A COMPARISON OF POPULATION AND HEALTH HISTORIES AMONG SEVEN MONTANA BIGHORN SHEEP POPULATIONS

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Abstract: We compared detailed population and health histories between seven bighorn sheep populations. Data from partial health histories of other bighorn sheep populations are also presented. The Tendoy Mountains and Quake Lake sheep herds are small herds (<200) of low density that experienced epizootic pneumonia outbreaks. The Highland-Pioneer and Lost Creek sheep herds are larger herds (200-400) of higher population density experiencing recent epizootic pneumonia outbreaks. Upper and Lower Rock Creek and the Perma-Paradise sheep herds are larger herds (200-400), with high densities but have not experienced a recent epizootic. Total population, sex and age composition, serologic profiles, bacteriologic investigations and mortality causes were examined and compared between each herd unit. Diagnostic evaluations were conducted during each epizootic pneumonia outbreak experienced during the study. Each epizootic event appeared to be characterized by unique combinations of either bacterial, viral or parasitic infections acting in combination to create clinical disease. Population parameters implicated in transmission of disease are discussed.

INTRODUCTION

One of the most significant problems associated with bighorn sheep management is the unpredictable and often devastating effects of epizootic events caused by pneumonia. Epizootics due to respiratory disease have been reported from many Rocky Mountain bighorn sheep (*Ovis canadensis*) herds throughout the North American Continent (Thorne et al.1982, Onderka and Wishart 1984, Bailey 1986, Andryk and Irby 1986, Coggins 1988, Spraker et al. 1984, Festa-bianchet 1988). Lungworms, bacteria (especially *Pasteurella* spp.), respiratory viruses, associations with domestic livestock and various types of stress are often reported as the cause of these epizootic events (Foreyt et al. 1994, Foreyt and Jessup 1982, Spraker et al. 1984, Forester and Senger 1964, Thorne et al. 1982).

In Montana bighorn epizootic disease events have been reported in several bighorn herds since 1924 (Forrester and Senger 1964). Early investigations of these events focused on the importance of lungworms as the pathogen responsible, hence the references to lungworm-pneumonia complex (Marsh 1938, Forrester and Senger 1964, Becklund and Senger 1967, Forrester 1971). During the mid 1980's a series of die-offs occurred along the Rocky Mountain Front (Andryk and Irby 1986, Worley et al. 1988). Limited diagnostic investigations indicated that these mortalities resulted from *Pasteurella* spp. and lungworm infections. It was hypothesized that the epizootic events during that period started with the transmission of a pathogen from bighorn populations in Canada and Glacier National Park that experienced similar die-offs in the early 1980's (Andryk and Irby 1986). However, lack of diagnostic evaluation of sheep mortalities and the absence of any prior health history information from the Canada and Glacier National Park herds prevented an accurate and complete determination of the factors that caused respiratory disease in these bighorns.

To improve our ability to monitor bighorn herd health and provide adequate diagnostic services during mortality events Montana Fish, Wildlife and Parks (MFWP) Wildlife Research laboratory, the Montana Department of Livestock Diagnostic Laboratory and Veterinary Molecular Biology at Montana State University (MSU) implemented several memorandums of agreement (MOA). The MOA's were not structured to strictly apply to bighorn herd health monitoring. However, they provided the opportunity to determine herd health parameters for several bighorn sheep herds as requested by various agency biologists. As a result of this program seven herd units were monitored to determine several basic health parameters and evaluate causes of mortality.

Several epizootic events occurred in southwestern Montana during the 1990's. Mortalities caused by pneumonia occurred in 1991 in the Tendoy Mountains, 1993 in Lost Creek, 1994 in the Highland-Pioneer Mountains, and 1996 near Quake Lake. During these events MDFWP attempted to assess the causative pathogens involved. In addition some health data were available to compare between herd units and evaluate changes in health parameters that might explain the factors causing die-offs. This paper presents the information available from four recent die-offs and compares these data with health information from three other herds that have not undergone a recent epizootic event.

Our objectives were: (1) to refine a general health monitoring technique applicable to bighorn sheep herds in Montana (2) to identify bacterial, viral, and parasitic pathogens common to bighorn sheep. (3) to compare health parameters between herds that have experienced recent epizootics and those that have not undergone recent die-offs. (4) to measure changes in the trends of various health parameters over time. (5) to search for common bighorn sheep population parameters that might have value for predicting epizootic events.

STUDY AREA

The study area encompasses bighorn sheep habitat within the entire state of Montana. Bighorn sheep habitat in Montana is highly variable ranging from low breaklands (700 m) found along the Missouri breaks of eastern Montana to the lower mountain valleys (1500 m) and high rocky peaks (3900 m) of the Rocky Mountain Cordillera that transects western Montana.

Through intensive management and frequent transplants the number of bighorn sheep herds in Montana has been expanded from 14 established herds in 1950 (Couey 1950) to over 40 herd units in 1998. Bighorn herd sizes range from 30 to nearly 1000.

METHODS

All bighorn sheep mortalities were investigated as opportunity allowed. Sheep from various regions that could not be transported immediately were frozen whole in regional freezers for later transport. Individual sheep were necropsied at the MFWP Wildlife Laboratory or the Department of Livestock State Diagnostic Laboratory to determine causes of mortalities. Epizootic events were evaluated by collecting tissue specimens from mortalities during a field necropsy and, if possible, from hunters and biologists or by transporting whole carcasses to the laboratory for necropsy. Gross lesions were submitted for histopathologic examination, routine bacteriologic culture and virus isolation. Histopathology was performed by board certified pathologists from the State Diagnostic Laboratory.

