Summary of Health and Trace Mineral Testing of Bighorn Sheep at the Luscar and Gregg River Mine Sites of West-Central Alberta

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Abstract: An important part of reducing disease related risks associated with translocation of wildlife is to understand the disease history of the source population. Bighorn sheep (*Ovis canadensis*) from the Luscar and Gregg River mines located in west-central Alberta have been translocated to several locations in the western U.S. and Alberta since 1984. I obtained test results for 282 bighorn sheep captured on the mine sites for health and trace element testing prior to translocation or for release on site. Contagious ecthyma is endemic in bighorns at both mine sites, but general body condition is good and no severe cases have been recorded. Bluetongue virus, parainfluenza-3 virus, infectious bovine rhinotracheitis, bovine viral diarrhea, and vesicular stomatitis were not detected during this study. Low antibody prevalence against bovine respiratory syncytial virus (0.026) was detected in 1990, but not in 1995. Low antibody prevalence for ovine progressive pneumonia was detected in 1999/2000, but not in 1990 or 1995. Anaplasmosis, Johne's disease, Leptospirosis, and *Brucella ovis* were not present. A number of strains of *Mannheimia (=Pasteurella) haemolytica* and *Pasteurella trehalosi* were isolated from the upper respiratory tract of bighorn sheep at the Luscar Mine. At least 28 biovariants were identified, 13 of which were unique. *Pasteurella multocida* was not cultured from this population. Test results for exposure to *Toxoplasma gondii* were negative for 16 bighorn sheep captured in 1990. *Psoroptes* spp. mites were not detected on any sheep and ticks (*Dermacentor andersoni*) were uncommon. This summary presents a general health profile of a high quality bighorn sheep population that has had little, if any, contact with domestic livestock.

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Key words: Alberta, bighorn sheep, Gregg River Mine, health testing, Luscar Mine, *Ovis canadensis*, trace elements, translocation

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The decline and extirpation of bighorn sheep *(Ovis canadensis)* populations throughout much of the western United States in the 1800s (Buechner 1960) resulted in extensive efforts by wildlife managers to rehabilitate and restore locally extirpated or diminished populations (Krausman 2000). Recovery plans for bighorn sheep populations in the U.S. and Canada often use translocation as a tool to fill unoccupied habitats and to augment existing herds. However, disease-related mortality was likely a large part of the problem, and disease, primarily pneumonia, continues to play a major role in depressing the growth of bighorn sheep populations and contributing to local extirpations (Singer et al. 2000, Cassirer and Sinclair 2007). Understanding the disease history of the source population can reduce disease-related risks associated with translocating bighorn sheep by minimizing the possibility of exposing animals to novel pathogens. Testing

source populations for presence of, or exposure to, pathogens before translocation to a new area was recommended by Jessup et al. (1995), IUCN (1998), Dubay et al. (2002), and Foster (2005). Protocols for disease testing of herds of origin and release, and for moving bighorn sheep from Canada to the U.S., were developed by the Western Wildlife Health Committee (2001*a*; *b*).

Bighorn sheep voluntarily colonized reclaimed lands associated with two open pit coal mines located in west-central Alberta, Canada in an area known as the Coalbranch. The two mines: Elk Valley Coal Corporation, Cardinal River Operations, Luscar Mine (Luscar Mine) and Coal Valley Resources Inc., Gregg River Mine (Gregg River Mine) are situated at the base of the Front Ranges of the Rocky Mountains and support a high quality population of bighorn sheep. These sheep are characterized by large body size (MacCallum 1991), high lamb:ewe ratios, high density and numbers, and strong population growth (Fig. 1). In 2006 the autumn lamb:ewe ratio was 69 lamb:100 ewe. The maximum count in late autumn 2006 was 1,065 sheep, and the annual rate of gain on the two mines between 1986 and 2006 was 7.3% during which time ewes were removed at an average annual rate of 7.4% (Bighorn Wildlife Technologies 2007*a; b*). No pneumonia outbreak has been recorded in the mountain ranges containing the mines since bighorn sheep were first studied in the area (Stelfox 1964*a; b*, 1966, Lynch 1971; 1972, Smith and Lynch 1974, Kosinski 1976, Smith et al. 1977, MacCallum 1991; 1997, MacCallum and Kielpinski 1991), nor during annual surveys conducted on the two mines since 1985 (Bighorn Wildlife Technologies 2007*a; b*).

Introduction of diseases from domestic sheep has been implicated as a cause of pneumonia in bighorn sheep but it is unlikely that bighorn sheep on the Luscar and Gregg River mines have come into contact with domestic sheep, goats, or pigs. The nearby mining hamlet of Cadomin supported a dairy from 1912 to 1952; likewise, there was a dairy in the former mining towns of Luscar and Mountain Park (Hughes 1995, CIM 1998, Chiesa and Smilanich 1999). The dairy at Luscar was located near the present day plant for the Luscar Mine. Feed and stock were brought in by train as an all weather road joining the Coalbranch communities to the outside world was not completed until 1951. Horses and mules were used in the underground coal mines in the Coalbranch, but there were no domestic sheep or goats. Pigs may have been kept for a short time prior to slaughter (Ross 1976). The hamlet of Cadomin is the nearest habitation and is subject to Yellowhead County Bylaw No. 03.06 (3)a. The bylaw states: "*No fur-bearing animals, fowl or livestock other than domestic animals* [male or female dog or cat] *shall be permitted within a hamlet*".

