitude of 800 m. Irrigated hayfields sloped slightly towards the river at an altitude of 490 m to 580 m and covered a surface area of approximately 1600 m by 300 m. Approximately 3000 m north of the hayfields and at an altitude of 340 m, there is a steppe immediately adjacent to the river which was also used extensively by lambs and ewes.

The study site was within the Central Interior Ecoprovince characterized by cold winters, warm summers, and a precipitation maximum in late spring or early summer (Demarchi 2011). More specifically, the Big Bar band occupied the Fraser River Basin Ecosection. This ecosection has a warm and dry summer climate with minimal moisture, and winters can be cold and bring deep snow. Vegetation reflected these dry conditions, and was predominated by bunchgrasses, including big sagebrush, bluebunch wheatgrass, and needle-and-thread (Demarchi 2011).

Field Observations

Daily observations of lambs and ewes occurred from 21 June until 18 July 2011. During this period, the number of sheep present, lamb:ewe ratios, and age and sex structure (when possible) were recorded; also, sick lambs were identified along with their clinical signs. None of the sheep were individually marked but any significant identifying characteristics were noted.
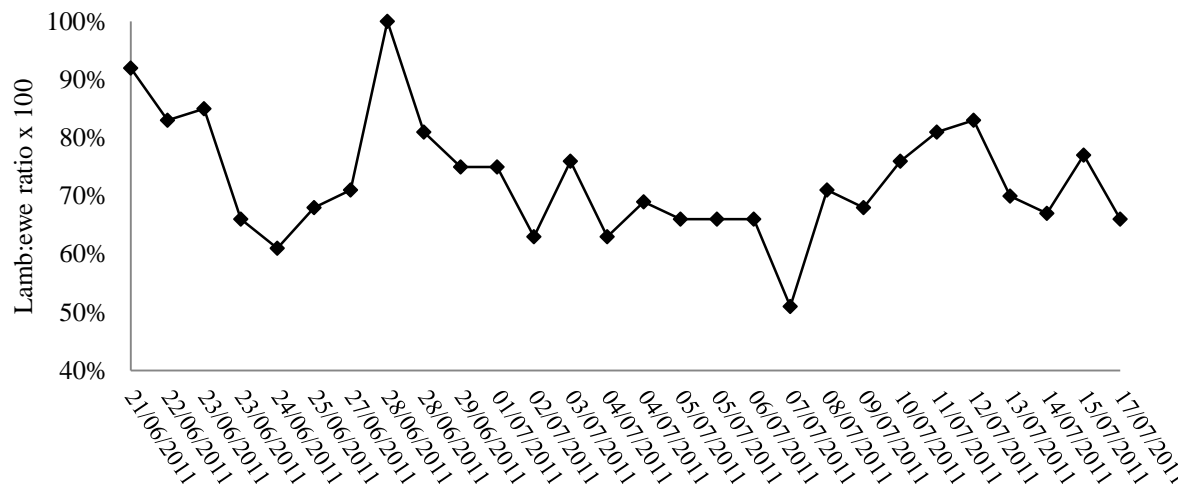
Fig. 1. Ratio of lambs to ewes observed between 21 June and 17 July 2011. Number of ewes observed each day was variable and depended on which groups were seen.

Each day, a concerted effort was made to locate and count a maximum number of ewes and lambs in order to calculate lamb:ewe ratios (Fig. 1). All ewes were counted regardless of their reproductive status; therefore, the presence of non-breeding immature and geriatric ewes could have resulted in low ratios.

On some days, it was necessary to calculate and plot (Fig. 1) two lamb:ewe ratios. This was done in situations where it was not possible, according to time and location, to determine if observed animals had already been previously counted.

Fecal Lungworm Assessment

Throughout the 4 week study period, fresh bighorn sheep feces were opportunistically collected from observed groups while prioritizing lamb feces. Lamb feces were easily differentiated from those of adults by their smaller size. Samples (n = 76) were retrieved within a few hours of defecation, transferred to labeled whirl-pak bags, and chilled prior to processing.

A modified Baermann technique (Forrester and Lankester 1997) was used to quantify lungworm larvae in fecal samples. The number of larvae in the 76 fecal samples is reported in larvae per (dried) gram (LPG) of feces. Initially, at least one larvae per sample was identified microscopically to genus, and later at least one larvae was identified for every ten counted.

Twenty-six parasite samples were transferred to 3 ml microvial tubes, frozen initially at -20° C,

and later stored at -80° C. Similarly, unprocessed fecal samples were frozen under the same conditions in their labeled bags.

Four fecal samples, which were diarrheic (BB82, BB89, BB90, and BB91), were immediately frozen. Lambs were observed to be scouring prior to sample collection, and the small piles of diarrheic feces recovered indicated that at least three of the four samples were from lambs.

Post-mortem Evaluation and Diagnostic Tests

On 15 July and 17 July 2011, two ill lambs (lambs 1 and 2) in severe respiratory distress were killed by gunshot to the neck, severing the spinal cord. Autopsies were performed immediately. Tissues collected for histopathology were placed in 10% neutral buffered formalin and selected duplicates were frozen. On 19 July 2011 a dead lamb (lamb 3) was retrieved from the hayfield by the landowner. The carcass was frozen and shipped to the Canadian Cooperative Wildlife Health Centre in Saskatoon, Saskatchewan for complete autopsy. In the three lambs, sections from all lung lobes were sampled for histopathology.

Fresh or frozen sections of lung from all three lambs were submitted to Prairie Diagnostic Services Inc. (PDS, Saskatoon, Saskatchewan, Canada), where they were cultured aerobically at 37° C on blood, MacConkey, and chocolate agar media. Swabs of the tympanic bullae, pharynx,

and affected lung surface from lambs 1 and 2 were collected using sterile polyester tipped applicators (Puritan Medical, Guilford, Maine, USA) and shipped to the laboratory on Leighton transport media. Swabs from lamb 1 were similarly cultured at the Animal Health Center (AHC, Abbotsford, BC, Canada) and those of lamb 2 cultured at PDS. Swabs and lung tissue from lamb 2 were also submitted for culture on Hayflick's broth and agar.

Frozen lung from each lamb was tested for infectious bovine rhinotracheitis (IBR), parainfluenza virus type 3 (PI3), respiratory syncytial virus (RSV), and bovine viral diarrhea (BVD) at PDS using immunofluorescence. In all cases, frozen lung tissue was cut onto chrome alum coated slides, dried, fixed in acetone, and then incubated with primary monoclonal antibodies. Monoclonal antibodies used were clones 3F11 and 1H6 (Dr. V. Misra, University of Saskatchewan, Saskatoon, SK) for IBR; clone 2E2 (Dr. D. Haines, University of Saskatchewan, Saskatoon, SK) for PI3; clone 8G12 (Dr. G. Anderson, University of Nebraska, Lincoln, NE) for RSV; and clones 20.10.6 and 15.C.5 (Dr. E. Dubovi, Cornell University, Ithaca, NY and IDEXX laboratories) for BVD. Following a rinse cycle, slides were incubated with the fluorescein isothiocyanate (FITC)-conjugated secondary antibody (goat anti-mouse IgG FITC conjugate (Cappel)) and binding was detected using a fluorescent microscope.

Nested-polymerase chain reaction (PCR), based on the amplification of part of the 16S rRNA, was used to detect *Mycoplasma* spp. Primary (GPO1 and MSGO) and secondary (Myins and MSGO) genus-specific primers were used as described by Yoshida et al. (2002). DNA was extracted from diseased lung using a DNeasy Blood & Tissue kit (Qiagen Inc., Toronto, Ontario, Canada). Two PCR reactions were run for each sample; 2 ul of DNA was combined with 48ul of a master mix preparation that contained 4.0 ul of primary or secondary primers. Both mixtures were put through a thermal cycler. Following a standard protocol, speciation of *Mycoplasma* spp. was done by sequencing the PCR amplicons with an applied Biosystem's Gene Amplification PCR system 9700 (National Research Council, Saskatoon, Saskatchewan, Canada). Obtained sequences were compared to those archived in GenBank ® (National Center for Biotechnology Information, U.S. National Library of Medicine, Bethesda, MD, USA). A similar nested-PCR technique was performed on lung for herpesvirus detection. For each tissue submission, 5 ul of DNA was combined with 45 ul of a master mix preparation that contained 7.5 ul (DFA, ILK, KGI) and 5.0u l (TGV, IYG) of primers, during primary and secondary PCR, respectively; both products were put through a thermal cycler (VanDevanter et al. 1996). PCR amplicons were visualized using a QIAxel DNA screening kit (Qiagen Inc., Toronto, Ontario, Canada).

Formalin-fixed tissues were processed routinely for histology; embedded in paraffin wax, sectioned at 4 μm, stained with hematoxylin and eosin, and examined microscopically.

RESULTS

Field Observations

Clinical signs displayed by sick lambs included coughing, diarrhea, poor body condition, and lethargy. Coughing was infrequent, episodic, and of variable duration and severity. Occasionally, bouts of coughing were severely debilitating and lasted up to 1 minute, with violent head jerking and clearly audible dry coughs; eventually the lamb collapsed. A second common clinical sign was diarrhea; lambs had darkly soiled rumps, thighs, and hocks with encrusted fecal material matted in their hair. A few lambs were thin as evidenced by ribs, verterbral spines and other bony protuberances being prominent. Some lambs were considered weak or lethargic, since they moved slowly and would frequently lie down, often at inappropriate times (e.g. during group movements). Lambs considered sick had scruffy hair coats. At least one was lame but otherwise appeared healthy, suggesting a traumatic etiology. Most sick lambs had several of these clinical signs.

Coughing and diarrhea increased in prevalence and severity throughout the study; although, on 21 June 2011, during an initial visit to the site, two severely sick lambs with respiratory disease were observed and were suspected to have died within the next 48 hours. Their carcasses were never found. From 22 June until 29 June 2011 only two more coughing lambs were seen in 154 lamb observations. Comparatively, on 15 July 2011, an observation of 31 lambs identified 32–39% of

lambs showing one or more of the aforementioned clinical signs.

Lamb:ewe ratios were calculated from daily group observations within the study area. A concerted effort was made to count all of the ewes and lambs each day; however, this was limited by the terrain and the frequent movement and mixing of groups. As a result, ratios varied depending on which groups were observed that day. In this investigation lamb:ewe ratios were used to track trends in lamb mortality, especially if carcasses or mortality was not directly observed. After the initial loss of two lambs, lamb:ewe ratios remained relatively stable at around 70% (Fig. 1) indicating little or no lamb mortality.

Fecal Lungworm Assessment

Seventy-six (70 ewe and 6 lamb) fecal samples were collected. Larvae per gram ranged from 0–51, and the average LPG in ewe and lamb feces was 6 and 1, respectively.

Post-mortem Evaluation and Ancillary Diagnostic Tests

Pathology was similar in all lambs, only varying in severity. Autopsied lambs had moderate to marked diarrhea, characterized by matting of hair coats by feces from the perianal area to the hocks. They were thin; subcutaneous and abdominal fat was absent and pericardial fat was minimal. Bilaterally, 20–80% of the anteroventral lung was firm, consolidated, dark red to tan, and had a lobular pattern. In lambs 1 and 2, airways were partially occluded by a viscous, mucopurulent exudate. Freezing artefact in lamb 3 complicated the interpretation of airway content. Despite meticulous dissection of airways, only one *Protostrongylus rushi* pulmonary nematode was identified (from lamb 1). A friable adhesion of the cranial right lung lobe to the pericardium was observed in lamb 3. In all three lambs, mediastinal and bronchial lymph nodes were enlarged and had variably reddened cortices, and in lamb 3, the retropharyngeal lymph node was similarly enlarged. The gastrointestinal tract of all lambs was unremarkable.

Significant microscopic findings were limited to the lungs in all three lambs. Lesions consisted of atelectasis, bronchial epithelium hyperplasia, lymphoplasmacytic hyperplasia and cuffing of airways, mild and multifocal thickening of alveolar septa by lymphocytes and plasma cells, and a marked increase in intra-alveolar macrophages. The airway lumens of lambs 1 and 2 were often narrowed, contained minimal to moderate amounts of neutrophils and sloughed epithelium, and were usually surrounded by an intact bronchial/bronchiolar ciliated epithelium. Comparatively, airways and less frequently, alveoli of lamb 3 were diffusely and markedly expanded by neutrophils that effaced airway epithelium; these foci were multifocally admixed with bacterial colonies. Cross-sections of nematode profiles were absent from examined lung sections.

Accordingly, a lymphoplasmacytic to minimally suppurative bronchopneumonia with prominent airway cuffing and regional lymphadenopathy was identified in lambs 1 and 2. Lamb 3 had a moderate suppurative bronchopneumonia with prominent lymphoplasmacytic airway cuffing and intralesional bacteria, with regional lymphadenopathy and locally extensive fibrinous pleuritis.

Tests for BVD, herpesvirus, RSV, and PI3 were negative in all lambs. Bacterial culture and polymerase chain reaction results are detailed in Table 1. PCR consistently detected *Mycoplasma ovipneumoniae* in affected lung tissue collected from each lamb. Generally, bacterial culture results were mixed and dissimilar among lambs, and growth intensity varied from low (lamb 1 and 2) to high (lamb 3).

DISCUSSION

In recent years it appears that collectively the KCCC herd's population has increased, but remains low relative to surveys in the late 1980s and early 1990s. Surveys conducted in April 2011 observed 247 sheep (C. Procter, unpublished data), an increase relative to surveys done in 2006 which observed 151 sheep (23 lambs, 98 ewes, 30 rams), yet well below results from a survey in 1990 when 525 bighorn sheep were observed (Lemke and Jury 2006).

The population's decline from 1990 onward is attributed to disease and subsequent management practices. In the autumn of 1993 weak lambs and poor lamb survival was reported, and in 1995,

Table 1. Bacteriology results (culture and nested-polymerase chain reaction (PCR)) from three autopsied lambs.