Herd health monitoring was performed when animals were captured for translocation or field research. Blood was drawn from the jugular vein, a pharyngeal swab was taken from the tonsilar crypt and fecal samples were collected. Each animal was inspected for external parasites or indicators of other health problems. Fecal collections from sheep bedding areas or from radio monitored study sheep were collected from individual sheep within some herd units to monitor trends in parasite loads.

Blood samples were transported to the MFWP laboratory and centrifuged to extract serum. Whole blood samples are submitted to the State Diagnostic Laboratory for hematology. Standard large animal serum chemistries are performed. Standard approved serum tests were conducted to determine antibodies for *Brucella abortus*, *Brucella ovis*, Bluetongue, Infectious Bovine Rhinotracheitis (IBR), Bovine Virus Diarrhea (BVD), Para Influenza-3 (PI3), Bovine Respiratory Syncytial Virus (BRSV), Ovine Progressive Pneumonia, and Leptospirosis (eight serovars). Excess blood serum was archived for future testing.

Fecal samples were refrigerated and transported to the MFWP laboratory. A modified Baermann procedure was used to determine the number and relative concentrations of lungworm larvae shed by each animal (Dinaburg 1942, Beane and Hobbs 1983). The modified Lane fecal flotation procedure was used to recover ova and oocysts from feces (Dewhirst and Hansen 1961). Cover slips from each tube were examined under light microscope to determine the number and type of ova and oocysts present.

Bighorn sheep populations were monitored through annual or periodic aerial census conducted during the winter by MFWP biologists. The population survey methods implemented and timing of surveys was variable within the winter period occurring from December through April depending upon suitable flying conditions and funding. Summarized data from each flight included a total count of all sheep and a classification of rams, ewes and lambs when possible. Ram and lamb per ewe ratios were calculated using the data sets provided for each herd unit.

RESULTS

Population Histories

Population and health histories were completed for seven populations of bighorn sheep in Montana. There was considerable variation in the quality of population data sets, the frequency of surveys and data reporting standards that affected our ability to make detailed comparisons between herd units. However, we were able to determine gross trends in population size and ram/ewe and lamb/ewe ratios for most units. All herd units increased in total population size during the period 1985 until the early 1990's. All herds, with the exception of the upper and lower Rock Creek units, declined in population at some time from the early 1990's to present. The Rock Creek herds appear to be somewhat stable (Figure 1). The Plains unit appears to have increased, then stabilized. Various forms of management were implemented to control growth including increased hunter harvests and capture and removal for transplanting sheep to other populations in Montana.

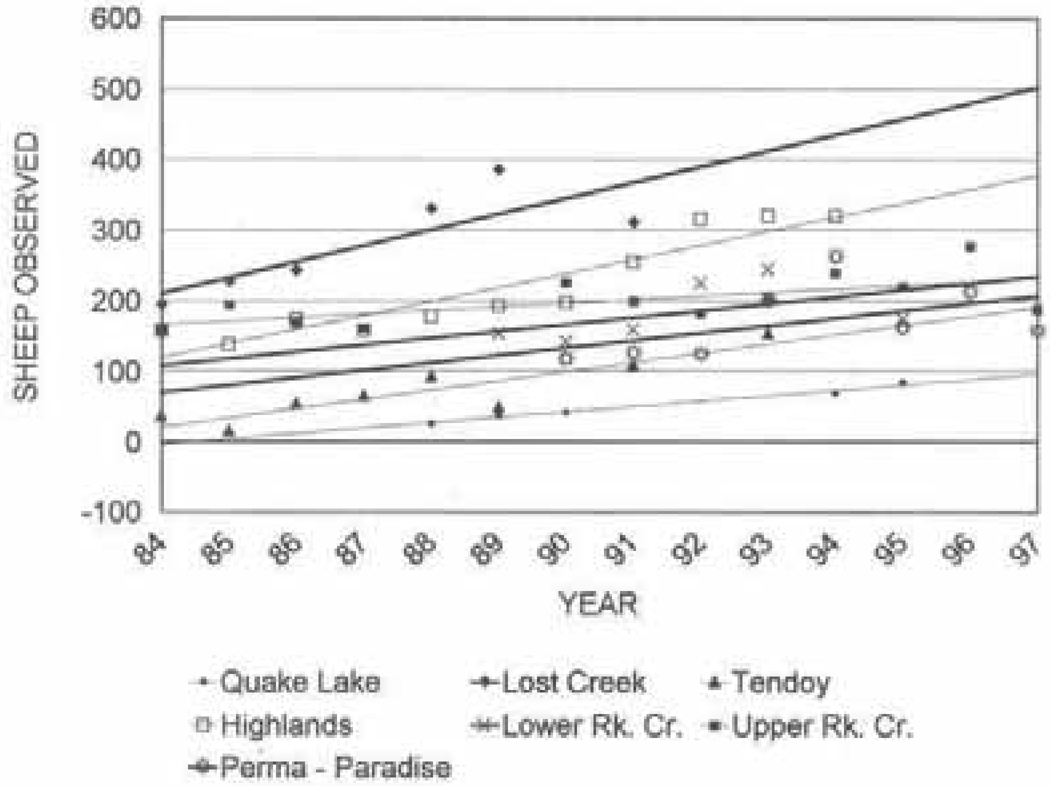


Figure 1. Linear regression total sheep counts conducted in the winter to early spring for sheep herds in western Montana.