The Luscar and Gregg River mines are separated from arable land to the east by a minimum of 80 km of boreal forest that is unsuitable for bighorn sheep. Jasper National Park and the Rocky Mountains lie west of the mines. The dominant land use north and south of the mines is timber harvesting, resource extraction, recreation, and wilderness-based tourism. Horses and some llamas are used for bighorn sheep hunting in the area. Because of the size and health of the bighorn sheep population

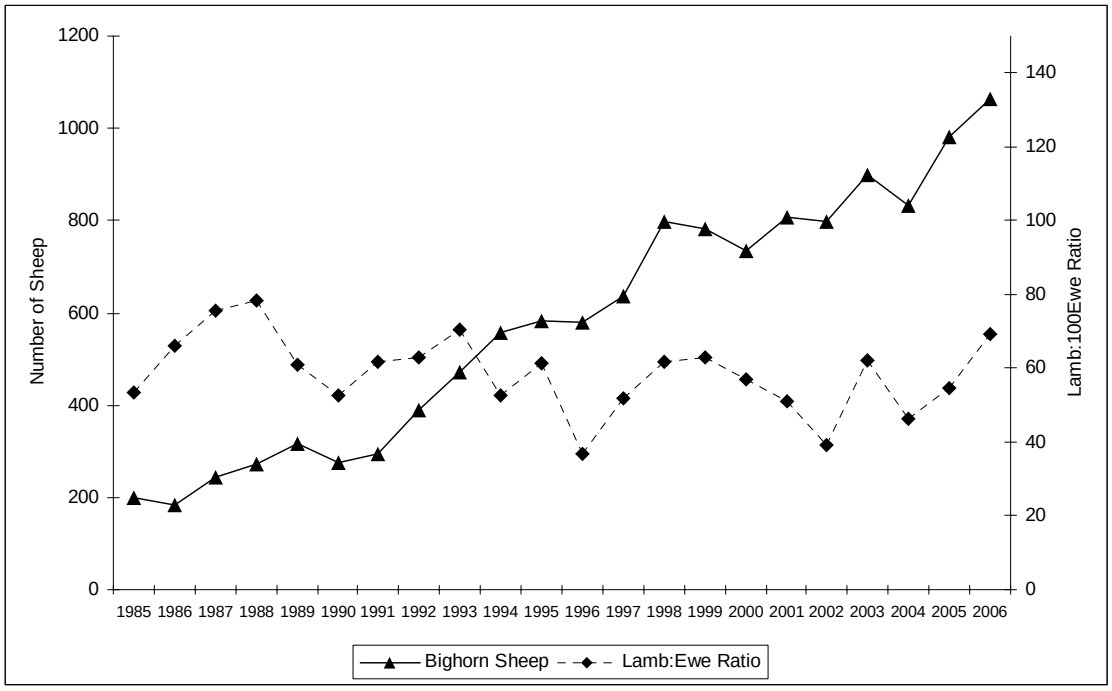

Figure 1. Maximum count of multiple fall surveys, and lamb:100 ewe ratio of bighorn sheep on Luscar and Gregg River mines, Alberta, 1985 to 2006.

on the mines, and ease of capture, these animals are used frequently for translocations to the U.S. and Alberta. The health and trace element profile presented in this paper indicates a high quality bighorn sheep population with no history of pneumonia outbreaks, and little, if any, exposure to domestic livestock.

Study area

The Luscar and Gregg River mines are located on the east side of the Canadian Rockies about 50 km south of Hinton, Alberta. The two mines lie adjacent to each other and are separated by the Gregg River. The mines occur in subalpine habitat immediately below alpine habitat and are characterized by a Cordilleran Climatic Regime and Rocky Mountain vegetation comprised of lodgepole pine (*Pinus contorta*), Engelmann spruce (*Picea engelmanni*), and subalpine fir (*Abies lasiocarpa*) forests, primary succession shrub communities (*Salix* spp.-*Betula glandulosa*), and scattered grasslands (Strong 1992). Summers are cool (July daily mean temperature <13° C) and showery, with a short 165 to 170 d growing season (Chetner et al. 2003). The frost-free period is 85 to 95 consecutive days. Most precipitation falls in summer (>325 mm between May 1 to August 31). Winters are snowy (250 to 275 mm precipitation between September 1 and April 30) and cold (January daily mean temperature -12 to -10°C) and characterized by frequent chinooks (warm dry winds that descend on the eastern side of the Rocky Mountains) that periodically reduce snow cover.

Much of the mined areas are reclaimed specifically as bighorn sheep habitat by provision of high quality herbaceous food in close proximity to escape terrain. Other features important to bighorn sheep, such as readily available mineral licks exposed by the mining process, also are present (MacCallum and

Geist 1992). Reclamation is on-going on both mines. Bighorn sheep that occupy the mines are part of a large metapopulation inhabiting the Front Ranges of the Rocky Mountains. Conventional radio-telemetry with 19 bighorn sheep from the mines indicated that these sheep are part of 2 local populations that interact with 5 nearby populations (MacCallum 1997). The 7 local populations straddle approximately 210 km of the Jasper National Park eastern boundary. Bighorn sheep from the Front Ranges responded to the mine reclamation by occupying the new habitats, expanding their range, and exhibiting a rapid population growth. Similar responses by bighorn sheep were documented for logging and burning in Utah (Smith et al. 1999). The entire metapopulation has not been surveyed in one year; however, a composite of surveys during different years indicates a minimum winter count of 1,542 bighorn sheep in the metapopulation. Components are: 211 sheep in the Fiddle-Whitehorse-Drummond-Rocky River units (excluding provincial lands) of Jasper National Park (Bradford 1987); approximately 30 sheep in Wildlife Management Unit (WMU) 436, 150 sheep in WMU 437, and 327 sheep in WMU 438, all on provincial lands excluding the 2 mines (Hobson and Ficht 2002); and 824 sheep on the mines in winter 2006 (Bighorn 2007*a; b*). Note the number of sheep in WMU 438 increased from 235 in 1963 (Stelfox 1964a). This metapopulation is now one of the largest in North America (Toweill and Geist 1999).