Lamb/ Lab[b]	Lung culture			PCR			Swab culture[a]				
	1	2	3	1	2	3	1			2	
							L	P	T	L	T
PDS	*B. trehalosi* 2+ Few *Pseudomonas*	*Pasteurella* spp. 1+ *Pseudomonas* spp. 1+	*S. suis* 4+ *P. multocida* 1+	*M. ovipneumoniae* (99% identity)			ND			-	A
AHC	*P. multocida* 1+	ND	ND	ND			-	ND	B	ND	ND

M. ovipneumoniae = *Mycoplasma ovipneumoniae*; *S. suis* = *Streptococcus suis*; *B. trehalosi* = *Bibersteinia trehalosi*
[a] = L is lung surface; P is pharynx; T is tympanic bullae
[b] Lab = Diagnostic laboratory (PDS: Prairie Diagnostic Services or AHC: Animal Health Center)
A = 1+ *Lactobacillus* spp.; 1+ *Mannheimia haemolytica*
B = 1+ *P. multocida*; few *E.coli* (non-haemolytic)
- = negative (no growth)
ND = not done

lungworm and polymicrobial pneumonia was confirmed as the cause of mortality in a lamb. In an effort to mitigate this decline 102 animals were transplanted from the KCCC herd to the western USA between 1994 and 1996, and ewe harvests were increased under Limited Entry Hunting. Despite practices to favor lamb growth and recruitment, which initially may have worked, from 1999 to 2006 the spring lamb:ewe ratio declined from 39% to 23% (Lemke and Jury 2006).

Currently, although most bands of the KCCC herd appear to be doing well, recruitment rates in the Big Bar area have been consistently low, and the result has been a stagnant population (C. Procter, unpublished data). Midway through our field program, a maximum of 96 sheep (32 lambs, 46 ewes, 18 rams) were observed at one time.

The number of lambs that died during the 2011 study period was lower than anticipated based on past survey observations by regional wildlife biologists. In 2011, only three lambs are known to have died, one of which was found dead, while two others were euthanized on account of severe illness. These latter would have likely died naturally, but we cannot say for certain.

Clinical disease was observed in lambs estimated between 50 and 90 days of age. Familiarity with the band and herd predicts the peak of lambing during late April (C. Procter, personal observation), thus sick lambs observed on July 15 and the dead lamb recovered on July 19 would have been approximately 76 and 80 days old, respectively.

In spite of clinical disease in approximately 1/3 of the lambs, the lamb:ewe ratio remained relatively stable throughout the summer. Mortality did occur later in the year; aerial surveys, conducted in March 2012, revealed a lamb:ewe ratio of a mere 8% (50–52 ewes, 2–4 lambs; C. Procter, unpublished data). When and why these lamb losses occurred is unknown, but a decline of this severity is not likely due entirely to predation, but rather disease may be a contributing factor. Especially since adjacent bands of sheep, which should be exposed to comparable predation, appear to have higher recruitment rates.

Although the lamb sample size was low and findings are only from one year, the results of this investigation allowed significant preliminary conclusions to be drawn.

Observations of sick lambs confirmed previous reports of respiratory disease, but also identified concurrent diarrhea for the first time. Post-mortem examination and histology of the gastrointestinal tract failed to reveal the cause. Moreover, feces and segments of intestine from autopsied lambs were tested for parasites and bacteria, yet no significant pathogens were identified. Future studies will focus on obtaining better samples for diagnostic investigation. Additionally, the impact of an alfalfa-rich diet has been postulated.

The role of certain respiratory pathogens in respiratory disease in the Big Bar lambs is becoming clearer. Fecal analysis concomitant with little sign of pulmonary nematodes, and an absence of compatible gross and histologic lesions in autopsied lambs, indicates lungworm is not

important in young lambs in this band. Furthermore, many respiratory viruses were not detected. Rather, the distribution and gross appearance of pulmonary lesions suggested a bacterial cause. Histology further confirmed this, and the presence of marked lymphoplasmacytic cuffing of airways, a lesion regarded to be nearly pathognomonic for *M. ovipneumoniae* infection in domestic sheep (Nicholas et al. 2008), prompted pursuit of *Mycoplasma* spp. using PCR. Although an array of bacteria were isolated (Table 1), these were both inconsistent in type and number among lambs. Interestingly, as detailed in Table 1, lamb 1 and lamb 2 had relatively low bacterial growth in comparison to lamb 3. The difference may be attributed to the stage or chronicity of pulmonary disease; the two first lambs were euthanized by gunshot early in the pathogenesis of pneumonia, relative to lamb 3, which died naturally of bacterial respiratory disease. Additional findings of fibrinous pleuritis, neutrophil-rich bronchopneumonia, and numerous bacterial colonies in lamb 3 support the culture results and indicate a more severe and advanced pneumonia.

The fact that *Mycoplasma* spp. was not isolated on aerobic culture is not surprising, considering the organism is fastidious and requires particular media nutrients and certain oxygen levels to thrive (Nicholas et al. 2008). Polymerase chain reaction did succeed in consistently identifying, with a 99% similarity, *M. ovipneumoniae* in the diseased pulmonary tissues of all three lambs.

Therefore, gross findings, microscopic lesions, and results of ancillary testing confirm the importance of bacterial pneumonia in these lambs. Molecular techniques consistently identified *Mycoplasma ovipneumoniae* in diseased lung, at early and late stages of respiratory disease, supporting the pathogen's primary role in bronchopneumonia in lambs of this band of the KCCC herd during the summer of 2011. These results are in agreement with recent research by others (Besser et al. 2012), which indicates that *Mycoplasma ovipneumoniae* can act as a primary pathogen to predispose bighorns to secondary microbial invasion. This may lead to fatal suppurative polymicrobial bronchopneumonia, such as with lamb 3. The virulence determinates of *Mycoplasma* spp., such as its polysaccharide capsule, its ability to evade the host's humoral response, and its detrimental effect on respiratory cilia compromise the lung's protective mechanisms and allow colonization by opportunistic flora (Nicholas et al. 2008; Ongor et al. 2011).

The preliminary conclusions of our investigation of poor lamb recruitment in the Big Bar band of the KCCC herd indicate infectious disease, and especially pneumonia, is a significant cause of morbidity and mortality in lambs. We also conclude that *M. ovipneumoniae* was the initiating cause of lamb pneumonia, and was involved in potentially fatal bacterial bronchopneumonia. Further study is required to determine if this is a consistent finding among years, the relative importance of other pathogens in causing mortality, better understanding the causes of diarrhea, and how factors such as: inclement weather, the concentration of lambs and ewes on hayfields, contact with domestic animals, and predation, etc. contribute to mortality.

This work identified *M. ovipneumoniae* as a likely candidate for initiating pneumonia in bighorn lambs and, if this is a consistent finding, will provide a focus for future research which may lead to development of targeted, novel, mitigation strategies.

ACKNOWLEDGMENTS

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SUMMER DIET AND FEEDING LOCATION SELECTION PATTERNS OF AN IRRUPTING MOUNTAIN GOAT POPULATION ON KODIAK ISLAND, ALASKA

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Abstract: The introduced mountain goat (*Oreamnos americanus*) population on Kodiak Island, Alaska, exhibited 60 years of rapid growth, resulting in an irruptive wave that expanded across the island from the initial introduction site. This unusual situation provided a rare opportunity to quantify and compare mountain goat summer diet and feeding location selection patterns at different stages along an irruptive growth cycle for an ungulate population. Diet composition analyses (via microhistological analyses of fecal pellets) indicated a temporal shift in summer mountain goat diets, which was likely driven by the onset of alpine plant growth following snowmelt. Sedges and forbs were important forage items and were increasingly consumed throughout the summer (June–August). Fern rhizomes were important in June (>16% of pellets), but less so (<1% of pellets) in July and August. Shrubs, mosses, and lichens were consistently consumed in small quantities (<5% of pellets), and therefore likely do not represent favored mountain goat summer forage on Kodiak Island. Consistent with our predictions, areas on Kodiak where mountain goats had completed an irruptive cycle (initial rapid population growth, decline to a lower abundance, and stabilization at a stochastic carrying capacity) had less forage cover at a lower diversity. However, contrary to our expectations, we found no evidence that feeding location selection patterns varied among goat subpopulations at different stages of irruptive growth, suggesting that this factor was independent of population history. Instead, we found that the area where mountain goats were at the highest density had the highest forage diversity and the most long-awned sedge (*Carex macrochaeta*) cover (i.e. the highest quality forage), which suggests that mountain goats there may not have reached carrying capacity yet. Mountain goats selected feeding locations close to escape terrain with abundant long-awned sedge, regardless of subpopulation density or history. Overall, our work is among the first to quantify mountain goat diets and feeding location selection on Kodiak Island and will guide management and research of the growing population.

In 1952 and 1953, eighteen mountain goats (*Oreamnos americanus*) were introduced to Kodiak Island, Alaska, a large, geographically isolated island on which native large mammalian herbivores were historically absent (Paul 2009). By 2011, the population had grown exponentially to approximately 2,500 and had expanded to all known available habitats on the island. This process led to conservation concerns because introduced ungulates can cause detrimental landscape-level effects by altering vegetation structure and composition, soil system functioning, and chemical processes (Hobbs 1996, Spear and Chown 2009). Additionally, impacts can be especially severe on island and alpine ecosystems that are less resilient to disturbance (Courchamp et al. 2003). Therefore, empirical data about mountain goat foraging ecology on

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Kodiak Island are needed to understand potential impacts to native flora and to focus future research priorities.

Mountain goat diets are not well understood compared to other North American ungulates and it is unclear how the species' diets may vary across populations. Available habitats in southeastern Alaska contain diverse subalpine coniferous forests that are absent, and alpine plant community assemblages that differ, from Kodiak Island, which could lead to differences in mountain goat diet selection. Microhistological analysis of fecal pellets is a common technique for estimating mountain goat diets, but has yet to be applied to Kodiak. An observational study conducted in the 1970s at the initial introduction site (Hjeljord 1973) provided baseline dietary information and, through comparison with an updated assessment of diets, a unique opportunity to understand whether diets have changed in response to subsequent variation in population density, and whether the diets differ spatially across the island.

To more fully understand potential impacts of non-native mountain goats, it is critical to quantify not only diet, but also feeding location selection. Mountain goat habitat selection has been well-documented (Von Elsner-Schack 1986, Laundre 1994, Gross et al. 2002, Poole and Heard 2003), but mountain goat feeding location selection has received little attention (Hjeljord 1973). Quantifying the physical and forage-related attributes associated with mountain goat feeding locations provides a crucial link between their diets and spatial ecology, and is a first step toward developing an understanding of nutritional-based carrying capacity.

Mountain goat densities and the relative duration of occupancy at a particular location vary spatially across Kodiak Island as a function of their relative distances to the initial introduction site (Cobb 2011). This unusual ecological state offers a rare research opportunity to quantify variations in diet and feeding location selection patterns among spatially distinct mountain goat subpopulations with different densities and histories of occupancy. Annual surveys show that mountain goats at the initial introduction site have undergone a complete irruptive population growth cycle: an initial growth phase (phase 1), a subsequent decline to a lower abundance (phase

2), and a final "post-decline" population stochastic carrying capacity at a lower abundance (phase 3; sensu Caughley 1970). During the 1970s (approximately 10–20 years following introduction), mountain goat subpopulations colonized habitats surrounding the initial introduction site, increased in density (phase 1), and are predicted to follow the same trend of decline and stabilization (phases 2 and 3) exhibited at the initial introduction site (Cobb 2012). Subpopulations located on the current periphery of the population's range established in the 1990s are at low densities, but are predicted to follow a similar pattern as the other regions.

If the irruptive growth cycle observed on Kodiak Island has resulted in declines in plant diversity and preferred forage abundance, as predicted by Caughley's (1970) model, then we expect these changes to result in observable differences in plant community composition and related differences in diet and feeding location selection patterns across a spatial gradient related to distance from the initial introduction site. Specifically, we predict that more recently established mountain goat subpopulations (closer to the initial introduction site and in earlier phases of the irruptive growth cycle) will have greater availability of preferred forage, show a narrower diet breadth (more diet selection), and exhibit stronger evidence for feeding location selection than longer established subpopulations in later phases of the irruptive growth cycle.

STUDY AREA

Kodiak Island (9,375 km^2), Alaska, separated from mainland Alaska by the Shelikof Strait, is the largest island in the Kodiak Archipelago. The island is approximately 160 km long and varies in width from 15 km to 130 km. The Kodiak National Wildlife Refuge encompasses 6,803 km^2 of Kodiak Island, or 73%. Topography is primarily mountainous, with elevations ranging from sea-level to 1,362 m. The sub-arctic maritime climate on Kodiak Island is characterized by long wet winters with alternating snow and rain events, and cool wet summers. Average annual precipitation between 2006 and 2011 was 195 cm (Kodiak airport weather station). Summer precipitation

averaged 12 cm in June, 9 cm in July, and 13 cm in August. The average annual temperature was 4.9º C, and ranged from -1.2º C in January to 12.9º C in August. Summer temperatures averaged 9.8º C in June, 12.4º C in July, and 12.9º C in August. The summer growing season in the alpine generally runs from early June to late September.

Native terrestrial mammals sympatric with mountain goats included Kodiak brown bear (*Ursus arctos middendorffi*), red fox (*Vulpes vulpes*), short-tailed weasel (*Mustela erminea*), and tundra voles (*Microtus oeconomus*). Introduced sympatric mammals included Sitka black-tailed deer (*Odocoilus hemionus sitkensis*) and snowshoe hare (*Lepus americanus*). Levels of predation on mountain goats were unknown, but believed to be insignificant, due to few observations of bear-goat interactions and only a limited number of confirmed bear kills on mountain goats (J. Crye, Alaska Department of Fish and Wildlife, personal communication). Kodiak was the most popular mountain goat hunting destination in Alaska, and hunting occurred island-wide from 20 August to 25 October. Between 2007 and 2011, hunters harvested an average of 159 goats annually (Van Daele and Crye 2010).