Highlands-Pioneers Herd Unit

Native populations of bighorn sheep were extirpated from the Highland-Pioneer Mountains in the early 1900's. Sheep were reintroduced to the area in 1967 when 27 sheep were transplanted from the Sun River. The initial transplant population was supplemented with 31 sheep in 1969. The population expanded in size and range up through the mid 1990's so that sheep today extend across the Big Hole River and into the foothills of the Pioneer Mountains. The number of males in the population grew and the herd became well known for it large trophy quality rams. The number of sheep was estimated between 350-400 (Weigand 1994, Semmens 1996) (Figure 2). Harvests were increased in 1992 and 1993 to 39 and 40 sheep. In addition, 35 sheep were captured and transplanted from the population in 1992 to reduce sheep numbers. In 1993 the population was at an all time high. Parasitology data indicated an increased lungworm load and some significant gastrointestinal parasites within the population (Hoar 1995). By late November 1994, sheep hunters in the area reported observing clinical signs of pneumonia. Diagnostic work from two sheep mortalities confirmed pneumonia complex with strong evidence of chronic lungworm infection. Sheep mortalities continued to be recorded from December 1994 through March 1995. The population declined by 87 percent and the current population contains less than 50 individuals (Figure 2).

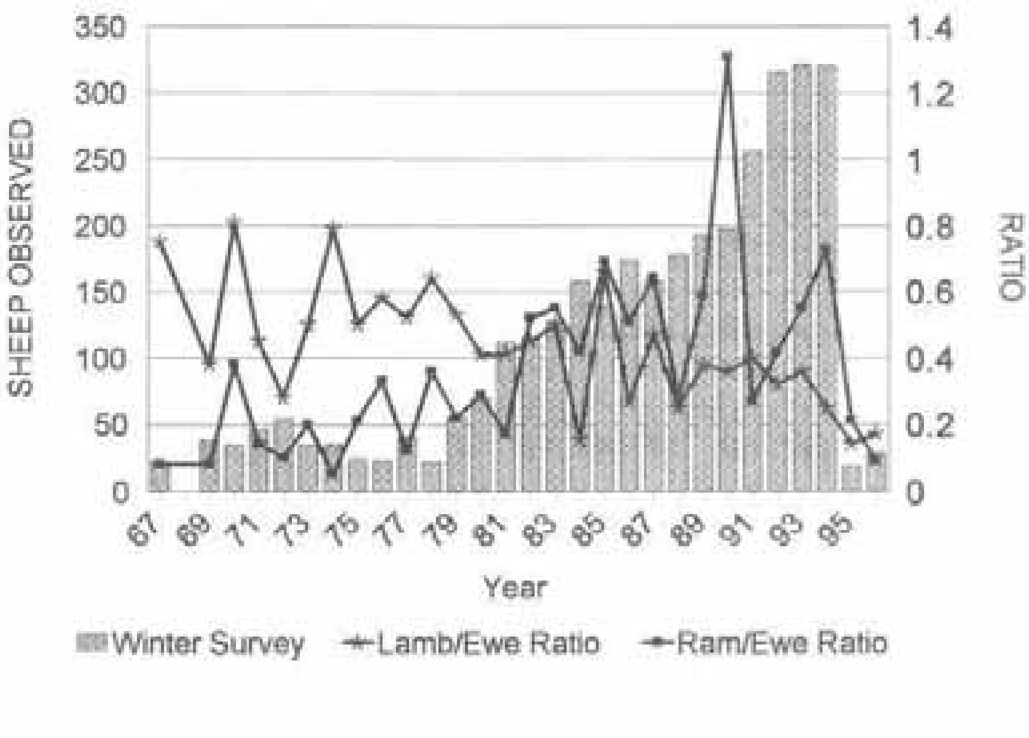


Figure 2. Highland - Pioneers sheep herd total winter survey counts with lamb /ewe and ram/ewe ratios.

Lost Creek Herd Unit

Bighorn sheep were established in the Lost Creek area when 25 bighorns were transplanted from the Sun River herd unit into Olson-Foster Gulch in 1967 (Mussehl and Howell 1971). Forty to sixty sheep were reported for this unit in 1971 and 1972 (MFWP unpub report). Eighty sheep were observed on the winter range in 1974. This population grew to about 138 sheep by 1978 and increased to approximately 386 sheep by 1989 (Dan Hook, pers. Comm.). In an attempt to reduce the population, 60 sheep were captured in February 1991 and transplanted to other sheep herds in Montana. In October 1991 hunters began reporting bighorn sheep with clinical signs of pneumonia. Sheep were observed with respiratory disease from October through December. The population declined and surveys the winter of 1992 indicated fewer than 150 sheep survived the epizootic. Lamb production was depressed for several years and the population has decreased slightly or remained stable since 1991. The survey for 1997 indicated a total sheep count of 130 individuals (Figure 3).