Methods

I obtained disease and trace element test results from states and agencies that translocated bighorn sheep from the Luscar Mine to various locations in the U.S. and Alberta between 1990 and 2001. Results also were assembled from various captures conducted for research projects on the Luscar and Gregg River mines since 1985. Various laboratories were used (Appendix A). Field testing protocols varied from year to year depending on the jurisdiction involved. Analysis and interpretation of laboratory tests in veterinarian reports and published literature were quoted in the absence of laboratory reports and referred to especially for interpretation of sero-positive or false-positive results.

Viruses. Clinical signs as well as biopsies of the mucosal epithelium from the vulvar region were used to confirm contagious ecthyma (CE, orf). Agar gel immuno-diffusion (AGID) and complement fixation (CF) (Veterinary Diagnostic Laboratory, Oregon State University 1995) were used to detect exposure to bluetongue virus (BTV). Parainfluenza-3 virus (PI-3) was tested for using virus neutralization (VN) (Nevada Department of Agriculture, Animal Disease Laboratories 1990) and haemagglutination inhibition (HI) (Veterinary Diagnostic Laboratory, Oregon State University 1995). Testing was conducted on blood serum to determine exposure to bovine respiratory syncytial virus (BRSV), infectious bovine rhinotracheitis (IBR), bovine viral diarrhea (BVD), and vesicular stomatitis (VS) using virus neutralization. Agar gel immunodiffusion was used to test for ovine progressive peumonia (OPP)

Bacteria. Agglutination (AGG) (Nevada Department of Agriculture, Animal Disease Laboratories 1990) and CF were used to test for *Anaplasma marginale* (Anaplasmosis). *Mycoplasma avium para-tuberculosis* (Johne's disease) was tested for using CF (Veterinary Diagnostic

Laboratory, Oregon State University 1995) and enzyme linked immunosorbent assay (ELISA) (Allied Monitor 1995). Serum was used to test for *Leptospira pomona, L. grippotyphosa, L. hardio, L. icterohaemorrhagiae,* and *L. canicola* using microscopic agglutination titer (MAT). *Brucella ovis (*brucellosis) was tested for using blood agar plate (BAPA) (Nevada Department of Agriculture, Animal Disease Laboratories 1990), Brucellosis card test (Animal Disease Research and Diagnostic Laboratory, South Dakota State University 1999) and the ELISA test. Pharyngeal swabs were taken and bacterial cultures were used to test for *Mannheimia (= Pasteurella) haemolytica, Pasteurella trehalosi* (serotype 3 and biotype 2) and *Pasteurella multocida*. *Hemophilus somnus (=Histophilus somni)* was tested for using AGG. Microtiter agglutination (MTA) was used to diagnose *Campylobacter* spp. Bacterial cultures also were used to assess infections of the horn cores.

Parasites. AGG was used to determine exposure to *Toxoplasma gondii*. Gastrointestinal parasites were detected by faecal flotation and lungworms (*Protostrongylus* spp.) were detected using the Baermann technique. ELISA was used to determine if sheep had been exposed to *Psoroptes ovis* (scabies).

Trace Minerals. I also include data on trace mineral levels in whole blood, serum, hair from routine samples, and liver tissue analyzed at necropsy of dead sheep. Trace mineral concentrations for total copper, zinc, sodium, potassium, phosphorus, calcium, magnesium, and iron in serum and plasma were obtained by mixing with a protein-precipitating agent prior to analysis by inductively coupled plasma elemental analysis spectrometers (ICP-AES) (Anderson et al. 2001). Total selenium in animal tissues including blood and serum was obtained by digesting samples in concentrated nitric acid. Selenium concentration is then determined by inductively coupled plasma mass spectrometry (ICP-MS) (Ricks et al. 2005).

Results

Since 1985, 327 bighorn sheep have been captured on the mine sites. I was able to obtain results for 282 of these sheep (Table 1). Results of virus and bacteria tests as well as tests for gastrointestinal parasites and lungworms for the Luscar Mine sheep are presented in Tables 2 and 3, respectively.

On the Luscar and Gregg River mines, CE is most often observed in lambs in spring as scabs on their mouth, which eventually heal after 2 to 3 wk. During the 1999 capture, 51 sheep were sampled and two (1 female yearling and 1 female 4.5 yr) were identified with symptoms of contagious ecthyma and released on site (Cassirer 1999).

During the February 1999 and 2000 captures of bighorn sheep at the Luscar Mine, ulcerative lesions were identified on the edges of the vulva in a number of adult ewes (MacLeod, unpublished). In January and March 2001, 2 biopsy samples from ewes with similar lesions were sent to the Veterinary Pathology Laboratory of Alberta Agriculture in Edmonton and the Canadian Cooperative Wildlife Health Centre in Saskatoon. Both labs reported that the lesions were suggestive of contagious ecthyma. However, results were not conclusive and the origin remains unknown (Bollinger 2001, MacLeod 2001).