We selected three study sites (Hidden Terror, Uyak, and Hepburn) on Kodiak Island (Fig. 1) based on their distance from the initial introduction site, their duration of occupancy by mountain goats, and their histories of population growth (Cobb 2012). Aerial surveys by the Alaska Department of Fish and Game (ADFG) and the U.S. Fish and Wildlife Service (FWS) provided annual estimates of subpopulation sizes (FWS, unpublished data). The Hidden Terror study site (76 km^2) was located in northeastern Kodiak Island and encompassed the initial introduction site. The subpopulation there peaked in density in 1985 (2.09/km^2 or 167 goats) and then declined to 1.21/km^2 (66 goats) in 2011. Elevations ranged from sea-level to 1,130 m. The Uyak study site (48 km^2) was centrally-located on Kodiak Island (48 km from the introduction site). Mountain goats colonized the site in the 1970s and then increased annually to a record high density in 2011 (2.54/km^2, 122 goats). Elevations ranged from sea-level to 1,320 m. The Hepburn study site was a 62 km^2 peninsula in southeastern Kodiak Island, 74
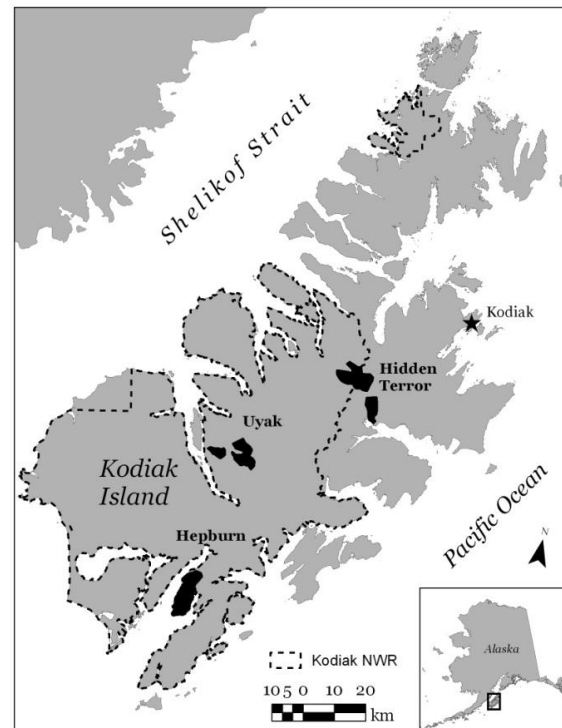
Fig. 1. Locations of study sites on Kodiak Island, Alaska.

km from the initial introduction site. Mountain goats colonized this site in the mid-1990s and were still at low densities in 2011 (0.75/km^2 or 47 goats). Elevations ranged from sea-level to 700 m.

Lower elevation habitats (sea-level to 300 m) consisted of a matrix of mixed forb meadows, open alder with forb meadows, and dense alder habitats (Fleming and Spencer 2007). The mixed forb meadow habitat consisted of Nootka lupine (*Lupinus nootkatensis*), woolly geranium (*Geranium erianthum*), fireweed *(Epilobium angustifolium)*, goldenrod (*Solidago lepida*), Jacob's ladder (*Polemonium acutiflorum*), paintbrush (*Castilleja unalaschcensis*), and burnett (*Sanguisorba stipulate*). The open alder with forb meadow habitat type consisted of patches of dense alder (*Alnus crispa*), often mixed with salmonberry (*Rubus spectabilis*) and elderberry (*Sambucus racemosa*), and patches of forbs such as fireweed, lupine, and cow-parsnip (*Heracleum lanatum*). Forb-dominated habitat types were more common, and alder-dominated habitats were less common, in lower elevation regions (<150 m) at the Hepburn and Hidden Terror study sites, but the inverse was observed at the Uyak study site. Alpine regions (>150 m) were

composed of tundra, forb meadow, heath, prostrate shrub tundra, exposed bedrock, talus slopes, and snow-covered habitat types (Fleming and Spencer 2007). Common alpine plants included long-awned sedge (*Carex macrochaeta*), mosses, lichens, partridgefoot (*Luetkea pectinata*), and black crowberry (*Empetrum nigrum*). Snow was present at the study sites above approximately 600 m at the start of our field season (1 June) and was completely melted by mid-July.

METHODS

We visited each study site twice in 2011, during the growing season: once in the early summer (June–early July) and once in the late summer (late July–August). During each sampling occasion, we collected fresh mountain goat pellets and compared vegetation diversity and abundance between locations where goats were observed feeding ("feeding locations") and randomly selected areas in the alpine ("available locations").

Diet

We quantified mountain goat diets using microhistological analyses of fecal pellets (Hinnant and Kothmann 1988). To collect pellets, we observed a mountain goat group until at least one defecated. We then slowly approached the center of the group's location and searched for fresh pellets. We considered pellets to be fresh if they were moist, soft, had a slimy sheen, and were free of mold and insects. We collected approximately 25 mg (15 pellets) of fresh pellets from individual pellet groups and stored samples in a WhirlPak (Nasco, Ft. Atkinson, WI). We kept pellet samples in a cool dry location in the field and then we froze them upon returning to the office (1–12 days later). We randomly selected 9–10 pellet samples from each study site visit and submitted the samples to the Wildlife Habitat Nutrition Lab at Washington State University (Pullman, WA) at the conclusion of the field season for microhistological analyses to estimate the relative percent composition of forage classes that were comprised >5% of the sample (Level B, 50 views/sample).

We quantified the influence of the day of the year and study site on diets using linear regression (Zar 2009).

Habitat Availability and Feeding Location Selection

We located mountain goat groups by conducting ground-based and fixed-wing aerial surveys of the study sites. We defined feeding locations as the centroid of a mountain goat group observed feeding. We constrained selection of random locations to areas on Kodiak where mountain goats have been observed during summer aerial surveys (Kodiak Refuge, unpublished data) and typical mountain goat summer ranges (Hjeljord 1970, Von Elsner-Schack 1986, Fox et al. 1989, Poole and Heard 2003), which was composed of low willow, alpine tundra, heath, forb-graminoid meadows, snow/ice, and fragmented rock habitat types. We used a GIS land cover classification map of Kodiak to delineate the extent of these habitats within each study site (Fleming and Spencer 2007). Additionally, we limited available habitats to areas over 150 m above sea-level because we did not expect mountain goats to occupy areas below this elevation during the summer (Hjeljord 1973). We designated random locations by creating 100 random waypoints in available habitats, for each study site visit, using Spatial Analyst in ESRI® ArcGIS 9.3 (Environmental Systems Research Institute, Redlands, CA). We included an inhibition distance (minimum allowable distance between random waypoints) of 100 m to eliminate potential overlap between transects (below) and to ensure a more even sampling distribution across study sites. We uploaded random waypoints into portable GPS units (Garmin® GPSmap 76CSx), which we used to locate random locations in the field.

Our methods for conducting plant surveys were the same at feeding and random locations. We inserted an aluminum stake into the ground at the location, selected a random compass bearing using a random number table, and extended a tape measure from the stake along the random bearing for 16 m in both directions. Starting from the stake, we placed a 50 cm by 20 cm plot frame to the right side of the tape measure at 2-m intervals, for a total of 17 plots per location (Daubenmire 1959). Within each plot, we defined cover as the percentage of the plot that was encompassed by the sum of imaginary minimum convex polygons

Table 1. Canopy cover classes with associated range of percent canopy covers used to quantify vegetation cover at mountain goat summer feeding and random locations, Kodiak Island, Alaska.

Code	Range	Mid
T	0-1%	0.50%
0	1-5%	3%
1	5-15%	10%
2	15-25%	20%
3	25-35%	30%
4	35-45%	40%
5	45-55%	50%
6	55-65%	60%
7	65-75%	70%
8	75-85%	80%
9	85-95%	90%
X	95-100%	97.5%

drawn on leaf tips of undisturbed canopies (ignoring inflorescences) and projected onto the ground (Kent 2012). We classified cover into 12 classes based on their relative percentages of a plot, following a modified Domin scale (Currall 1987; Table 1). For each plot, we estimated cover of forb and sedge species, and plant classes for other plants (grasses, rushes, ferns, lichens, mosses and willow; Studebaker 2010, USDA NRCS 2013).

To summarize available forage at each location, we quantified forage diversity and cover. We defined forage diversity as the sum of unique plant species and habitat classes observed in all plots at a location. We quantified forage cover (relative spatial cover of a plant species or class at a location) as the median percent value for a particular plant's cover class within a plot, averaged across all plots at a location.

Because mountain goats are associated with steep terrain that they use to escape from predators (Hamel and Côté 2007), we included a measure of distance to escape terrain as a predictor of feeding location selection. Escape terrain has been described as steep rocky slopes ranging from >25° to >33° (Adams and Bailey 1982, Gross et al. 2002). To be conservative, we considered escape terrain as slopes ≥33°. We defined the distance to escape terrain as the distance (m) from random and feeding locations to the edge of the closest pixel of escape terrain, defined by a 30 m pixel USGS

Digital Elevation Model (DEM) in GIS (ESRI 2012).

Habitat selection of northern ungulates, such as mountain goats, is affected by forage availability and thermodynamics, which are influenced by relative solar radiation (Keating et al. 2007). To determine if mountain goat feeding location selection was correlated with solar radiation, we estimated hypothetical solar illumination (12:00 pm, 1 July) across Kodiak Island using the ArcGIS's Hillshade function applied to the DEM. We then standardized hillshade values by converting to *z*-scores (Zar 2009), and then extracted standardized hillshade values at random and feeding locations.

We considered random and feeding locations as the sampling unit for statistical analyses. To avoid overfitting models and to simplify the results, our predictors included forage cover estimates for the top 8 forage classes (genera, if classified) in mountain goat summer diets (as determined above), and 4 additional habitat predictors (forage diversity, distance to escape terrain, hillshade, and study area) in statistical tests. The top-8 forage classes composed approximately 96% of the mountain goat pellets.

We tested for differences between pairs of study sites using Mann-Whitney *U* tests (Zar 2009). We quantified feeding location selection with logistic regression models using the same predictors. To assess relative correlation between predictors, we computed a Pearson product-moment correlation matrix. If pairs of predictors showed high correlation (>0.30; Zar 2009), we retained the predictor that had the greatest biological significance. To evaluate competing candidate models, we examined differences in ΔAIC_c (Akaike's Information Criterion) using a backwards, step-wise approach (Burnham and Anderson 2002). Finally, we calculated AIC_c weights (*w*) to determine relative support for each of the top models.

RESULTS

We visited each study area twice, between 2 June and 19 August 2011. Visits averaged 8 days long and ranged from 4 to 10 days.

Table 2. Major forage classes in mountain goat pellet samples ($n = 59$), quantified through microhistological analyses of pellet samples collected in summer 2011, Kodiak Island, Alaska.

Forage class	Average percent	Genus	Average percent	Common name
Sedges	34.5%	*Carex*	34.1%	Sedges
		Eriophorum	0.3%	Cottongrasses
		Eleocharis	<0.1%	Spikesedges
Forbs	22.2%	*Lupinus*	14.1%	Nootka lupine (only spp.)
		Geranium	7.0%	Woolly geranium (only spp.)
		Potentilla	0.3%	Cinquefoils
		Galium	0.2%	Bedstraws
		Taraxacum	0.2%	Dandelions
		Epilobium	<0.1%	Willowherbs
		Polygonum	0.1%	Bistorts
		Stellaria	<0.1%	Chickweeds & stitchworts
		Achillea	<0.1%	Yarrows
		Artemisia	<0.1%	Mugworts & wormwoods
		Astragalus	<0.1%	Vetches
		Campanula	<0.1%	Bellflowers
		Oxytropis	<0.1%	Locoweeds
		Pedicularis	<0.1%	Louseworts
		Penstemon	<0.1%	Beard-tongues
		Ranunculus	0.1%	Buttercups & spearworts
		Rumex	<0.1%	Sorrels & docks
		Saxifraga	0.1%	Saxifrages
Rushes	17.4%	*Juncus*	14.2%	Rushes
		Luzula	3.2%	Wood-rushes
Grasses	12.4%	*Alopecurus*	3.5%	Foxtails
		Calamagrostis	3.5%	Reedgrasses
		Poa	3.5%	Meadow-grasses, bluegrasses, tussocks & speargrasses
		Hordeum	2.4%	Barleys
		Hierochloe	0.5%	Sweetgrasses
		Phleum	<0.1%	Catstails & Timothy grasses
Ferns[a]	8.1%		8.1%	
Mosses[a]	5.8%		5.8%	
Lichens[a]	2.0%		2.0%	
Shrubs	1.2%	*Salix*	0.7%	Willows
		Empetrum	<0.1%	Crowberries
		Vaccinium	<0.1%	Cranberries & blueberries

[a] Not classified to genus level

Diet

We collected 97 pellet samples from Hidden Terror, 65 samples from Uyak, and 38 samples from Hepburn ($n = 200$). From these, we submitted 10 samples per study site, per visit, for microhistological analyses, except for the first Hepburn visit, for which we were only able to collect 9 samples because foul weather shortened our time in the field ($n = 59$).