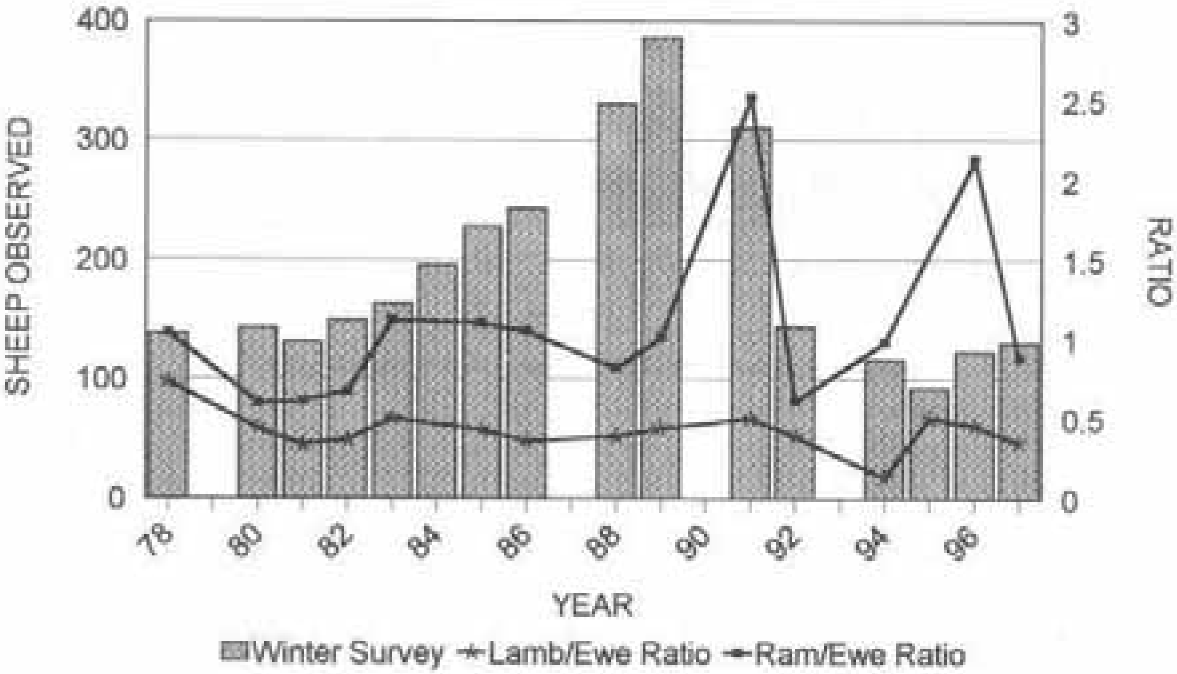


Figure 3. Lost Creek sheep herd total winter survey counts with lamb/ewe and ram/ewe ratios.

Tendoy Mountains Herd Unit

Thirty-six sheep were initially transplanted into the Tendoys in 1984 from Rock Creek. In 1985 this herd was supplemented with 15 sheep from the Perma-Paradise bighorn sheep herd. This population grew rapidly to 92 sheep in 1988. The first hunting season was established in 1988, with 3 either sex permits issued. This quota continued until 1991 when it was increased to 5 either-sex permits and 10 ewe/lamb permits. In 1993, a pneumonia epizootic eliminated approximately 75% of the population (Figure 4). The epizootic event occurred from September through December. The hunting season was subsequently closed.

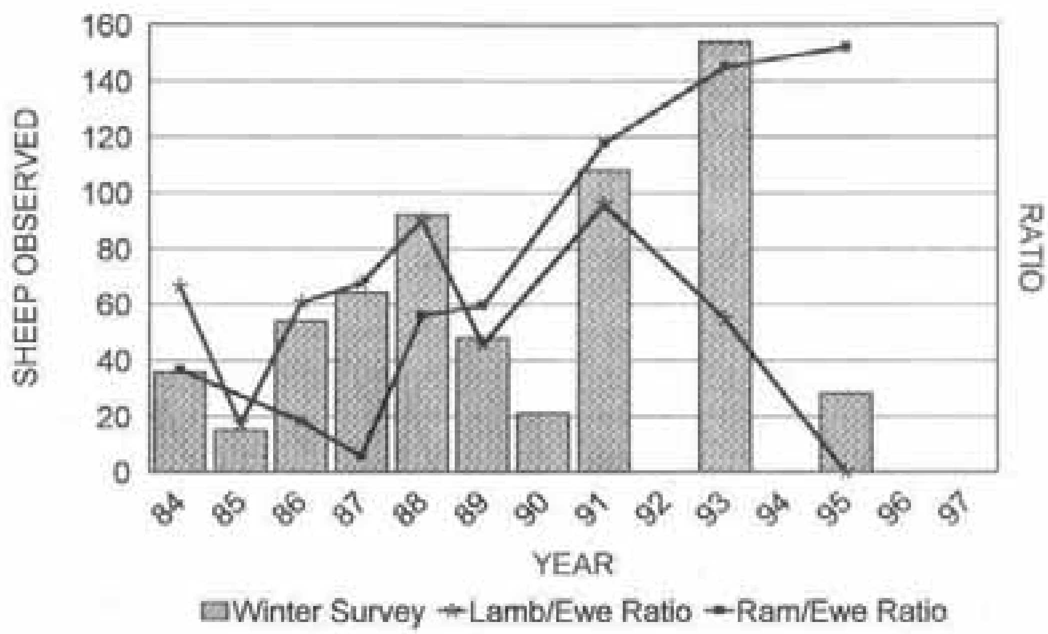


Figure 4. Tendoys sheep herd total winter count with lamb/ewe ratios and ram/ewe ratios.

Quake Lake Herd Unit

The population known to winter near Hebgen Dam was reported to be 28 sheep in 1949 and was referred to as the Hilgard herd (Couey 1950). Beuchner (1960) noted that the Hilgard population remained small in years prior to 1960. In December 1981 a survey indicated the population was at least 59 (Roy 1992). The herd went through a die-off in the early to mid 1980's (Kurt Alt, pers. comm.). The loss of sheep went unnoticed until sheep were no longer observed on the winter range. By 1987, only five sheep were observed where more than 50 had wintered less than a decade before. A small remnant of about 16 sheep survived near Hebgen dam and in the Henry's Lake area (Kurt Alt pers comm.). The population was augmented in 1989 with 23 sheep from Thompson Falls and again in 1990 with 18 sheep from Lost Creek. A third supplement of 26 sheep from Wildhorse Island was released in December, 1993. A severe winter in 1996-97 produced high snowpack and the population went through a weather/pneumonia related die off reducing the population to less than 25 animals. Most of the sheep mortality was during the months of January and February following significant snow accumulations. A February 1998 survey counted only 12 ewes with 3 lambs (Figure 5). A few other sheep are known to be scattered throughout the former range of this herd.