A number of strains of *Pasteurella haemolytica* and *Pasteurella trehalosi*

(serotype 3 and biotype 2) were isolated from the upper respiratory tract of bighorn sheep at the Luscar Mine. At least 28 biovariants were identified (Cassirer 2005). *Pasteurella multocida* was not

Table 1. Bighorn sheep captured for translocation and/or testing at Luscar Mine, Alberta, 1985 to 2007.

Year	Capture Date	Destination	Available Test Results	Total Translocated
1985	May	game farms, AB	0	18
1986	March 13, 14	game farms, AB	0	6
1986	Apr 9, May 6	Edmonton Valley Zoo, AB	0	2
1986	May 6, 20	AB Fish and Wildlife	0	3
1989	Feb 27	Nevada	0	20
1990	Jan 22	Nevada	25	25
1992	Feb 20	Nevada	31	31
1995	Feb 7	Oregon	49	49
1998	Feb 11	Plateau Mtn., AB	18	31
1999	Feb 9, 10	Hells Canyon, U.S.	20	20
1999	Feb 9, 10	South Dakota	20	20
1999	Feb 9, 10	Luscar Mine, AB	11	0
2000	Feb 8	Hells Canyon, U.S.	37	37
2000	Feb 8	Luscar Mine, AB	1	0
2000	Feb 9	Mount Baldy, AB	0	7
2001	Jan 31	Utah	32	32
2001	Jan 31	Luscar Mine, AB	9	0
2001	March 26	Luscar Mine, AB	10	0
2003	Apr 29	Gregg River Mine, AB	1	0
2004	Nov 24	Ram Mountain, AB	0	6
2005	Mar 16	Ram Mountain,, AB	0	6
2007	Mar 23	Ram Mountain, AB	12	12
2007	Mar 23	Calgary Zoo, AB	2	2
Total			282	327

Table 2. Virus and bacteria testing of bighorn sheep from the Luscar Mine, Alberta, 1990 to 2001. N = negative; P = positive.

	Date	Purpose/Destination	n	Laboratory	Outcome
VIRUSES: Contagious ecthyma (CE)	occasional	Annual surveys	few		Individuals - See text
	1999-2001	Translocation	few		Released on site - See text
Bluetongue (BTV) and epizootic	1990	Nevada	16	WADDL	N [a]
haemorrhagic disease (EHDV)	1992	Nevada	6	WADDL	N [b]
	1995	Oregon	49	OSU VDL	N
	1999-2000	Idaho/South Dakota	89	BAHL	N [c]
Parainfluenza-3 (PI-3)	1990	Nevada	16	WADDL	N [a]
	1995	Oregon	49	OSU VDL	N
	1999-2000	Idaho/South Dakota	89	BAHL	N [c]
Bovine respiratory syncytial virus	1990	Nevada	16	WADDL	4 of 16 positive [a]
(BRSV)	1995	Oregon	49	OSU VDL	N
	1999-2000	Idaho/South Dakota	89	BAHL	N [c]
Infectious bovine rhinotracheitis (IBR)	1990	Nevada	16	WADDL	N [a]
	1995	Oregon	49	OSU VDL	N
	1999-2000	Idaho/South Dakota	89	BAHL	N [c]
Bovine viral diarrhea (BVD)	1990	Nevada	16	WADDL	N [a]
	1995	Oregon	49	OSU VDL	N
	1999-2000	Idaho/South Dakota	89	BAHL	N [c]
Vesicular stomatitis (VS)	1990	Nevada	16	WADDL	N [a]
BACTERIA: Anaplasmosis (ANA)	1990	Nevada	16	WADDL	N [a]
	1995	Oregon	49	OSU VDL	N
	1999-2000	Idaho/South Dakota	89	BAHL	N [c]
Johne's Disease (= Paratuberculosis)	1995	Oregon	39	OSU VDL	N
Leptospirosis	1990	Nevada	16	WADDL	N[a]
	1995	Oregon	49	OSU VDL	N

Brucellosis (*Brucella ovis*)	1990	Nevada	16	NADL	N[a]
	1992	Nevada	6	NADL	N[b]
	1995	Oregon	49	OSU VDL	N
	1999-2000	Idaho/South Dakota	89	BAHL	1 sero false-positive, 1 false-suspect (ELISA). Both N on ELISA retest and card test (Cassier 1999). [c]
	2001	Utah	32	BAHL	N
Pasteurella spp. and *Mannheimia* spp.	1998	Plateau Mtn.	18	VPL	*P. haemolytica* 1 of 18 *P. haemolytica* (not type T) 3 of 18
	1999-2000	Idaho/South Dakota	88	DPUG	*P. trehalosi*, *Mannheimia* spp.
	2001	Research	10	AAFRDL	*P. haemolytica* 6 of 10 *Pasteurella* spp. 6 of 10 *P. trehalosi* 3 of 10
Ovine progressive pneumonia (OPP)	1990	Nevada	16	WADDL	N[a]
	1995	Oregon	49	OSU VDL	N
	1999-2000	Idaho/South Dakota	89	BAHL	0.01 (prevalence) [c]
Hemophilus sp.	1990	Nevada	16	WADDL	present in 13 of 16
Hemophilus somnus	1995	Oregon	49	OSU VDL	present in 46 of 49
Campylobacter sp. (Vibrio)	1990	Nevada	16	WADDL	16 of 16
PROTOZOA: Toxoplasmosis	1990	Nevada	16	WADDL	N

[a] Tronstad (1990), [b] Tronstad (1992), [c] Cassirer (2005)

Table 3. Prevalence (% infected) and intensity (mean number larvae, eggs, or oocysts per g faeces) of gastrointestinal parasites and lungworms in bighorn sheep from Luscar Mine, Alberta.