Microhistological analyses revealed that mountain goats largely consumed sedges (34.5% of pellet biomass) followed by forbs (22.2%), rushes (17.4%), grasses (12.4%), ferns (8.1%), mosses (5.8%), lichens (2.0%), and shrubs (1.2%; Table 2). The most commonly consumed forbs were in the *Lupinus* (14.1%) and *Geranium* (7%) genera; the only species in these genera on Kodiak were Nootka lupine and woolly geranium.
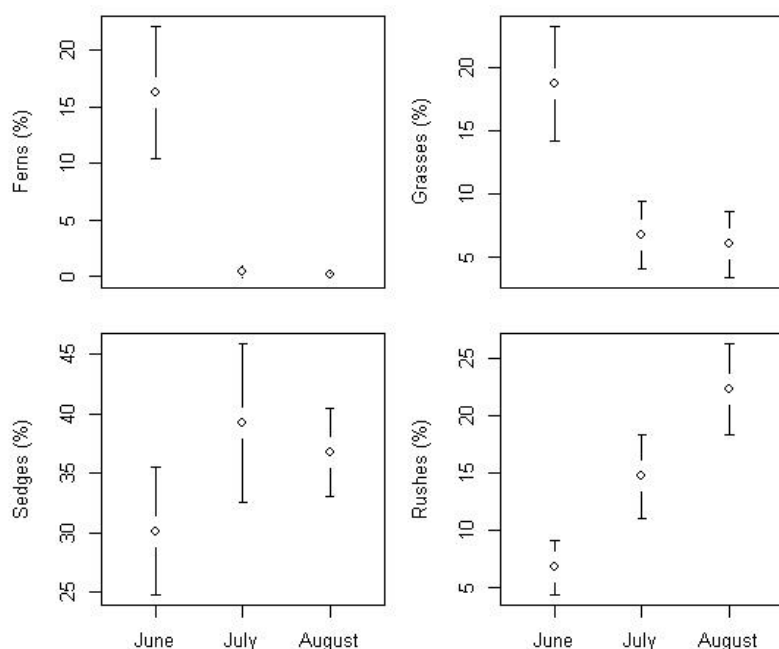
Fig. 2. Percent composition of ferns, grasses, sedges, and forbs in mountain goat summer diets by month, 2011, Kodiak Island. The percent composition of lichens and shrubs did not vary significantly over time. Diets were estimated by microhistological analyses of pellet samples. Circles indicate average percent compositions and bars extend to 95% confidence intervals.

average than those at Hidden Terror (SE = 3.97, P = 0.09) and 8.0% more than those at Hepburn (SE = 3.97, P = 0.05). Goats at the Hidden Terror study site (the introduction site) ate 5.2% more forbs on average than goats at Uyak (SE = 2.67, P = 0.05) and 6.8% more than those at Hepburn (SE = 3.0, P = 0.03). However, goats at the Hidden Terror study site also consumed 10% less ferns than goats at Uyak (SE = 3.32, P < 0.01) and 14.0% less than those at Hepburn (SE = 3.78, P < 0.01). Goats at the Hepburn study site (newly established subpopulation) ate 7.6% more moss (SE = 0.95, P < 0.01) than goats at Uyak and 9.0% more than those at Hidden Terror (SE = 1.09, P < 0.01). Alternatively, we found no evidence that fern, forb, lichen, or shrub consumption varied among study sites.

Mountain goats consumed more sedges and rushes, and less ferns and grasses, as the season progressed, according to regression analyses (Fig. 2). More specifically, from June to July, mountain goats significantly increased their sedge consumption (P = 0.02), from 30.2% (SE = 1.16) to 39.2% (SE = 1.68) and forbs (P < 0.01), from 18.9% (SE = 1.43) to 24.8% (SE = 2.34). Rush consumption increased significantly each month (P < 0.01), from 6.8% (SE = 1.16) in June, to 14.7% (SE = 1.68) in July, and 22.3% (SE = 1.84) in August. In contrast, from June to July mountain goats significantly decreased their consumption of grasses (P < 0.01) from 18.7% (SE = 2.23) to 6.7% (SE = 1.25), and ferns (P < 0.01) from 16.2% (SE = 2.84) to 0.4% (SE = 0.23). Mountain goats did not vary their consumption of moss, lichen, and willow over the summer.

After accounting for monthly variation, regression results indicated that mountain goat diets, as estimated by pellet sample composition, varied among study sites (Fig. 3). Goats at the Uyak study site (the highest density subpopulation) consumed 6.9% more sedge on

Habitat Availability and Feeding Location Selection

We recorded 161 unique plant species and habitat classes at 298 locations (72 feeding and 226 random). The most common plant species were moss spp. and long-awned sedge, which occurred at 86% and 74% of locations, respectively. Other common plants included partridgefoot (49%), arctic daisy (*Dendranthema arcticum*; 47%), black crowberry (40%), and variegated sedge (*Carex stylosa*; 37%).

The eight most common mountain goat forage items identified in diet analyses were: long-awned sedge, variegated sedge, woolly geranium, Nootka lupine, rushes, grasses, ferns, and moss. We did not include forage diversity in feeding location selection modeling because it was correlated (>0.30) with other predictors.

Forage cover and habitat predictors differed between study sites, according to Mann-Whitney U tests (Table 3). Hidden Terror (introduction site) had lowest forage diversity (P < 0.01) and the least long-awned sedge, moss, grass, fern, and moss
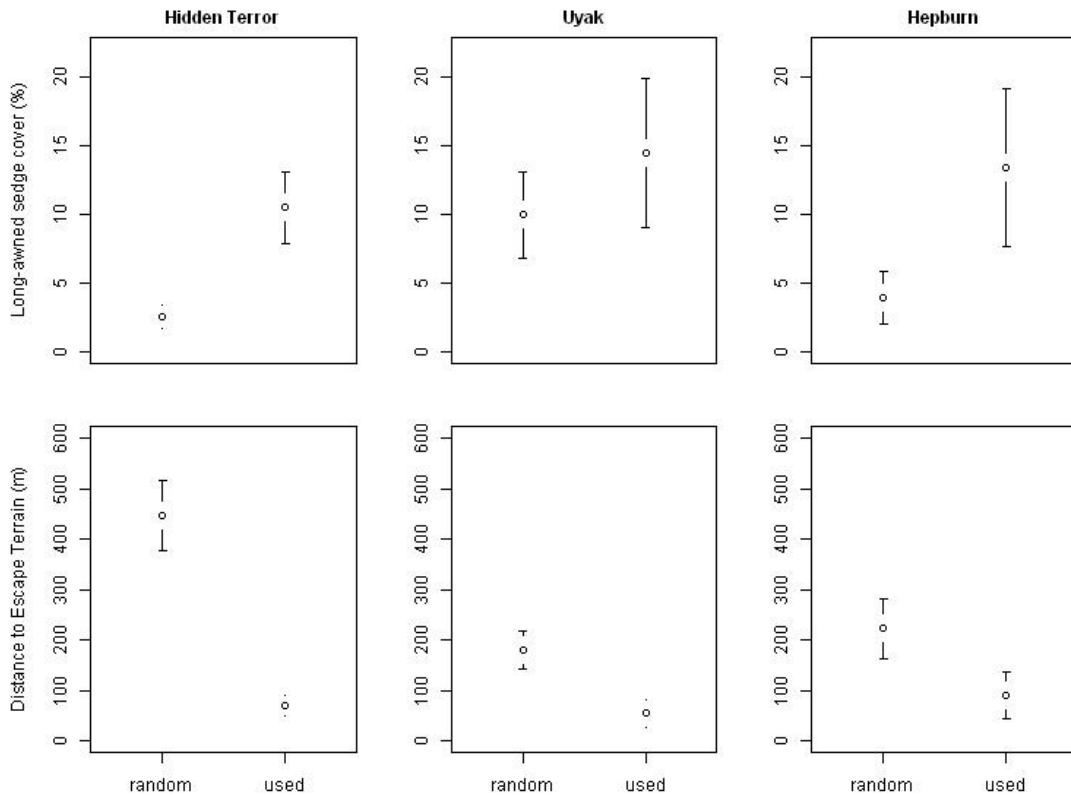
Fig. 3. Percent cover of long-awned sedge (*Carex macrochaeta*) and distance to escape terrain (m) at random and feeding locations, by study site during summer 2011, Kodiak Island. Circles indicate average percent covers and bars extend to 95% confidence intervals.

cover. Alternatively, Uyak (highest mountain goat densities) had the highest forage diversity ($P = 0.01$) and the most long-awned sedge cover ($P < 0.01$). Hepburn (lowest mountain goat densities and most recently colonized) had more moss cover than other study sites ($P = 0.02$).

The most parsimonious model for feeding location selection included nine predictors: long-awned sedge, woolly geranium, Nootka lupine, rush, grass, fern, and moss cover; hillshade, and distance to escape terrain (Table 4). Variegated sedge and study site were not in the top three most parsimonious models. According to this model, mountain goats selected feeding locations that were closer to escape terrain and had abundant long-awned sedge, rush and moss cover; and little woolly geranium, Nootka lupine, grass, and fern cover. The most significant covariate associated with feeding location selection, based on ΔAIC_c values, was distance to escape terrain, followed by long-awned sedge cover (Table 5, Fig. 3).

DISCUSSION

We predicted that areas on Kodiak where mountain goats have completed an irruptive growth cycle (i.e. established, then peaked in density, and finally declined to a lower ecological carrying capacity) would have less preferred forage cover at a lower diversity than areas occupied by mountain goats that are at earlier stages of colonization. Our results lend some support for this prediction. The Hidden Terror study site, where mountain goats were introduced to Kodiak and have completed an irruptive growth cycle, had lower forage diversity and less long-awned sedge, woolly geranium, grass, fern, moss, and lichen cover than other study sites. However, there was not a consistent relationship between site occupancy and forage: forage diversity and cover were generally lower at the Hepburn site than the Uyak site, despite mountain goats having colonized Hepburn approximately 20 years after Uyak. Although the irruptive growth of Kodiak's

Table 3. Results of Mann-Whitney *U* tests for differences in mountain goat forage cover and habitat predictors between pairs of study sites, 2011, Kodiak Island. Study sites with significantly larger values (*P* ≤ 0.05) are listed. Ties (*P* > 0.05) are indicated with a dashed line.

Cover class	Hidden Terror: Uyak	*P*-value	Hidden Terror: Hepburn	*P*-value	Uyak: Hepburn	*P*-value
Long-awned sedge	Uyak	>0.01	Hepburn	0.18	Uyak	<0.01
Variegated sedge	--	0.14	--	0.07	Hepburn	0.01
Woolly geranium	Uyak	<0.01	Hepburn	<0.01	--	0.20
Nootka lupine	Uyak	<0.01	--	0.06	--	0.15
Rushes	Hidden Terror	<0.01	Hidden Terror	<0.01	--	0.66
Grasses	Uyak	<0.01	Hepburn	<0.01	--	0.09
Ferns	Uyak	<0.01	Hepburn	<0.01	--	0.43
Mosses	Uyak	<0.01	Hepburn	<0.01	Hepburn	0.02
Forage diversity	Uyak	<0.01	Hepburn	<0.01	Uyak	0.01
Distance to escape terrain	Hidden Terror	>0.01	Hidden Terror	<0.01	--	0.20
Hillshade	--	0.06	--	0.24	--	0.60

goats may have led to the observed differences in forage, as documented in introduced ungulate populations elsewhere (Caughley 1970), we cannot completely rule out that observed differences in vegetation diversity and cover among study sites may have existed prior to the arrival of goats because the composition of plant communities prior to goat colonization is unknown.

The study site with the highest mountain goat density on Kodiak (Uyak) also had the highest forage diversity and the most forage cover, for all forage classes except mosses and rushes. This was an unexpected result because irrupting nonnative ungulate populations are typically known as threats to biodiversity and forage abundance through herbivory, rooting, digging, and trampling

(Spear and Chown 2009). As stated earlier, it is possible that habitats with the highest densities of mountain goats had greater forage biodiversity and cover than other areas prior to the arrival of mountain goats, and which then led to a rapid increase in mountain goat subpopulation densities. By 2011, mountain goat densities at the highest density study site (Uyak, $2.54/km^2$) had already exceeded the maximum mountain goat density at the Hidden Terror ($2.09/km^2$) site, before the subpopulation there subsequently crashed to a lower density. Pre-introduction carrying capacities at Hidden Terror and Uyak may have differed, and it is possible that the Uyak subpopulation had yet to reach carrying capacity. Despite the apparent lack of impacts to forage from the highest density goat subpopulation, future impacts by growing

Table 4. Logistic regression model output for the top candidate model evaluating mountain goat feeding location selection, summer 2011, Kodiak Island, Alaska.

Predictor	Estimate	SE	*p*-value
(Intercept)	-1.04	0.39	<0.01
Distance to escape terrain	-0.01	<0.01	<0.01
Long-awned sedge cover	0.14	0.03	<0.01
Fern cover	-1.67	0.61	<0.01
Woolly geranium cover	-0.21	0.07	<0.01
Rush cover	1.21	0.35	<0.01
Nootka lupine cover	-0.29	0.11	<0.01
Moss cover	0.03	0.01	<0.01
Hillshade	-0.16	0.09	0.06
Grass cover	-0.09	0.60	0.12

Table 5. Top ten candidate models for feeding location selection. The final model included nine predictors that were removed individually for comparison. K is the number of predictors in the model. Distance to escape terrain (m) was the strongest predictor of a mountain goat feeding location selection, followed by long-awned sedge cover (%), and then fern cover.

Model	k	AIC$_c$	ΔAIC$_c$	w
Full[a]	10	187.16	0	0.44
(-Grass cover)	9	187.81	0.65	0.32
(-Hillshade)	9	188.71	1.55	0.20
(-Moss cover)	9	193.04	5.88	0.02
(-Nootka lupine cover)	9	196.49	9.33	0.00
(-Rush cover)	9	197.73	10.57	0.00
(-Woolly geranium cover)	9	198.75	11.59	0.00
(-Fern cover)	9	201.93	14.77	0.00
(-Long-awned sedge cover)	9	205.94	18.78	0.00
(-Distance to escape terrain)	9	235.24	48.08	0.00

[a] Full model = Intercept + Distance to escape terrain + Long-awned sedge + Fern + Woolly geranium + Rush + Nootka lupine + Moss + Hillshade + Grass

mountain goat subpopulations at Uyak and Hepburn are likely if population growth rates remain unchanged. Therefore, continued monitoring of forage diversity, abundance, and quality is needed.