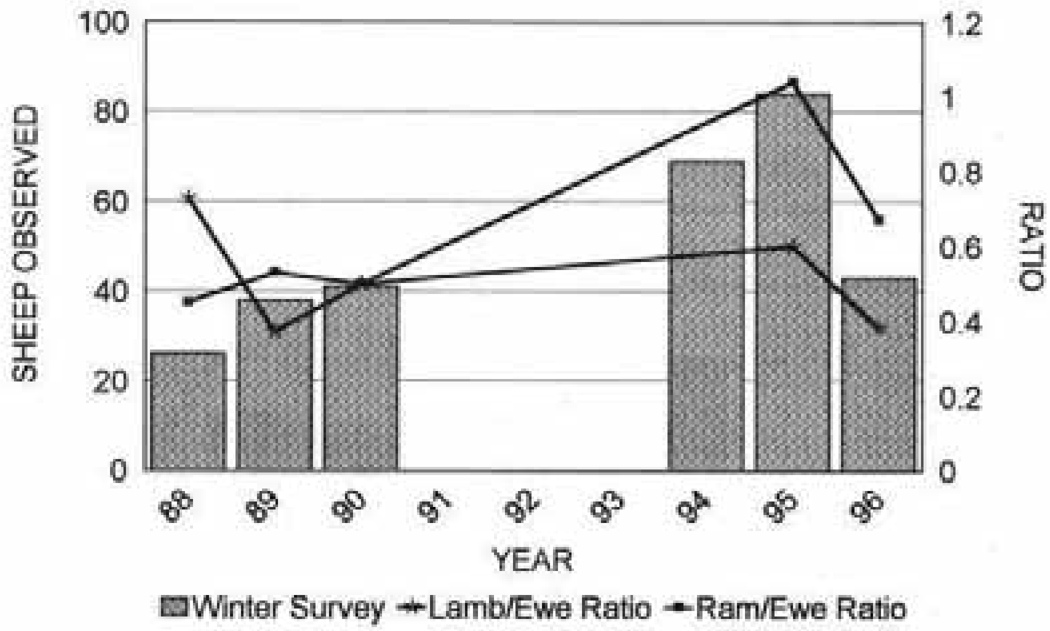
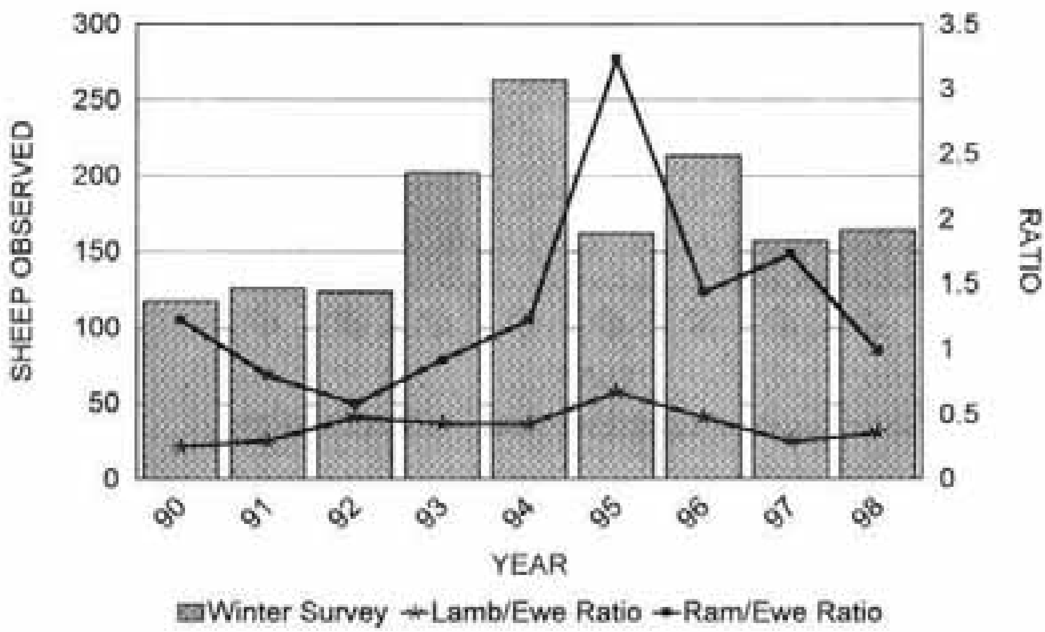


Figure 5. Quake Lake sheep herd winter survey total counts with lamb/ewe and ram/ewe ratios.

Perma-Paradise

Brown (1974) indicates that native bighorn sheep were observed near Plains since 1808 by many early travelers visiting the Thompson River country. Couey (1950) reported an estimate of 25 sheep for this population located in a 4-mile area north of the Clarks Fork of the Columbia River and east of the Thompson River. Between 1949 and 1959 bighorn sheep apparently disappeared from the area. In May, 1959 a transplant of 13 bighorns from the Sun River reestablished sheep in the Thompson River area (Brown 1974). In September, 1959 an additional six sheep from Wildhorse Island were released. The Perma-Paradise herd unit was established in 1979 when the Flathead Indian Reservation introduced 20 bighorn sheep into the area. Early surveys in 1988 discovered that the population had expanded to nearly 100 animals (Tom Lemke, pers.comm.). By 1990 the population was 190 animals and grew to about 480 sheep from 1990 to 1994 (Sterling pers. comm.). In March 1995, 45 sheep were captured near Perma and transplanted to other sheep herds in Montana. The population has declined to slightly over 200 animals since 1995. No reported epizootic events have been reported in this herd (Figure 6).