Parasite	Date	Purpose	N	Laboratory	Prevalence (Intensity)
Coccidia (*Eimeria* spp.)	1990	Nevada	16	Tronstad 1990	Present
	1999-2000	Idaho/SD	71	WADDL	97 (410)
	March 26, 2001	Research	10	CCWHC 2001	100 (358)
	March 23, 2007	Research	14	FVMUC	100 (937)
Strongyles	1999-2000	Idaho/SD	71	Cassirer 2005	0
Trichostrongyles	March 26, 2001	Research	10	CCWHC 2001	90 (1.5)
Species 1	March 23, 2007	Research	6	FVMUC	100 (77)
Species 2	March 23, 2007	Research	14	FVMUC	93 (15)
Nematodirus spp.	1990	Nevada	16	Tronstad 1990	Present
	1999-2000	Idaho/SD	71	Cassirer 2005	59 (7)
	March 26, 2001	Research	10	CCWHC 2001	60 (6.7)
	March 23, 2007	Research	14	FVMUC	79 (30)
Moniezia sp.	1990	Nevada	16	Tronstad 1990	Present
	1999	Idaho/SD	37	WADDL 1999	3 (28)
	March 23, 2007	Research	14	FVMUC	43 (86)
Marshallagia sp.	March 26, 2001	Research	10	CCWHC 2001	100 (17)
	March 23, 2007	Research	14	FVMUC	100 (71)
Trichuris spp.	1999-2000	Idaho/SD	71	Cassirer 2005	45 (5)
	March 26, 2001	Research	10	CCWHC 2001	50 (12)
	March 23, 2007	Research	14	FVMUC	93 (108)
Tapeworm	Oct 10, 1992	hunter kill	1	Pybus 1997	Present
	March 26, 2001	Research	10	CCWHC 2001	20 (124)
Protostrongylus spp.	Oct 85-Sep 86	Research	329	MacCallum 1991	96 (792)
	March 1987	Research	28	Unpublished	100 (828)
	April 1987	Research	27	Unpublished	100 (1419)
	May 1987	Research	29	Unpublished	100 (217)
	April 1989	Research	25	Unpublished	100 (128)
	October 1989	Research	31	Unpublished	100 (621)
	January 1990	Nevada	16	Tronstad 1990	Present
	April 1990	Research	27	Unpublished	96 (185)
	October 1990	Research	34	Unpublished	97 (130)
	Apr 91-Mar92	Research	311	Unpublished	95 (394)
	Feb 1999, 2000	Idaho/SD	83	Cassirer 2005	83 (47)
	March 26, 2001	Research	10	CCWHC 2001	100 (135)
	March 23, 2007	Research	14	FVMUC	100 (138)
Scabies *(Psoroptes* sp.)	1995	Oregon	49	UCD	1sero false-positive

1999-2000	Idaho/SD	89	WADDL	Negative

cultured from this population (Table 2).

Since 1998, several skulls of mature bighorn sheep rams from the vicinity of the Luscar and Gregg River mines have been returned or reported to the Alberta Fish and Wildlife Diagnostic Lab in Edmonton indicating horn core deterioration that was identified when the sheaths were removed during the taxidermy process. These skulls have weakened and degenerated bone cores (bone material covered by the keratin horn sheath). The bone changes appear to be associated with a long-term bacterial infection in some skulls. Bacteria from two fresh heads with affected horn cores was identified as nonspecific secondary bacterial invaders (*Staphylococcus* spp. and *Corynebacterium* spp.). Neither skull had any evidence of a primary bacterial pathogen associated with potential bone core erosion (Pybus 2006).

Gastrointestinal parasite eggs, oocysts, or larvae detected in faeces of sheep from the Luscar Mine included *Eimeria* spp. [protozoan]; trichostrongyles, thread-necked strongyles (*Nematodirus* spp.), abomasal worm (*Marshallagia* sp.), and whipworm (*Trichuris* spp.) [nematodes]; and a tapeworm *(Moniezia* sp.) [cestode].

Cassirer (2005) detected no strongyles (other than *Nematodirus* spp.) in 83 samples in 1999 and 2000; however, trichostrongyles were detected in 10 sheep (90% prevalence) sampled March 26, 2001 (Table 3). Kutz (2007) reported the presence of *Marshallagia* sp., *Nemotodirus* sp., *Eimera* (at least 2 species), *Trichuris* sp., and 2 species of *Trichostrongylus* in samples from 14 lambs captured March 23, 2007 on the Luscar and Gregg River mines. Trichostrongyles are very common in bighorn sheep (Uhazy and Holmes 1971, Samuel et al. 1977).

All or most sheep shed larvae of the lungworms *Protostrongylus stilesi* and/or *Protostrongylus rushi* (Table 3). Mean number of larvae was high (>1400 LPG faeces) during the rut in late autumn and during late winter in 1985/86. A two-sample t-test of log normalized data was used to compare LPG values between 1985/86 and 1991/92. There was no difference ($F = 1.05$, df = 315, $P = 0.3352$).

Psoroptes sp. (scabies) infection was not detected (Table 3). Blood serum from 49 sheep captured on the Luscar Mine in 1995 was negative for exposure to *Psoroptes ovis* with one exception. This sheep may have been a false-positive (Boyce 1995).

The Rocky Mountain wood tick (*Dermacentor andersoni*) is present but few have been observed on the bighorn sheep during winter capture events.