Mountain goats in areas on Kodiak that have completed an irruptive growth cycle were predicted to have a broader diet (show less selection for certain forage items) because declines in preferred forage would increase the energetic cost of locating and consuming such forages, and cause goats to seek alternative food items (MacArthur and Pianka 1966). Contrary to our predictions, we did not find a consistent correlation between mountain goat summer diets and their stage along the irruptive growth cycle. Although we found no consistent correlation between mountain goat diets and irruptive growth, we found that mountain goats on Kodiak in the highest density subpopulation consumed more sedge than any other subpopulation, which is viewed as a high quality summer forage for northern ungulates (Fox 1991). This finding is likely because sedge was most abundant at that site. In contrast, mountain goats in the lowest density subpopulation consumed the most moss, which is seen as a low quality forage for northern ungulates (Ihl and Barboza 2007).

As expected, the summer diets of mountain goats on Kodiak consisted largely of alpine sedges and forbs, as reported elsewhere for coastal Alaska

(Hjeljord 1973, Fox et al. 1989, White et al. 2012). Introduced goats in Montana and Colorado primarily consumed grasses, sedges, and rushes in the summer (Saunders and Saunders 1955, Hibbs 1967) and fall (Varley 1994). Although this suite of plants tend to dominate goat diets, browse plants have been found to be a primary summer food in Montana and South Dakota (Casebeer 1948, Richardson 1971). Like other ungulates, summer forage intake by mountain goats is largely driven by the need for rapid growth and weight gain to counterbalance annual weight loss over the winter due to nutritional deprivation. By consuming sedges and forbs mountain goats on Kodiak focused on high quality forage, which has high cellular content, little cell wall material, and minimal secondary compounds (Fox et al. 1989). Alpine plants contain more nitrogen (i.e. higher quality) than their counterparts at lower elevations and continue to emerge from areas adjacent to receding snow banks throughout much of the summer (Fox 1991), which provides goats with highly nutritious new growth over an extended time period.

Mountain goats on Kodiak Island shifted their diets between June and August by consuming more sedges and forbs, and less ferns and grasses, as the summer progressed. This dietary shift, most pronounced between June and July, was consistent across all study sites and was likely linked to increased availability of new alpine vegetative growth following snowmelt. Higher elevations on Kodiak Island were still largely snow-covered through most of June, which presumably presented limited forage that was more similar to winter conditions. Seasonal dietary shifts by mountain goats have been observed on Kodiak (Hjeljord 1971) and elsewhere (Hjeljord 1973, Varley 1994, Degano and Catan 2002), and have been tied to changes in forage availability and quality (Pfitsch and Bliss 1985). The only previous mountain goat diet study on Kodiak found that mountain goats in the Hidden Basin area (a portion of this study's Hidden Terror study site) utilized tall rigid grasses and sedges during the winter,

especially Altai fescue (*Festuca altaica*) and coiled sedge (*Carex circinata*), which maintain an upright structure and green tissue even on snow-covered slopes (Hjeljord 1971). Hjeljord (1971) observed mountain goats spending much of their feeding time digging through litter to consume lady fern (*Athyrium filix-femina)* rhizomes in the winter, and blue-joint (*Calamagrostis canadensis*) and fern rhizomes in early spring (May). Our results expanded upon these findings by showing that ferns and grasses are still important components of Kodiak's mountain goat diets well into summer (late June) and this dietary pattern appears to be independent of population density and a history of irruptive growth.

Our feeding location selection models indicated that proximity to escape terrain was the most critical element of mountain goat feeding location selection on Kodiak, as previously identified in other areas (Gross et al. 2002, Poole and Heard 2003, Hamel and Côté 2007). However, unlike other populations that are vulnerable to predation by wolves (*Canis lupus*), black bear (*U. americanus*), and brown bears (Fox and Streveler 1986), mountain goats on Kodiak are only at risk of predation by brown bears, golden eagles (*Aquila chrysaetos*), and humans (Côté and Beaudoin 1997, Demarchi et al. 2000). Levels of bear and eagle predation on mountain goats were unknown on Kodiak, but thought to be minimal because observed interactions between the species and discoveries of mountain goat predation events were rare. Despite increasingly liberal hunter harvest pressure (5–10% targeted kill rates in 2010), the goat population has exponentially grown for over 60 years (Van Daele and Crye 2010). It is unlikely that this observed rate of mountain goat population increase would have been possible in combination with heavy bear and eagle predation.

Our feeding location selection models indicated that mountain goats on Kodiak selected feeding locations that had abundant and homogeneously distributed long-awned sedge, a highly nutritious forage throughout summers in Alaska (Fox 1991). Like many northern ungulates, mountain goats are considered selective feeders and display seasonal preferences for specific classes and species of forage (Festa-Bianchet and Côté 2008). This selective feeding behavior typically manifests itself in selection for specific habitat types that harbor the greatest abundance of preferred forage items. Mountain goat feeding locations have been described as alpine meadows near cliffs (Von Elsner-Schack 1986). Confirming our findings, Hjeljord (1971) found that mountain goats in the Hidden Basin region selected sedge meadows and slopes as feeding locations during the summer in the 1970s, where their preferred forage was also long-awned sedge. Our microhistological results of mountain goat pellets collected at feeding locations also confirmed the importance of sedges in the summer diets of mountain goats.

Long-awned sedge was also found to be heavily used by Kodiak bears in the spring (Atwell et al. 1980). Given overlapping dietary preferences, the potential exists for forage competition between bears and mountain goats. Bears have been observed congregating at high densities (0.85/km^2) on localized patches of long-awned sedge, presumably because it is fast growing, nutritious, and one of the first to emerge following snowmelt, but before salmon spawning (Atwell et al. 1980). Although the potential for competition exists, we did not directly observe interactions between bears and mountain goats to support this hypothesis.

Understanding the diet, feeding location selection and behavioral patterns of a growing Kodiak mountain goat population is a critical first step for developing empirically-driven harvest management strategies. Our results show that mountain goat feeding location selection is driven by access to high quality sedges and forbs, and proximity to escape terrain. This finding was universal, regardless of goat population densities or history. If Kodiak's mountain goat population continues to grow it will likely exceed its nutritional carrying capacity and cause a reduction in their preferred forage species, which could in turn affect other species such as bears, which also rely on these forage species. Additional work is therefore needed to further understand the relationship between the resource selection patterns, population dynamics, and harvest management options for mountain goats on Kodiak Island.

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IRRUPTION, CRASH, AND RECOVERY OF AN INTRODUCED MOUNTAIN GOAT POPULATION IN THE CRAZY MOUNTAINS, MONTANA 1941–2011

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Abstract: Common debates in mountain goat (*Oreamnos americanus*) management include sustainable harvest rates, whether goat populations exhibit compensatory reproduction to changes in population size, differences in population dynamics of native and nonnative populations, and influence of harvest pressure on demographics and trophy quality. We analyzed the 70-year history of an introduced mountain goat population in the Crazy Mountains to shed light on these issues. The reintroduction of 21 mountain goats in the Crazy Mountains in 1941-1943 established the first nonnative population in North America. This population experienced a rapid "irruptive" phase from 1941–1957, increasing to 342 observed goats followed by a rapid "crash" in numbers, declining to 165 observable goats in 1961. From 1961–1976 the observable population declined to 35 goats, and remained stable between 1976–1989 ranging from 23-47 observed goats. In 1989 the population began a "recovery" phase and increased from 47 to 371 observed goats in 2011. Goat hunting harvests varied from conservative seasons (1953–54) to liberal seasons (1955–1967) to no hunting (1976–1989) to an Adaptive Harvest Management (AHM) approach (1993-2011), designed to respond to population indices and dampen population fluctuations. Annual mean harvest of 8.7% (range 5.3–13.5%) of observed goats since inception of AHM in 1993 has resulted in a gradually increasing population (r = 0.07), compared with rapid population growth between 1943–1957 (r = 0.41). Recruitment trends since 1993 have been stable, averaging 22 kids per 100 adults (range 18–37). Analysis of age at harvest and horn lengths of harvested goats did not indicate change in demographics or trophy quality over time. Based on the Crazy Mountain model, it may be possible for wildlife managers to increase harvest levels on introduced goat populations to reduce the negative effects of "boom and bust" population cycles.

Key words: Oreamnos americanus, mountain goat, Montana, population dynamics.

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A COMPARISON OF MORTALITY RATES FOR DESERT AND ROCKY MOUNTAIN BIGHORN SHEEP UNDER TWO COUGAR REMOVAL REGIMES

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Abstract: Desert bighorn sheep (*Ovis canadensis nelsoni*) were listed as a state endangered species in New Mexico in 1980 when their numbers were <70 animals in the wild. In the 1990s, radiocollaring and monitoring efforts documented that approximately 85% of known-cause mortality was due to cougar (*Puma concolor*) predation. A cougar removal program in desert bighorn ranges was initiated in 2001, and new herds were subsequently added to the program as bighorn were reintroduced into new ranges. Overall average annual mortality declined from 0.21 (SE = 0.01) to 0.11 (SE < 0.01) and cause-specific average annual mortality from cougar predation declined from 0.16 (SE = 0.01) to 0.05 (SE < 0.01) from the time prior to implementing cougar removal (1992–2002) to the time following implementing cougar removal (2002–2011). Desert bighorn historically occupied the San Francisco River (SFR) in the Gila National Forest. Following their extirpation in the first half of the 1900s, the New Mexico Department of Game and Fish introduced Rocky Mountain bighorn sheep (*Ovis canadensis canadensis*) into the area because no desert bighorn were available for transplant. Cougar removal has never been implemented to protect the SFR herd; however, overall average annual mortality increased from 0.19 (SE = 0.03) in 1997–2001 during the period prior to cougar removal in desert herds, to 0.24 (SE = 0.02) in 2003–2011 during the period following cougar removal in desert herds. Cause-specific average annual mortality from cougar predation increased from 0.08 (SE = 0.03) to 0.13 (SE = 0.03) in the same time periods. Cougar-caused mortality sharply increased from October 2009–2011, with a cause-specific average annual mortality rate of 0.31 (SE = 0.06). These data suggest that without cougar removal in desert bighorn herds, mortality rates may have been much higher. A recently implemented cougar removal program in the SFR is designed to prevent the bighorn herd from being extirpated.

Historically, thousands of desert bighorn sheep (*Ovis canadensis nelsoni*) were likely distributed in most arid mountain ranges in southern and central New Mexico. Evidence of their occupation is available for 14 ranges (Buechner 1960). During European settlement of New Mexico, as in other western states, bighorn populations declined rapidly due to diseases introduced by domestic livestock and illegal hunting (Buechner 1960). Bighorn are particularly sensitive to bacterial pneumonia, a disease carried by domestic sheep and easily transmitted to wild sheep. Approximately 5 million domestic sheep grazed annually in New Mexico by the 1880s (Scurlock 1998); these sheep were likely a major factor in bighorn population declines. Bighorn hunting was prohibited in 1889, but uncontrolled market hunting continued to be an important cause of mortality in some areas.

In 1980, with <70 desert bighorn in the wild, desert bighorn were listed as a state endangered species in New Mexico (NMDGF 2003). In the 1960s, the New Mexico Department of Game and Fish reintroduced bighorn to the San Francisco River (SFR) and Turkey Creek areas in the Gila National Forest. No desert bighorn were available

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at the time; therefore, Rocky Mountain bighorn (*Ovis canadensis canadensis*) were released instead. In the 1980s and 1990s, translocation of desert bighorn, primarily out of the Red Rock captive breeding facility, was the principal management action used to increase population numbers. The first transplant occurred in 1979. Despite transplanting 249 bighorn between 1979 and 2001, the desert bighorn population remained below 170 individuals.

Through monitoring radiocollared bighorn in the 1990s, it was documented that cougar (*Puma concolor*) predation was the principal limiting factor in all desert bighorn populations where radiocollared individuals were monitored (Rominger and Dunn 2000, Rominger et al. 2004), with 85% of all known-cause mortalities attributed to cougar predation (NMDGF 2003). Cougar predation has been documented to limit desert bighorn populations throughout their range (Wehausen 1996, Hayes et al. 2000, Creeden and Graham 1997, Kamler et al. 2002, Rominger et al. 2004). Predator control of top-carnivores is controversial (Reiter et al. 1996, Minteer and Collins 2005, Rominger et al. 2006); however, predator control is a recommended management action for the conservation of endangered species (Hecht and Nickerson 1999). In 2001, the New Mexico Department of Game and Fish implemented a cougar removal program to protect the remaining state endangered desert bighorn.

The purpose of this study was to compare desert bighorn mortality rates from all causes of mortality and from cause-specific cougar predation mortality during the period prior to cougar removal to the period following cougar removal. Although cougar removal was not implemented in the SFR Rocky Mountain bighorn population during these time periods, mortality rates in SFR can serve as a comparison group with which to evaluate efficacy of the program in desert bighorn herds, and recommend management actions in the SFR herd.

STUDY AREA

This study took place in 5 mountain ranges in the Chihuahuan desert of southern New Mexico: the Hatchet, Peloncillo, Ladron, Fra Cristobal, and San Andres mountains. The vegetation was classified as desert grassland (Dick-Peddie 1993),

and was dominated by grama (*Bouteloua* spp.), juniper (*Juniperus* spp.), agave (*Agave* spp.), yucca (*Yucca baccata, Y. schotti*), sotol (*Dasylirion wheeleri*), oak (*Quercus* spp.), and mountain mahogany (*Cercocarpus montanus*; Sandoval 1979). Elevation ranges from approximately 1300 m to a maximum of 2510 m (San Andres Peak), and contains steep, rocky slopes. Average daytime maximum temperatures range from 13^0 C in December and January, to 34^0 C in June and July. Average daytime minimum temperatures range from -6^0 C in January to 18^0 C in July. Average annual precipitation is 26.4 cm with approximately 65% falling between July–October (National Oceanic and Atmospheric Administration 2012 and Western Regional Climate Center 2013).