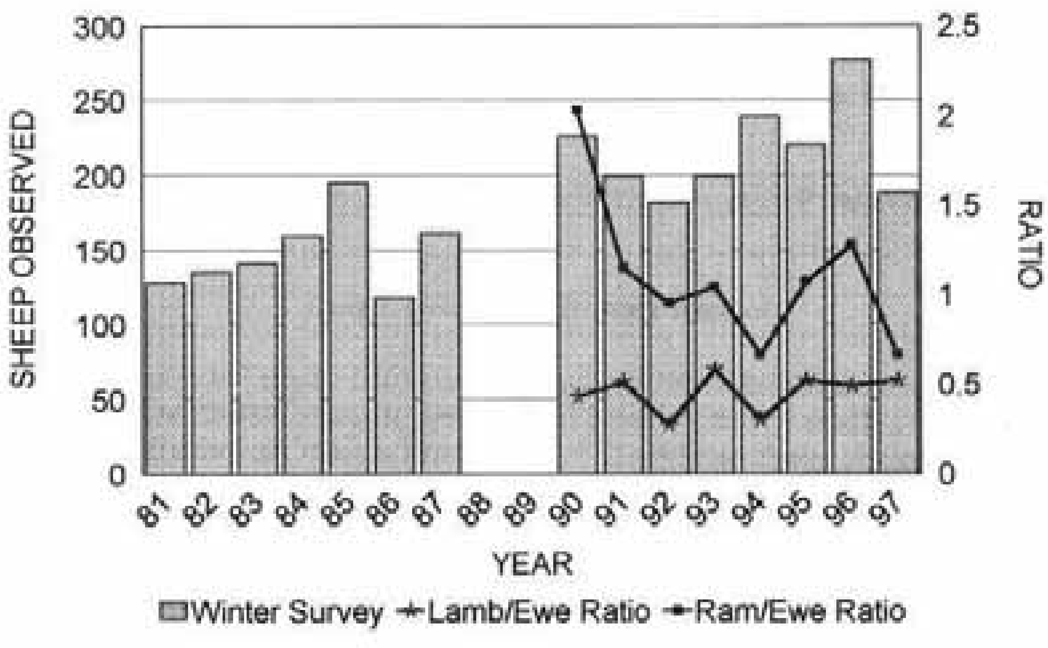
Figure 6. Perma-Paradise sheep herd winter survey total counts with lamb/ewe and ram/ewe ratios.



Upper and Lower Rock Creek

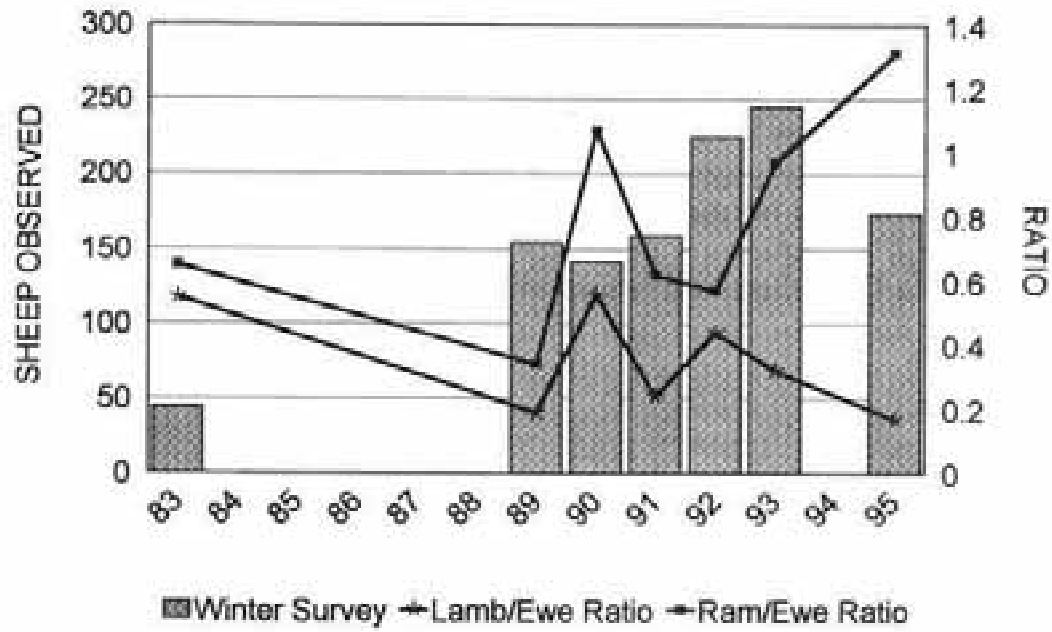
Couey (1950) reported a group of 40 sheep in the head of Rock Creek near Philipsburg. This native population was apparently much larger at one time (Couey 1950, Aderhold 1968). Bighorns were said to be more plentiful than deer prior to 1895 (Berwick 1968). The number of bighorns in Rock Creek declined in 1915 but began increasing by the 1940's (Berwick 1968). The population declined again in the 1960's from about 200 sheep to less than 15 (Berwick 1968, Cooperrider 1969). It was reported that the major cause of the decline was deterioration of the habitat. The Rock Creek sheep herd was supplemented with a transplant of 31 sheep from Sun River in 1975. In 1978, 76 sheep were observed in the upper Rock Creek drainage and the population was estimated to be approximately 100 sheep (Butts 1980). This sheep herd grew steadily from 100 sheep in 1978 to 277 in 1996 (Dan Hook, pers. comm.). In March 1996, 45 sheep were captured and transplanted to other herds from the upper Rock Creek herd unit. Surveys in 1997 indicated that 188 sheep remained in the upper Rock Creek herd (Figure 7).