Trace minerals in liver and serum of bighorn sheep from the Luscar and Gregg River mines are summarized in Tables 4 and 5. Mean selenium (ppm ww) in whole blood (Table 5) included 2 data points identified as outliers (1.4 and 1.81 ppm ww). These samples were from female sheep 6 mo old. After removal of the outliers, a two-sample t-test indicated no differences in selenium values ($P = 0.15$) between lambs (n=22) and all other ages (n=107).

Table 4. Mineral concentrations (ppm ww) in liver of 3 bighorn sheep from Luscar and Gregg River mines, Alberta. Information from 2000 provided by F. Cassirer, Idaho Fish and Game.

	Female 2.8 yr Feb 2000	Female 4+ yr Feb 2000	Female 1 yr Apr 2003	Approximate adequate ranges [a]	Adequate mature sheep mineral levels
Laboratory	UIASL	UIASL	BCAHC	UIASL	BCAHC
Molybdenum	1.20	1.60	NS[b]	0.40-0.80[c]	NS
Zinc	62	47	44	25-50	30-75
Cadmium	0.24	0.32	< 0.2	< 0.20	< 0.50
Lead	BDL[b]	BDL	< 2	< 2.00	< 5.0
Manganese	2.10	2.60	2.3	2.00-5.00	2.0-4.5
Iron	221	138	220	40-100	30-250
Copper	5	6	35.9	25-100	25-100
Selenium	0.622	0.583	0.56	0.250-0.800	0.25-1.50
Calcium	NS	NS	71	NS	38-80
Magnesium	NS	NS	168	NS	118-220

[a] The indicated ranges are only guidelines and the analytical results need to be interpreted in conjunction with management and dietary factors, as well as clinical and/or postmortem observations
[b] NS = Not Sampled; BDL = Below Detection Limit
[c] Based on domestic sheep

Table 5. Mineral concentrations (ppm ww) in serum of bighorn sheep from Luscar Mine, Alberta, 1999 to 2001. Approximate adequate ranges are from UIASL.

	N[a]	Mean	SD	Min	Max	Range	Approximate adequate ranges[b]
Copper	126	0.53	0.23	0.07	2.20	2.13	1.17 - 2.56
Zinc	129	0.86	0.44	0.34	2.20	1.86	0.90 - 1.84
Calcium	129	96	10	63	114	51	80 – 100
Magnesium	129	24	2	16	32	16	20 – 33
Phosphorus	129	48	13	25	91	66	35 - 82
Iron	129	1.63	0.45	0.96	3	2.04	1.60 - 2.20
Selenium	50	0.182		0.04	1.40	1.36	0.040 - 0.130
Selenium [c]	131	0.613		0.3	1.81	1.51	0.040 - 0.130

[a] Does not include blanks, below detectable levels , or quantity not sampled.
[b] The indicated ranges are only guidelines and the analytical results need to be interpreted in conjunction with management and dietary factors, as well as clinical and/or postmortem observations
[c] Whole blood

Whole blood selenium levels differ among years (MacCallum 2006). Mean

values (ppm ww) were 0.648 in 1999 (n=52 sheep); 0.750 in 2000 (n=38); and 0.443 in 2001 (n=41). After removal of the two outliers (as above), one-way analysis of variance indicated differences between years (P = 0.0002).

Mean selenium concentration in 36 hair samples from 1999 (0.791 ppm ww, range 0.400 - 1.100) was within normal values (MacCallum 2006). For comparison, normal levels of selenium in wool of domestic sheep are 0.20 - 4.00 ppm dw (UIASL).

Discussion and summary

Dubay et al. (2002) compiled a comprehensive literature review and risk assessment of specific disease concerns for translocation of bighorn sheep. I summarized the status of specific diseases on the Luscar and Gregg River mines and threat to bighorn sheep (Appendix B) using the risk assessment from Dubay et al. (2002) and other literature as noted.

Viruses. Contagious ecthyma is enzootic in bighorn sheep of the Luscar and Gregg River mines, particularly lambs in spring. General body condition of sheep in this study was good (MacCallum 1991) and no severe outbreaks have been recorded, even though they have occurred in nearby Jasper National Park (Samuel et al. 1975), to the south at Ram Mountain (Jorgenson 1990), and elsewhere (Merwin and Brundige 2000). Ewes and lambs with symptoms of CE are released on site.

Foreyt et al. (1996) published health parameter data for bighorn sheep considered healthy on Hall Mountain, Washington. No viruses were isolated, although low antibody prevalence against PI-3 (12%), BVD (2%), and RSV (<1%) indicated exposure to these respiratory viruses. In 7 bighorn sheep populations in Montana, Aune (1998) detected serologic evidence for respiratory virus antibodies in all herds regardless of whether they had experienced an epizootic pneumonia outbreak. The most common respiratory viruses were PI-3 and BRSV. Sero-prevalence did not compare uniformly with virus isolation results in the Montana study (Aune et al. 1998). Cassirer (2005) reported antibodies to PI-3 in each [Hell's Canyon] population every year sampled except the Lostine population in 2002; prevalence ranged from 9 to100%. Titers to other viral pathogens occurred with low prevalence in resident sheep in the Canyon, including BTV (5 individuals in 5 populations), BRSV (2 individuals in 1 population), BVD (7 individuals in 3 populations), EHD (5 individuals in 4 populations), and OPP (3 individuals in 2 populations). No titers were detected to IBR (Cassirer 2005).