This study also included the SFR drainage. The predominant vegetation was classified as pinion-juniper woodland (Dick-Peddie 1993), and was dominated by juniper and pinion pine (*Pinus edulis*), and by willows (*Salix* spp.) and cottonwood (*Populus fremontii*) in the riparian zone. Desert scrub comprised of oaks, mesquite (*Prosopis juliflora*), cat-claw acacia (*Acacia greggii*), mountain mahogany (*Cercocarpus montanus*), and yucca (*Yucca* spp.), with grama grasses (*Bouteloua* spp.*)* in the understory was also found in the area. Elevation ranges from approximately 1280 m to 1770 m. Average daytime maximum temperatures range from 14^0 C in January to 33^0 C in June and July. Average daytime lows range from -5^0 C in November and December to 14^0 C in July. Average annual precipitation is 45.5 cm with 53% falling between July–October (Western Regional Climate Center 2013).

METHODS

Bighorn Sheep Capture and Monitoring

From 1992–2011 desert and Rocky Mountain bighorn were captured using the helicopter netgun method (Barrett et al. 1982). Rocky Mountain bighorn were also captured using drop-nets and dart-guns with a Carfentanil (Wildlife Pharmaceuticals, Inc., Fort Collins, CO) and xylazine hydrochloride (Rompun®; Bayer, Inc., Etobicoke, Ontario, Canada) cocktail. Both subspecies of bighorn were radiocollared with

mortality sensor collars from a variety of manufacturers (AVM Instrument Co., Livermore, CA, USA; Advanced Telemetry Systems, Isanti, MN; Lotek, Newmarket, Ontario, CA; Telemetry Solutions, Concord, CA, USA; and Telonics, Mesa, Arizona, USA).

Bighorn sheep were monitored during fixed-wing telemetry flights conducted approximately monthly, and from the ground with varying intensity. When a mortality signal was obtained, biologists went to the mortality site to assess cause of mortality. Cougar predation was considered cause of mortality in the presence of: a dragline from the kill to cache site; cougar tracks at the kill or cache site; canine puncture wounds in the neck or face; canine punctures or claw slices on the radiocollar; rumen extracted and uneaten or buried; carcass partially or completely buried with rocks, sticks, grass, etc.; broken neck; rostrum bones eaten back >10 cm; braincase cracked (female bighorn only); humerus and/or femur cracked; cougar hair or scrapes present at or near the kill or cache site; or multiple cache sites.

Cougar Removal Policy

Contracted houndsmen and snaremen began removing cougars in the Peloncillo, Hatchet, and Ladron mountains in October 2001, the San Andres in October 2002, and the Fra Cristobals in 2006. Following the first year of implementation, the cougar removal policy in the San Andres was different than in the other ranges; therefore, only data from the first year of cougar removal is included for the San Andres. Snaremen were required to use leg-hold snares and to check snares a minimum of once every 48 hours, with a minimum of once daily checks in certain circumstances.

STATISTICAL ANALYSIS

We used the nest-survival model in program MARK (White and Burnham 1999) to calculate bighorn mortality rates. We examined average annual mortality rates from all causes of mortality and from cougar predation only. For desert bighorn, we divided mortality data into 2 time periods: 1) a period prior to implementation of cougar removal which includes the period when no cougars were being removed to protect bighorn and the first year cougar removal was initiated

(Table 1); and 2) a period following implementation of cougar removal that begins one year after implementing cougar removal in each herd (Table 1). We hypothesized that one year of the management action would sufficiently reduce cougar numbers to afford protection for bighorn herds, and be sufficient time to induce a bighorn population response. Mortality rates were calculated on a state-wide level and for individual herds. For SFR Rocky Mountain bighorn, we calculated mortality rates for all causes of mortality and for cougar predation only for time periods generally corresponding to dates prior to cougar removal (1997–2001) and following cougar removal in the desert (2003–2011), although cougars were never removed in SFR. We also calculated annual mortality rates for SFR.

We used Akaike's Information Criterion corrected for small sample size (AIC_c) to determine if the model differentiating between cougar removal periods for desert bighorn, the model differentiating between time periods corresponding to the two cougar removal periods in the SFR, and the model differentiating between desert bighorn herds and the SFR during the two cougar removal periods, had more support than their respective dot models (models that contain all data and do not specify covariates).

RESULTS

Bighorn Capture

Desert bighorn: from 1992–2001, we monitored 167 radiocollared bighorn (151 radiocollars were deployed on transplanted bighorn, 12 were deployed on extant bighorn, and 4 were previously deployed and still alive). A total of 176 bighorn were transplanted and released into the wild during that time. From 2002–2011, we monitored 359 radiocollared bighorn (196 radiocollars were deployed on transplanted bighorn, 136 were deployed on extant bighorn, and 27 were previously deployed and still alive. Of the 27 previously radiocollared bighorn, 20 of them were included in the 1992–2001 analysis). A total of 216 bighorn were transplanted and released into the wild during that time.

SFR: from 1997–2001, we monitored 15 radiocollared bighorn (3 radiocollars were deployed on transplanted bighorn, and 12 were

Table 1. Dates for 2 different cougar removal policies in 5 desert bighorn herds in New Mexico, 1992–2011.

Cougar Removal Period	Mountain Range				
	Peloncillos	Sierra Ladron	Hatchets	San Andres	Fra Cristobals
Prior to cougar removal	Nov. 1997–May 1999; Oct. 2000–Sept. 2002	Oct. 1992–Sept. 2002	Nov. 1997–Sept. 2002	Oct. 1992–Aug. 1997; Oct 2002–Sept 2003	Oct. 1995–Sept 1999
Following cougar removal	May 1999–Sept. 2000; Oct. 2002–Sept. 2011	Oct. 2003–Sept. 2011	Oct. 2003–Sept. 2011	N/A	Oct. 2006–Sept. 2011

Table 2. Average annual mortality rate of bighorn sheep in New Mexico (1992–2011) from all causes of mortality and from cougar predation only prior to and following cougar removal in 5 desert bighorn herds, and in the San Francisco River Rocky Mountain bighorn herd during the same time periods in the absence of cougar removal.

Herd	Prior to Cougar Removal		Following Cougar Removal	
	All Causes of Mortality (SE)	Cougar Predation (SE)	All Causes of Mortality (SE)	Cougar Predation (SE)
All Desert Herds	0.21 (0.01)	0.16 (0.01)	0.11 (<0.01)	0.05 (<0.01)
San Francisco River	0.19 (0.03)	0.08 (0.03)	0.24 (0.02)	0.13 (0.03)
Peloncillos	0.25 (0.03)	0.22 (0.03)	0.09 (0.02)	0.05 (0.01)
San Andres	0.23 (0.02)	0.13 (0.02)	N/A	N/A
Ladrones	0.21 (0.02)	0.14 (0.02)	0.11 (0.03)	0.02 (0.01)
Hatchets	0.20 (0.03)	0.14 (0.03)	0.11 (0.03)	0.08 (0.01)
Fra Cristobals	0.18 (0.02)	0.18 (0.02)	0.17 (0.03)	0.07 (0.02)

deployed on extant bighorn). A total of 4 bighorn were transplanted into the herd during that time. From 2003–2011, we monitored 31 bighorn (14 radiocollars were deployed on transplanted bighorn, and 17 were deployed on extant bighorn. None of the animals were included in the 1997–2001 analysis). A total of 14 bighorn were transplanted into the herd during that time.

Mortality Rates

The overall average annual mortality rate for desert bighorn from all causes of mortality declined from 0.21 (SE = 0.01) prior to cougar removal to 0.11 (SE < 0.01) following cougar removal (Table 2). The average annual cause-specific mortality rate from cougar predation declined from 0.16 (SE = 0.01) to 0.05 (SE < 0.01) during the same time period. The average annual mortality rate for SFR Rocky Mountain bighorn from all causes of mortality increased from 0.19 (SE = 0.03) to 0.24 (SE = 0.02) and the cause

specific average annual mortality rate from cougar predation increased from 0.08 (SE = 0.03) to 0.13 (SE = 0.03) during the same time periods in the absence of cougar removal (Table 2).

Average annual mortality rates for each desert herd prior to cougar removal ranged from 0.18 (SE = 0.02) to 0.25 (SE = 0.03) for all causes of mortality; the SFR mortality rate of 0.19 (SE = 0.03) fell within that range (Table 2). Cougar predation mortality for each desert herd prior to cougar removal ranged from 0.13 (SE = 0.03) to 0.22 (SE = 0.03), with the SFR mortality rate of 0.08 (SE = 0.03) lower than any desert herd. Following cougar removal in desert herds, total mortality rates declined and ranged from 0.09 (SE = 0.02) to 0.17 (SE = 0.03). During that period the SFR total mortality rate increased to 0.24 (SE = 0.02), which was higher than during the period prior to cougar removal in desert herds, and surpassed all desert herds during the period of cougar removal. Cougar predation mortality rates
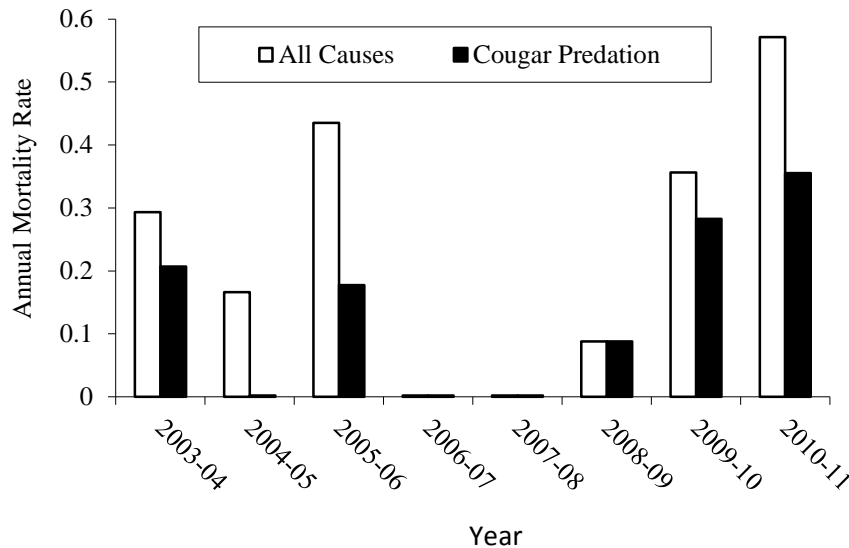
Fig. 1. Annual mortality rates from all causes of mortality and from cougar predation only in the San Francisco River Rocky Mountain bighorn herd, New Mexico from 2003–2011. All SE are between 0.02 and 0.06, with the exception of cougar predation mortality rates for 2009–10 and 2010–11 which are 0.08 and 0.09, respectively.

in desert herds declined following cougar removal and ranged from 0.05 (SE = 0.01) to 0.08 (SE = 0.01), while the SFR cougar predation mortality rate of 0.13 (SE = 0.03) increased from the period prior to cougar removal in desert herds, and surpassed all desert herds during the period of cougar removal (Table 2). Average annual cougar predation rate in SFR from 2009–2011 was 0.31 (SE = 0.06). Mortality rates for individual years for SFR bighorn from 2003–2011 ranged from 0.0 (SE = 0.00) to 0.57 (SE = 0.05) and cougar predation mortality rates ranged from 0.0 (SE = 0.00) to 0.36 (SE = 0.09; Fig. 1).

Model Selection

When evaluating mortality rates from all causes and from cougar predation only for desert bighorn, only the models that separate cougar removal periods had any support (Tables 3 and 4). In contrast, for models describing all causes of mortality and cougar predation mortality in the SFR, both the model combining cougar removal periods and the model separating cougar removal periods show support. However, the model combining cougar removal periods had a higher model weight and likelihood (0.7 and 1, respectively) compared with the model separating cougar removal periods (0.3 and 0.5, respectively), making it the top model. Finally, when comparing

mortality rates for all causes of mortality for all bighorn herds during each of the cougar removal policies, only the model separating the desert herds from the SFR had any support. In contrast, when comparing mortality rates from cougar predation for all bighorn herds during each of the cougar removal periods, both the model separating desert herds from the SFR and the model combining them received support. However, the model combining the desert herds and the SFR had a higher model weight and likelihood (0.7 and 1, respectively) compared with the model separating the desert herds from the SFR (0.3 and 0.4, respectively; Tables 3 and 4).

Desert Bighorn Population Response

The statewide desert bighorn population increased from <170 animals prior to implementing cougar removal in 2001 to approximately 650 in 2011 (Fig. 2). The SFR to approximately 50 animals, the population remained stable until it declined again starting in 2009. The 2011 population estimate was 35 bighorn (Fig. 3).

Cougar Removal

Cougars are a game animal in New Mexico, with a year-round season and a bag limit of 1 cougar per hunter. On average, 2.6 cougars are

Table 3. The model structure, Akaike's Information Criterion adjusted for sample size (AIC$_c$), differences in AIC$_c$ (ΔAIC$_c$), model weights, model likelihood, and the number of parameters for models predicting bighorn sheep mortality rates in New Mexico, 1997–2011.

Model	AIC$_c$	ΔAIC$_c$	AIC$_c$ Weight	Model Likelihood	No. Parameters
Desert bighorn					
Cougar removal policy	1627.9	0	1.0	1.0	2
(.)	1640.7	12.8	0	0	1
SFR					
(.)	306.2	0	0.7	1.0	1
Cougar removal policy	307.8	1.6	0.3	0.5	2
Different cougar removal policies					
Deserts vs. SFR	1935.7	0	0.92	1.0	4
(.)	1940.7	5.0	0.08	0.08	2

Table 4. The model structure, Akaike's Information Criterion adjusted for sample size (AIC$_c$), differences in AIC$_c$ (ΔAIC$_c$), model weights, model likelihood, and the number of parameters for models predicting cougar predation mortality rates for bighorn sheep in New Mexico, 1997–2011.