Figure 7. Upper Rock Creek sheep herd winter survey total counts and lamb/ewe and ram/ewe ratios.



In January 1979, 25 sheep were transplanted from Wildhorse Island to the lower Rock Creek drainage (Butts 1980). The lower Rock Creek herd grew from 25 sheep to 268 in 1996 (Mike Thompson, pers. comm.) (Figure 8). In February 1997, 34 bighorn sheep were captured and transplanted to other sheep herds from the lower Rock Creek herd.

Figure 8. Lower Rock Creek sheep herd winter survey total counts with lamb/ewe and ram/ewe ratios.



Mortality Patterns in Epizootic Events

Carcass searches were conducted in the Highlands-Pioneers and Quake Lake pneumonia epizootics (Table 1) . There were differences in the timing of recent die-offs at Quake Lake and the other recent epizootic events monitored. In Quake Lake most of the mortality occurred in January through February and was evenly distributed among age and sex groups. The Highland-Pioneers die-off began in October and extended into March. The Tendoy and Lost Creek die-offs started in September and October continuing into December. Mortalities in the Highland-Pioneers, Tendoy, and Lost Creek epizootic events were weighted toward lambs in the early periods then shifted into adult ewes as the epizootic continued.

Table 1. Sex and age patterns for mortalities investigated in the Quake Lake and Highlands-Pioneers die-offs.

	Males%	Ad. Females%	Lambs%
Quake Lake Jan. (N=19)	47.4	42.1	10.5
Quake Lake Feb. (N=18)	38.9	38.9	22.2
Highlands-Pioneers Dec.-Jan. (N=53)	26.4	51.0	22.6
Highlands-Pioneers Feb.-Mar. (N=65)	23.1	72.3	4.6

Kidney fat indexes were determined from bighorn sheep carcasses for the Quake Lake herd unit during the pneumonia epizootic. The mean kidney fat index for 14 sheep necropsied in January was 36.5% (range 1.0-169.9). This declined in February to 3.4% (range 1.0-18.8). Data on sheep condition was not available for the other herds during the die-off period.

Comparison of Herd Health Histories

Bacteria

Cultures of lung tissue from bighorn mortalities during individual pneumonia epizootics yielded a variety of bacteria (Table 2). The most common bacteria, *Pasteurella multocida* and *Pasteurella haemolytica*, were isolated from 16.6% to 71% of the lung tissue submitted. *Pasteurella haemolytica* isolates were commonly bio-type T. *Pasteurella haemolytica* type A2 was isolated from bighorn sheep during the Highland-Pioneer epizootic event. Bighorn sheep from this herd unit shared habitat with domestic sheep during all seasons. Other common bacteria isolated include *Streptococcus* spp. and *Actinomyces pyogenes*.

Pharyngeal swabs taken from healthy bighorn sheep populations resulted in cultures of bio-type T *P. haemolytica* and various sero-type combinations of 3,4,10, and 15 (Table 3). The percentage of swabs in which *P. haemolytica* was successfully cultured varied among herd units sampled and ranged from 7% to 46%.

Table 2. Culture results from lesions within lung tissue prosected from bighorn sheep during epizootic events in Montana, 1990-97.

Herd Unit	P. mult.*	P. haem.*	Bio-Sero Type (*P.haem.*)	Other
Lost Creek	1/19	7/19	T 3,4 T 3,4,10	Corynebacterium, Streptococcus, Actinomyces, Aeromonas
Tendoys	1/6	0/6	Not Attempted	Streptococcus, Actinomyces
Highland-Pioneer	4/12	6/12	A2 T 4,10,15 T 4,10 T 3,15 T 3 T 4	Streptococcus
Quake Lake	8/14	10/14	T 3, 4	Actinomyces, Moraxella

* Data indicates number positive / number tested.

Table 3. Biotype and sero-type of *Pasteurella haemolytica* cultures from pharyngeal swabs taken from captured bighorn sheep in Montana, 1990-97.

	Year	No. Pos.	No. Tested	Bio-type	Sero-type
Perma-Paradise	95	3	44	T	4 and 10, 15
Upper Rock Cr.	96	4	45	T	3, 15
Lower Rock Cr.	97	11	34	T	3
Wildhorse Island	93	58	125	T	4 and 3, 4
Tom Miner	95	2	10	T	4 and 4, 10

Viruses

Serologic evidence for respiratory virus antibodies were found in all bighorn sheep herds tested (Table 4). The most common respiratory viruses affecting bighorn sheep were PI3 and BRSV. We did not begin routine testing for BRSV until 1995. For those herds tested since 1995 for BRSV all have shown a high sero-prevalence. Sero-prevalence for BVD appeared to be herd specific. We found high sero-prevalence for BVD in the Lost Creek and Perma-Paradise herd.

Sero-prevalence did not uniformly compare with virus isolation results (Table 5). Although sero-prevalence for PI3 indicated significant challenge for bighorn sheep in the Highlands-Pioneer herd unit prior to an epizootic it was not recovered from lung tissues. Sero-prevalence for BVD was indicating potential viral challenge for bighorn sheep in the Lost Creek herd unit and BVD was isolated from 74% of the lung samples submitted to virology.