Bacteria. Prevalence of *Anaplasma* sp. was high in the bighorn sheep from Hall Mountain, Washington although its significance was unknown (Foreyt et al. 1996). Six percent of 82 of these sheep tested positive for *Brucella ovis* (titer >1:10), although it was not isolated from tissue, an indication that the reactions may have been false-positive. Antibodies to *Anaplasma* sp. were detected in 45 of 229 sheep in 5 of 6 [Hell's Canyon] populations (Cassirer 2005). No titers were detected to *Brucella ovis* in the Hell's Canyon bighorn sheep (Cassirer 2005).

The primary cause of bacterial infections of the bone core of older rams on the Luscar and Gregg River mines is unknown. Apparent infection of a 13-yr old captive ram (spring 2006) at the Thorne/Williams Wildlife Research Center in Sybille, Wyoming was reported (Schultz 2007): "*On the back side of his horn there was a crack less than 2 inches, about 4-5 inches on the base on the back side. It had*

some yellow/clear discharge and staining along the crack's edge." Potential factors include age, aggressive behaviour, trauma, and weakness of horn keratin. Older sheep often show signs of wear and tear - gray hairs about the face and muzzle, scarring of the face and body, longer or broomed horns, and worn or malaligned teeth. Bighorn sheep on the Alberta coal mines are considered a high quality population characterized by high lamb:ewe ratios, large body size, high density and numbers, and a strong population growth. Bighorn sheep from high quality populations tend to show more juvenile behaviour, i.e., fighting (Geist 1971). High degree of fighting between male sheep from the Luscar and Gregg River mines could contribute to increased amount of trauma to their horns including broken or cracked horns which may allow opportunistic bacteria to enter under the horn sheath.

Parasites. Seasonal variation occurred in the intensity of lungworm larvae in faeces from bighorn sheep on the Luscar Mine (MacCallum 1991). Larval output rose each month during the fall, peaked in December, then declined during the winter. Larval output during summer months was very low compared to winter months. The high prevalence of *Protostongylus* spp. in bighorn sheep from the Luscar Mine is consistent for the season sampled and appears to have no detrimental effect on individual sheep. Similar high prevalence in bighorns was documented at Hall Mountain, Washington (Foreyt et al. 1996) and in various Montana sheep herds (Aune et al. 1998), but LPG values overall were higher from the Luscar and Gregg River mines. Cassirer (2005) reported higher larval prevalence (G = 56.57, 5 df, $P < 0.0001$) and intensity ($F_{5, 346}$ = 25.07, $P < 0.0001$) in sheep transplanted to Hell's Canyon from Cadomin [Luscar Mine] and the Missouri Breaks than in resident sheep or in adults that died from pneumonia. LPG in faecal samples from bighorn sheep on the Luscar Mine and from on the nearby Redcap Range for March 1986 showed a significant difference (t = 3.02 df=29, $P < 0.05$) (MacCallum 1991). LPG values from sheep from Redcap were higher (n=21, $\bar{x}$ = 1499.1, SD=1155.6, range 54-3744) than those from the Luscar Mine (n=26, $\bar{x}$ = 673, SD=540, range 36-2380). Despite these high counts, there has been no outward manifestation of pneumonia to indicate multiple stressors are reducing resistance of the Luscar Mine herd to disease.

Similar to my findings, Foreyt et al. (1996) reported that ticks (*Dermacentor albipictus*) on sheep from Hall Mountain were uncommon.

Trace Minerals. Differences in concentrations of trace minerals considered adequate for bighorn sheep exist between testing laboratories (Table 4). Trace minerals were within adequate range (minimum UIASL, maximum BCAHC) for zinc, cadmium, manganese, iron, selenium, calcium, and magnesium. Lead was below the detection limit in the liver of two adult ewes (UIASL). Lead in the 1-yr-old female was at the level considered adequate by UIASL and well below the level considered adequate by BCAHC. Copper levels were below levels considered adequate for the two adult ewes and within normal range for the 1-yr-old female. Molybdenum was higher than levels considered adequate in the liver of the two adult ewes. Opportunistic collection of livers from dead sheep on the mines would augment the current small sample.

Mean concentrations of trace elements in serum samples from 129 bighorn sheep from the mines were within adequate range

(UIASL) for calcium, magnesium, phosphorus, and iron. Mean zinc concentration was below concentrations considered adequate, as was copper.

Mean selenium concentration was slightly higher than normal in serum and above normal (UIASL) in whole blood of sheep from the mines but mean concentration in serum was within adequate range used for bighorn sheep in B.C. (0.130-0.203 ppm ww, Lemke and Schwanthe 2005). Selenium concentrations in liver and hair samples were within values considered normal for bighorn sheep. There are no clinical signs of selenium toxicity in sheep from the Luscar Mine (MacLeod 2001). Selenium serum values at the Alberta reclaimed coal mines were higher than those from bighorns from various locations in B.C. (Lemke and Schwantje 2005) but lower than those from domestic sheep at low selenium exposure sites in an Idaho reclaimed phosphate mine (Fessler 2003). This suggests that bighorn sheep at the Luscar and Gregg River mines are not accumulating selenium in toxic amounts (MacCallum 2006). Selenium in these bighorn sheep may simply represent one end of the range of tolerance in wild sheep.

This paper summarizes test results for various pathogens and trace elements in bighorn sheep from the Luscar and Gregg River mines and provides a general health profile for a high quality bighorn population that has had little or no contact with domestic sheep, goats, or cattle. This documentation and the continued good health of the bighorn sheep from the Luscar and Gregg River mines support using these animals as a healthy source for translocation to other areas.