Model	AIC$_c$	ΔAIC$_c$	AIC$_c$ Weight	Model Likelihood	No. Parameters
Desert bighorn					
Cougar removal policy	1128.4	0	1.0	1.0	2
(.)	1147.7	19.3	0	0	1
SFR					
(.)	155.7	0	0.7	1.0	1
Cougar removal policy	157.0	1.3	0.3	0.5	2
Different cougar removal policies					
Deserts vs. SFR	1296.8	0	0.7	1.0	4
(.)	1298.8	1.99	0.3	0.4	2

killed per mountain range per year under the cougar removal program, although the number removed from each range varies (Table 5). Bighorn ranges in which cougars are removed constitute approximately 1% of cougar habitat in New Mexico, and cougar sign is observed in all bighorn mountain ranges annually.

DISCUSSION

Traditionally, four subspecies of desert bighorn sheep have been recognized, with desert bighorn in New Mexico belonging to the subspecies *mexicana*. Although this designation often persists, mitochondrial genetic research by Ramey (1995) suggests that lack of mitochondrial genetic and morphological variation between the desert bighorn subspecies makes it more reasonable to consider them a single subspecies. For this reason, in this publication we have chosen to designate desert bighorn in New Mexico, as well as all desert bighorn, as the subspecies *nelsoni*.

Cougar removal implementation varied in each mountain range. Although the objective was to minimize cougar numbers, houndsmen and snaremen worked part time and effort was not evenly distributed in each mountain range at all times. Gaps in coverage were primarily due to administrative processes and contractor availability. As such, this analysis is of the
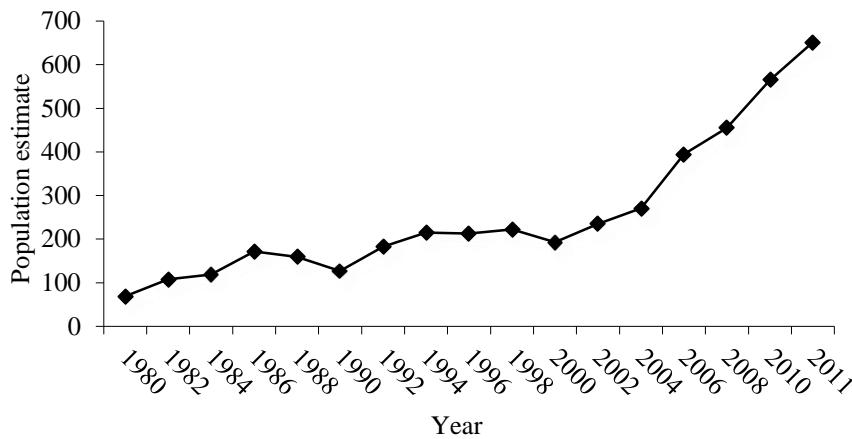
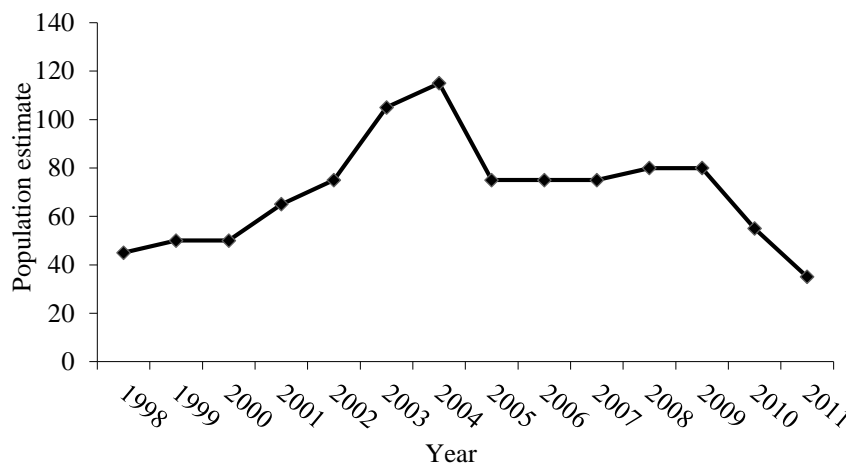Fig. 2. Desert bighorn population trend in New Mexico, 1980–2011.

Fig. 3. San Francisco River, NM Rocky Mountain bighorn population trend, 1998–2011.

removal to the period following cougar removal, and the cause-specific mortality rate from cougar predation declined 68%. In contrast, in the SFR where cougar removal did not occur, total mortality increased 21% during the same time period and cougar predation increased 38%. It is likely that in the absence of cougar removal, mortality rates in desert bighorn herds would not have decreased between the two time periods. Mortality rates from causes other than cougar predation remained constant in desert herds (0.05) during both time periods, demonstrating that cougar predation is an additive source of mortality. It also remained constant in SFR (0.11). The majority of other causes of mortality were unknown, although known causes included disease, old age, infection, fence entanglement, and legal harvest (Peloncillos only).

Mortality rates and causes in SFR varied greatly year to year. Low population numbers in the late 1990s resulted from a pneumonia epidemic that caused a large population decline. The population increased in the early 2000s and recovered to just over 100 animals when another pneumonia outbreak in 2005–6 caused another population decline. Average annual cougar predation mortality rates were high at 0.21 and 0.18 in 2003–4 and 2005–6 respectively, but no cougar predation was documented on radiocollared bighorn from 2006–2008. Cougar predation may have had a negative impact on SFR bighorn in some years, but other causes such as pneumonia were responsible for population declines in other years.

During the time period prior to implementing cougar removal in desert bighorn herds when cougar removal was not implemented in SFR, the mortality rate in SFR was similar to desert bighorn

management action as we were able to implement it.

SFR was historically populated with desert bighorn. Habitat differs from desert bighorn habitat in the 5 herds comprising this study primarily because it is a river canyon as opposed to a sky-island, defined as a mountain that is isolated by surrounding lowlands of a dramatically different environment. The current population in SFR is composed of Rocky Mountain bighorn, further differentiating this herd from the desert populations. The differences between desert bighorn herds and the SFR are great enough that the SFR population cannot be used as a control herd even though cougar control was never implemented in the SFR. However, it can be used as a comparison herd.

The mortality rate in desert bighorn herds declined 48% from the period prior to cougar

Table 5. Number of cougars killed in 5 mountain ranges October 2001–September 2011 to protect desert bighorn; additional cougars removed by sport harvest/road kill/livestock depredation in parentheses.

Year	Peloncillos	Sierra Ladrones	Hatchets	San Andres	Fra Cristobals	Total
2001–2002	4 (2)	4	1 (1)	-	1 (1)	10 (4)
2002–2003	5 (2)	7 (2)	4 (1)	16	5	37 (5)
2003–2004	5	0	0 (2)	3 (1)	3 (1)	11 (4)
2004–2005	0	4	1 (3)	3	4	12 (3)
2005–2006	0	2	6	3	2	13 (0)
2006–2007	3	4	1	4	3	15 (0)
2007–2008	0	10 (1)	1	0	2	13 (1)
2008–2009	1	2	0	1	4	8 (0)
2009–2010	5	7	1	0	1	14 (0)
2010–2011	0	8	1	0	3	12 (0)
Total	23 (4)	48 (3)	16 (7)	30 (1)	28 (2)	145(17)

herds, but the cause-specific mortality rate from cougar predation was 50% lower in SFR. Lower cougar predation rates excluded cougar removal from SFR. The cougar predation average annual mortality rate of 0.08 in SFR prior to cougar removal in the desert herds remained consistent during the first 6 years (2003–2009) of the time period following cougar removal in the desert but not SFR herds. The cougar predation mortality rate subsequently increased to 0.26 in 2009–10 and 0.36 in 2010–11, and total mortality rates increased to 0.36 and 0.57, respectively. Negative impacts of two years of high mortality caused the population estimate to decline from 80 to 35 animals.

Cougar removal has been successful in New Mexico because of the animal's social structure, which is quite different from mesocarnivores such as coyotes, where removal has not always been effective. Cougars are solitary animals that are relatively slow to recolonize vacated areas, and any individual cougar may prey upon desert bighorn (Logan and Sweanor 2001). In contrast, coyotes are pack animals and it is necessary to remove the alpha male and female to slow reproduction and predation (Blejwas et al. 2002). Decreased mortality rates in combination with transplants into the wild resulted in statewide desert bighorn population numbers increasing from approximately 170 to 650 animals in the 10 year period between 2001 and 2011, and enabled them to be removed from the New Mexico state list of threatened and endangered species in 2011.

Although cougar predation is not always a limiting source of mortality in SFR it is currently driving the population to extinction. Small populations of wild ungulates are more vulnerable to impacts of predation (Compton et al. 1995, Wehausen 1996, Hayes et al. 2000, Rominger and Weisenberger 2000, Wittmer et al. 2005). A policy of range-wide removal until the population recovers to levels where less aggressive removal actions could be implemented was found to be superior in reducing extinction risk compared to less aggressive strategies (Ernest et al. 2002). Although cougar removal may not be needed in all years in SFR, based on population trends in New Mexico desert bighorn herds prior to and following cougar removal, it is likely that SFR bighorn will go extinct without implementing a cougar removal program in the near future. For this reason, the New Mexico Department of Game and Fish commenced cougar removal and removed 8 cougars from May–November 2012 and will continue. Population monitoring will show if the bighorn population experiences the anticipated decline in cougar predation and subsequent increase in population numbers.

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MORTALITY FACTORS AND HABITAT USE OF CALIFORNIA BIGHORNS IN THE DESCHUTES RIVER, OREGON

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Abstract: Previous California bighorn sheep (*Ovis canadensis californiana*) mortality research in Oregon has focused on declining populations within the Hart and Leslie Gulch herds. The Deschutes River herd has been expanding since reintroduction in 1993, and has served as a major source for translocation over the past ten years. Beginning in December 2007 we radio-marked and monitored 52 adult bighorn to determine cause of adult mortality, evaluate herd range and habitat use, monitor herd health, and measure sex and age-specific survival.

California bighorn sheep (*Ovis canadensis californiana)* within the state of Oregon were extirpated by 1915, likely from a combination of disease and overharvest. Restoration efforts within the state began in 1954 when 20 sheep from Williams Lake, British Columbia (BC) were released within an enclosure on Hart Mountain. As this original herd expanded, surplus animals were captured and transplanted into vacant habitats throughout the state.

The initial reintroduction into the Deschutes River canyon occurred in 1993. Thirty-five sheep captured from the upper portion of the Owyhee canyon in Idaho were released at approximately river mile 18 on the east side of the Deschutes. Subsequent releases were made into the west side of the canyon from the Steens Mountain (n = 18) and Lower John Day River (n = 12) in 1995 and 1999, respectively. There are currently an estimated 475 sheep in the Deschutes River population. Since 1999, 175 individuals have been captured for both intrastate and interstate relocation. In addition, 93 rams have been harvested during authorized seasons as of November 2011.

STUDY AREA

The study area encompassed approximately 350 km^2 representing approximately 20 river miles within the Deschutes River canyon (Fig. 1). The Deschutes has an average discharge of 5,800 cubic feet per second. Flows varied little by season due to a dam at rivermile 100 that regulated water release. Elevations range from approximately 150 m along the river to 750 m on the rims surrounding the canyon. The canyon was characterized by generally open, grassy hillsides bisected by short side canyons and steep basalt cliffs. Vegetation was primarily open grassland, primarily bunchgrasses, with some shrub-steppe in areas less prone to fire disturbance. Canyon habitats were surrounded primarily by dryland agriculture. A train track runs through the study area along the west side of the Deschutes River.

METHODS

Fifty-two radio collars (Sirtrack, Inc.) were deployed on bighorn sheep during December 2007 and December 2008. Collars were distributed in 4 unique ram groups and 5 unique ewe groups at the general ratio of 1 collar for every 10 bighorns in

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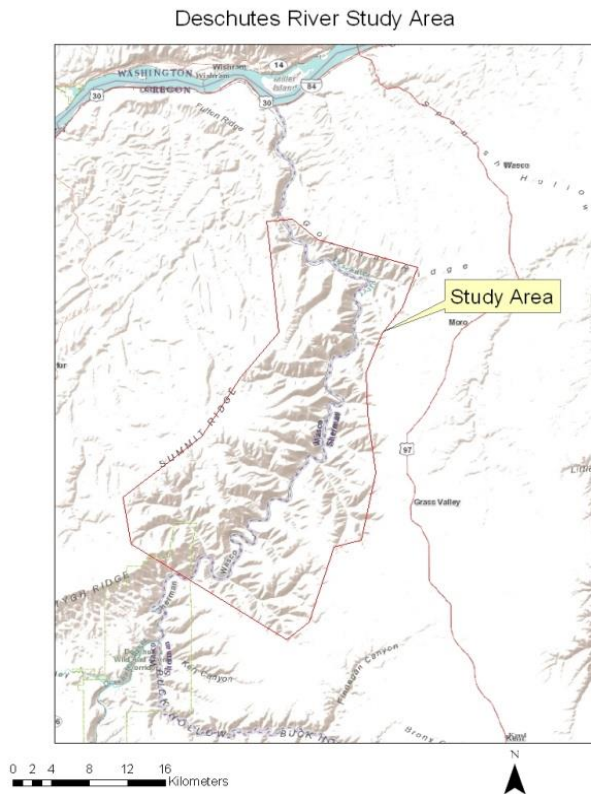
Deschutes River Study Area

Fig. 1. Deschutes study area.

the group. Both rams and ewes were radio-collared. All sheep were captured using an aerial net gun fired from a helicopter, processed, and released on site by capture personnel.

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

Collars were monitored bi-weekly for mortality either from fixed-wing aircraft or by vehicle. Mortalities were investigated as soon as possible to determine cause of death. Cause of death was

determined based on evidence collected at the site and visual inspection of the remains. If insufficient evidence existed, mortalities were classified as unknown.

We used the Kaplan–Meier product limit estimator (Kaplan and Meier 1958, White and Garrott 1990) to estimate survival probabilities ($S_{(t)}$) for each biological year. We used logistic regression to determine if sex, age class, or capture location predicted adult survival where the binary response variable was alive or dead (White and Garrott 1990).

All location data collected from GPS platforms were analyzed using ArcMap 10 (ESRI, Inc.) Home ranges were estimated for each distinct ram and ewe group using the 95% Kernel Density Estimator (KDE) and the Minimum Convex Polygon (MCP) estimators. Vegetative cover was also summarized for each ram group home range area.

RESULTS

Twenty-three rams were collared with 15 ARGOS-enabled GPS collars and eight VHF collars. GPS collars were programmed to attempt a location every seven hours for a period of 25 months. Twenty-nine ewes were fitted with VHF transmitters. All collars were set with an eight hour mortality sensor switch. Average age at capture for rams was 5 years and average age of captured ewes was 3.5. Based on comparison of blood chemistry, parasitology, and bacteriology with historic and normal values, there was no indication of herd health issues (Table 1).

Seventeen mortalities occurred between 2007 and 2011 (Fig. 2). Predation was the leading cause (7 individuals, 42% of mortalities) of identified mortality, followed by hunter harvest (4, 24%) and one collision with a train. Exact cause of death could not be determined for 5 (29%) animals. Of the predation-related mortalities, 4 were documented as mountain lion, 2 were likely mountain lion, and one was unknown predation. Six of the 7 predation mortalities were rams.

Home range estimates were derived for the 4 distinct ram groups. Of the 15 GPS collars deployed on rams, 14 provided sufficient data for home range calculation. Acquisition success on collars averaged 57% and approximately 11,000 viable data points were used for home range

Table 1. Blood chemistry of captured bighorns from Deschutes River, OR. December 2005 through December 2009.

Parameter	n	Mean	Median	Range
Selinium, serum	55	107.36	84	30-349 (ng/ml)
Sodium	43	155.21	154	149-171 (MQ/L)
Potassium	43	5.15	5.2	3.9-6.4 (MEQ/L)
Chloride	43	95.56	95	87-103 (MEQ/L)
Glucose	43	156.95	160	66-223 (MG/DL)
BUN	43	19.53	19	16-29(MG/DL)
Creatinine	43	1.65	1.7	1.3-2.1(MG/DL)
T. Protein	43	7.35	7.3	5.9-8.6(G/DL)
Albumin	43	4.16	4.2	3.1-4.9(G/DL)
T. Bilirubin	43	0.14	0.1	.1-.3 (MG/DL)
GGT	43	59.91	56	22-172(U/L)
AST	41	211.54	189	130-370(U/L)
Calcium	36	10.25	10.4	7.3-11.6(MG/DL)
I. Phos	43	7.43	7.3	5.1-10.7(MG/DL)
CK	42	1142.05	924.5	259-3862(U/L)
tCO2	43	5.19	4.8	1.5-14.1(MEQ/L)
SDH	35	31.55	27.8	10-74.1(IU/L)
Anion Gap	42	59.21	58.5	42-78
Magnesium	37	2.92	3.04	.33-3.54(MG/DL)

(42 ewes, 9 rams) were captured and removed for transplant and 47 rams were legally harvested.

Annual survival of ewes remained high throughout the study, never dropping below 95% (Table 3). Conversely, annual survival of rams dropped to 57% and 62% during the last two years of the study. As a result, survival differed between sex only for the last two years. Capture site was not a useful predictor of survival but comparisons may be limited by capture site sample size.

An initial assessment of habitat was conducted utilizing the existing vegetation cover layer through LANDFIRE (LANDFIRE 2006). This data provided an overlook of existing vegetation cover based on the percentage of cover of the live vegetative canopy for the dominant vegetation type (Table 4). For the study area, approximately 80% of the landscape fell into three main categories; herbaceous cover of between 50% and 60% canopy cover; herbaceous between 20% and 30%; and shrub cover between 10% and 20%.

calculation. Home ranges were calculated using data from 3 GPS collared animals each in the Harris, Lockit, and Mack's Canyon ram groups, and 5 GPS collared animals in the Jones Canyon group. These were established using data from points derived from individuals within each herd range. Data for all individuals within a ram group were combined to estimate MCP and KDE.

Herd home range for the four ram groups averaged 43.8 km^2 when estimated using MCP (Table 2). Each home range was evaluated for areas of concentrated use via the KDE. We found that overall home range size was reduced by an average of 70% if analyzed with a 93% probability distribution. Mean for core area was 13.2 km^2.

Overall the bighorn population within the Deschutes River increased approximately 25% during the study period, with annual growth rates varying from 8% to 14%. The ratio of rams:100 ewes was high (88:100–125:100; $\bar{x} = 104$). The ratio of lambs:100 ewes varied from 36:100–48:100 ($\bar{x} = 42$). Over the same period, 51 sheep
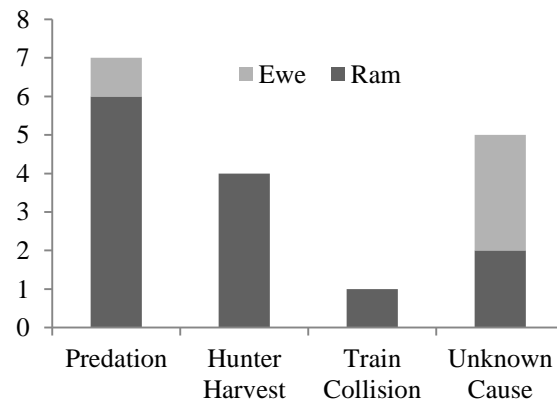

Fig. 2. Number of bighorn mortalities by type for each gender.

Table 2. Home range area (km²) for ram groups in the Deschutes River bighorn population, Oregon.

Ram Group	95% KDE	MCP
Harris	10.42	31.60
Jones	18.15	53.88
Lockit	10.25	46.80
Mack's	14.15	43.01
Average	13.20	43.80

Table 3. Annual survival of California bighorn sheep in the Deschutes River Canyon, Oregon, 2007 – 2011.

Period	Rams			Ewes		
	Lower 95%	$S_{(t)}$	Upper 95%	Lower 95%	$S_{(t)}$	Upper 95%
Dec '07 – June '08	0.76	0.92	1.0	0.87	0.95	1.00
July '08 – June '09	0.74	0.91	1.0	0.90	0.96	1.00
July '09 – June '10	0.36	0.57	0.78	0.89	0.96	1.00
July '10 – June '11	0.36	0.62	0.88	1.00	1.00	1.00
Dec '07 – June '11	0.21	0.42	0.62	0.67	0.82	0.96

Assessment of use based on calculated home ranges for the 4 ram groups show a similar pattern, suggesting that animals are using available habitat at a similar rate as is available within the landscape.

DISCUSSION

High survival and recruitment characterized the Deschutes herd for the study period.

When compared to past mortality projects within the state, predation appeared not to be playing a major role in the overall demographics or health of the Deschutes sheep population.

While we recognize that this particular study period did not show evidence of any potential disease or predation issues within the herd, continued monitoring and surveys will still be maintained to capture any potential events in the future.

Marked rams within the study area showed strong affinity for their established home ranges. No rams were noted within the summer range of another ram group, and very little overlap of noted locations was found during the rut period. None of the marked sheep in the study were found to cross the river itself, and all data suggest that there is a strong affinity of both rams and ewes to their established home ranges.

With the home ranges estimated by the GPS platforms, one probable benefit of current habitat usage is the lack of movement by males outside of the canyon corridor. Although there are few domestic sheep adjacent to the Deschutes corridor,

Table 4. Top three vegetation cover types by ram home range.

Herd Range	Vegetation Type	% Cover
Entire Study Area	Herbaceous 50>60	36.78
	Shrub 10>20	31.61
	Herbaceous 20>30	10.85
Harris Herd Range	Herbaceous 50>60	73.81
	Shrub 10>20	11.86
	Herbaceous 20>30	10.35
Jones Herd Range	Shrub 10>20	43.00
	Herbaceous 50>60	23.75
	Herbaceous 20>30	13.90
Lockit Herd Range	Shrub 10>20	67.60
	Herbaceous 30>40	18.62
	Herbaceous 20>30	4.34
Mack's Herd Range	Herbaceous 50>60	58.49
	Shrub 10>20	18.03
	Herbaceous 20>30	12.61

there is always potential for long-distance movements by juvenile males. There were no documented collar movements outside of the known occupied sheep habitat during the study period, and there have only been two documented sheep movements outside the corridor since the initial release. This low documented emigration rate will likely reduce the potential for introduction of pathogens from sheep within the herd.

The initial assessment of habitat use was done at a coarse scale, and a more refined summary will be looked at in the future utilizing the most recent data available.

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BRITISH COLUMBIA PROVINCIAL WILD SHEEP REGISTRY TOOL

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Abstract: There is a keen interest in wild sheep from various Government and non-Government groups in British Columbia and abroad, and the information that has been collected about these species is diverse. There is a lot of valuable information about wild sheep in British Columbia, but the data need to be compiled, organized, managed and made accessible for use. This project was established in order to build a tool that is centrally-located (single-source), as complete as possible, well-integrated to include multiple information sources, useful and accessible to various users, and maintained to ensure that the information remains current.

Numerous regional biologists, guide outfitters, and other sheep biologists have contributed to developing the registry over the years. This current project will also bring about the completion and update of the following previous HCTF-funded projects:

- Rocky Mountain Bighorn Sheep (*Ovis canadensis canadensis*) critical range mapping and herd registry (2002-03)
- California Bighorn Sheep (*Ovis canadensis californiana*) critical range mapping and herd registry (2002-03)
- Skeena-Omineca Thinhorn Sheep (*Ovis dalli*) range mapping and herd registry (2004-05)
- Peace Thinhorn Sheep range mapping and herd registry (2005-06)

The objectives of this project were to: determine users' requirements for this information; make the previously collected wild sheep information available through the BC Geographic Warehouse (BCGW, formerly the Land Resource Data Warehouse (LRDW)); identify information gaps; and determine reporting requirements. The intended outcomes were: 1) to compile information from various data sources into a single central location that can be used for comprehensive decision-making; 2) to provide up-to-date, relevant and consistent information about wild sheep that is readily available to various users; and 3) to foster shared stewardship of BC's wild sheep.

The poster illustrated the original herd/population boundaries established for both bighorn and thinhorn sheep, with examples of the information collected about each herd/population.

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PSOROPTIC MANGE: AN EMERGING DISEASE OF BIGHORN SHEEP IN BRITISH COLUMBIA

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Abstract: Psoroptic mange is a highly contagious disease of domestic and wild sheep and is caused by the non-burrowing ectoparasitic mite *Psoroptes ovis*. Clinical signs are variable and range from droopy and thinly haired ears to a more generalized skin disease that is characterized by intense itchyness with secondary lesions such as extensive hair loss and ulceration and crusting of the skin. In the past, outbreaks of psoroptic mange have been associated with significant declines in bighorn sheep (*Ovis canadensis*) populations.

In February 2011 a ram was diagnosed with psoroptic mange in Ollala, British Columbia. Subsequently, aerial surveillance of the Ashnola / Similkameen bighorn population revealed that the mite was widespread in the Similkameen valley, affecting approximately 17% of bighorn sheep observed. Enhanced surveillance is needed to gain a better understanding of the prevalence and geographical distribution of *P. ovis* in bighorn sheep in BC, and to evaluate the risk of transmission to neighbouring populations and domestic sheep.

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DEVELOPMENT OF HELI-SKI AVOIDANCE STRATEGIES FOR MOUNTAIN GOAT WINTER RANGE

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Abstract: Wildlife Guidelines for Backcountry Tourism/Commercial Recreation in British Columbia have been in place since 2002 with a revised version released in 2006. Heli-ski operators must have management plans in place which, in part, incorporate wildlife avoidance strategies as guided by the Provincial Wildlife Guideline document.

Illustrating the process of wildlife avoidance strategy development, specific to Skeena Region mountain goats (*Oreamnos americanus*) and the heli-ski industry, serves as a template for others to follow. The poster display was focused on a visual presentation of goat habitat modeling via a resource selection probability function (RSPF), confirmation of occupancy, spatial overlap with flight paths and ski runs, and a final product with accompanying avoidance strategies (flight path alteration, terrain masking, dropping of runs, altering drop-off and pick-up locations).

***Key words*:** mountain goat, *Oreamnos americanus*, heli-ski, disturbance, habitat model, resource selection probability function.

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NANNIES IN THE CROSSHAIRS: EFFECTIVENESS OF USING A SEX IDENTIFICATION QUIZ TO REDUCE HARVEST OF FEMALE MOUNTAIN GOATS IN ALASKA

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Abstract: Mountain goats *(Oreamnos americanus)* have relatively low survival and reproductive rates relative to other northern ungulates. Consequently, human harvest of mountain goat populations must be carefully managed to avoid overharvest and population declines. Unfortunately, correctly differentiating between male and female mountain goats in the field is difficult. As a result, either-sex harvest is reluctantly allowed throughout most of Alaska. Fortunately, a point system (males = 1, females = 2) can be used to set harvest quotas to reduce the likelihood of overharvest. Nonetheless, reducing female harvest is desirable to increase population resilience and provide greater hunting opportunity. In an effort to reduce female mountain goat harvest we initiated an educational program intended to increase the ability of hunters to correctly identify male and female mountain goats in the field. Specifically, we developed a mountain goat identification quiz (available in both a hard copy and interactive web-based format) that was designed to highlight the subtle morphological and behavioral characteristics associated with correctly identifying male and female mountain goats. In addition, we conducted follow-up phone interviews with successful hunters in order to evaluate whether the mountain goat identification quiz influenced the likelihood of hunters harvesting male vs. female mountain goats. We also examined other factors associated with harvest of male and female mountain goats such as hunter experience, shot distance, field conditions, and hunter intent. The results of this study provided key information needed to evaluate the effectiveness of hunter education materials to meet management goals, and insights into behavior and challenges mountain goat hunters face in the field.

Key words: mountain goat, *Oreamnos americanus*, harvest, hunter education.

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