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Appendix A. Laboratories used to test for disease and trace minerals in bighorn sheep of the Luscar and Gregg River mines, Alberta.

Laboratory	Abbreviation	Tests Conducted
Alberta Fish and Wildlife Diagnostic Lab, Edmonton, AB	AFWDL	bacteriology
Alberta Agriculture Food and Rural Development Lab, Edmonton, AB	AAFRDL	bacteriology
British Columbia Animal Health Centre, Abbotsford, BC	BCAHC	toxicology
Bureau of Animal Health Labs, Boise, ID	BAHL	serology
Canadian Cooperative Health Center, Saskatoon, SK	CCHC	histology
Faculty of Veterinary Medicine, University of Calgary, AB	FVMUC	parasitology
Nevada State Department of Agriculture, Division of Animal Industry, Animal Disease Laboratories, Elko, NV	NADL	serology, bacteriology
Oregon State University Veterinary Diagnostic Laboratory, OR	OSU VDL	serology
Department of Pathology, University of Guelph, ON	DPUG	bacteriology
University of Idaho Analytical Sciences Laboratory, Moscow, ID	UIASL	toxicology
University of Idaho, Caine Veterinary Teaching Center, Caldwell, ID	CVTC	bacteriology
University of California, Davis, CA	UCD	serology (scabies)
Veterinary Pathology Lab, Edmonton, AB	VPL	histology, bacteriology
Washington Animal Disease Diagnostic Laboratory, Pullman, WA	WADDL	serology, parasitology

Appendix B. Status of specific diseases on the Luscar and Gregg River mines and potential threat to bighorn sheep.

Disease	N	Luscar & Gregg R. mines	Threat to bighorns [summarized from Dubay et al. (2002) or as noted].
Viruses			
Contagious ecthyma (CE)	Fe	Present	Widespread and posing little risk.
Bluetongue (BTV) and epizootic haemorrhagic disease (EHD)	16	Not present	Widespread, poses health risk to areas where these diseases are absent or to naive animals translocated to enzootic area.
Parainfluenza-3 (PI-3)	15	Not present	Widespread and believed to pose little risk to bighorn sheep. Alone, PI-3 may not be important but may be fatal in combination with other pathogens and/or stressors.
Bovine respiratory syncitial virus (BRSV)	15	Low prevalence (0.026)	Widespread and believed to pose low risk to bighorn sheep, but information lacking. Alone, RSV may not be important but may be fatal in combination with other pathogens and stressors.
Infectious bovine rhinotracheitis (IBR)	15	Not present	Widespread and appears to pose little health risk to bighorn sheep.

Bovine viral diarrhea (BVD)	15	Not present	Widespread exposure, uncertain significance, requires more research.
Ovine progressive pneumonia (OPP)	15	Not present in 1990, 1995. Low prevalence in 1999-2000 (0.01).	Slowly progressive viral disease of adult [domestic] sheep caused by an ovine lentivirus (USDA 2003).
Vesicular stomatitis (VS)	16	Not present	Sporadic, reemerging viral disease of cattle, horses, and swine. Also affects [domestic] sheep and goats. Many wild species, including deer, bobcats, goats, raccoons, and monkeys susceptible (USDA 1996).
Bacteria			
Anaplasmosis (ANA)	15	Not present	Widespread but appears to pose little direct health risk for bighorn sheep.
Johne's disease (Paratuberculosis)	39	Not present	Isolated problems in bighorn sheep. Managers and veterinarians should monitor for clinical signs if the disease documented previously in a herd. Do not use such herds for translocations.
Leptospirosis	65	Not present	Widespread in many wildlife species, uncertain in bighorn sheep, but seems to pose minor health risk.
Brucella ovis	19	Not present	Uncertain for bighorn sheep. Additional research needed with bighorn sheep sympatric with infected elk and bison in enzootic areas. Testing bighorn sheep from enzootic areas should be considered.
Pasteurellosis	11	*Pasteurella trehalosi* 6 biovariants; 2 unique *Mannheimia* spp. 22 biovariants; 11 unique *P. multocida* not present	Many *Pasteurella* spp. and biotypes widespread and present in most bighorn sheep and domestic livestock herds. Many *Pasteurella* spp. of domestic sheep origin considered fatal to bighorn sheep. Those of bighorn sheep origin may present health risk to naive animals, but difficult to predictably identify. Capacity to predict effects of *Pasteurella* spp. on source or recipient bighorn sheep populations not yet available. Therefore, pre-movement culturing of bighorns in source and recipient herds can be considered; however, disease history is more important. Prevention of contact between all domestic and wild sheep is paramount.
Hemophilus sp.	65	Present High prevalence (0.91)	*Haemophilus somnus* (reclassified as *Histophilus somni*). Associated with respiratory disease in American bison, domestic sheep, and cattle. Also harboured in reproductive tracts and associated with reproductive failure in domestic sheep and cattle (Ward et al. 2006).
Campylobacter spp.	16	Present 100% prevalence (1.0)	Commonly found in intestinal tracts of dogs, cats, poultry, cattle, swine, monkeys, wild birds, and some humans (USDA 1991).
Parasites			
Toxoplasmosis	16	Not present	*Toxoplasma gondii* is one of the most common parasitic protozoan infections of humans and other warm-blooded animals. Worldwide from Alaska to Australia (USDA 2007).
Scabies (Psoroptic mites)	13	Not present	Localized with potential for substantial morbidity and mortality, especially in naive animals.