Table 4. Serologic prevalence for antibodies for respiratory viruses in captured Bighorn Sheep from Montana, 1990-97.

	IBR	PI3	BVD	BRSV
Lost Creek	1.8	76.8	100.0	--
Highlands-Pioneers	0.0	91.7	45.8	--
Perma-Paradise	0.0	47.7	100.0	81.8
Upper Rock Creek	0.0	48.9	0.0	73.3
Lower Rock Creek	0.0	58.8	0.0	100.0
Tom Miner	0.0	60.0	30.0	100.0
Gardiner YNP	0.0	66.6	0.0	86.6
Milltown-Bonner	0.0	55.2	0.0	72.4
Wildhorse Island	35.2	10.7	0.0	--

Parasites

Larval shedding for *Protostrongylus* spp. was monitored in fecal samples from nine different sheep herds in Montana. We observed larval shedding in all herds tested using Baermann techniques (Table 6). In addition, adult *Protostrongylus* spp. were identified either grossly and/or in histologic sections of lung tissue for the Highlands-Pioneers, Tendoy and Quake Lake herd units. All herds experiencing a pneumonia epizootic exhibited some level of *Protostrongylus* spp. infection with the exception of the Lost Creek herd. There was no evidence supporting significant lungworm infection during this particular epizootic.

Table 5. Results from virus isolation attempts from bighorn sheep lungs prosected during epizootics in Montana, 1990-97. Viruses tested for are Infectious Bovine Rhinotracheitis (IBR), Para Influenza-3 (PI3), Bovine Virus Diarrhea (BVD) and Bovine Respiratory Syncytial Virus (BRSV).

Herd Unit	IBR	BVD	PI3	BRSV
Lost Creek	0/19	14/19	2/19	0/19
Tendoys	3/6	1/6	0/6	0/6
Highland-Pioneers	0/9	0/9	0/9	0/9
Quake Lake	0/15	0/15	6/15	1/15

* Table data represents number successful isolations / number of attempts

Table 6. *Protostrongylus* spp. larval shedding from various bighorn sheep herds in Montana, 1990-1997. Mean larval density per gram of fecal material (LPG) counts conducted using Baermann techniques.

	Mean LPG	% Positive
Highlands (1)	116.6	100.0
Highlands (2)	1.2	26.5
Quake Lake	0.2	33.3
Upper Rock Creek	28.0	77.7
Lower Rock Creek	184.0	91.2
Perma-Paradise	5.1	89.7
Wildhorse Island	6.0	100.0
Pryor Mtns	5.5	40.4
Milltown-Bonner	153.0	100.0
Missouri Breaks	8.3	83.8

1/ Testing conducted prior to epizootic in 1994-95
2/ Testing conducted after treatment with anthelmintics in 1995-96.

Bighorn sheep parasites recovered from gastro-intestinal tracts or identified through fecal flotation include *Protostrongylus rushii, Protostrongylus stilesi, Marshallagia marshalli, Ostertagia ostertagi, Ostertagia trifurcata, Nematodirus abnormalis, Nematodirus davtiani, Chabertia ovina, Moniezia, Skrjabinema* and *Trichuris spp.* The abomasal nematode *Marshallagia marshalli* was the most significant gastro-intestinal parasite found infecting many bighorn sheep herds in Montana (Table 7). *Wyoming tetoni* was the only cestode identified in any sheep herd recently examined from Montana (Hoar et al 1996). *Eimeria crandallis, Eimeria ahsata, Eimeria ovinoidalis, Eimeria intricata, Eimeria granulosa* and *Eimeria ovina* were frequently found in fecal samples from the Upper Rock Creek herd unit indicating potentially significant coccidian infections for many sheep in this herd.

Table 7 Gastro-intestinal parasites identified in various sheep herds in Montana, 1990-97

Herd Unit	Parasite
Tendoy Mtns.	**Marshallagia**, Nematodirus, Eimeria
Quake Lake	Nematodirus, Moniezia
Lost Creek	**Marshallagia**, Nematodirus, Trichostrongyles
Highland-Pioneers	**Marshallagia**, Nematodirus, Ostertagia, Chabertia, Trichuris, Eimeria, Cestoda
Wildhorse Island	**Marshallagia**, Nematodirus, **Ostertagia**, Strongyloides, Haemonchus, Coccidia, Trichuris, Trichostrongylus
Upper Rock Creek	**Marshallagia**, Nematodirus, **Eimeria**, Skrjabinema
Lower Rock Creek	**Nematodirus**, **Coccidia**, Trichuris, dorsal spined larvae (P. odocoilei ?)
Pryor Mtns.	Marshallagia, Nematodirus, Strongyloides

* Bold indicates intensity sufficient to cause clinical parasitism.

DISCUSSION

Schwantje (1986) suggested several methods for monitoring bighorn herd health and recommended that monitoring should be considered only as corollaries to the study of population dynamics and range condition trends. We examined the population data for seven sheep herds to evaluate population parameters or changes in parameters that might indicate when bighorn sheep populations become susceptible to respiratory disease. Unfortunately, the data available were often incomplete for some herd units and did not yield to detailed quantification. Total population trend from four herd units that experienced epizootic events increased at about the same rate as two populations that did not experience any epizootic event during the study period. Not all herd units undergoing rapid population increase experienced an epizootic event during the study period (e.g. Perma-Paradise).

Population management designed to reduce sheep populations through capture and increased harvest in the Highland-Pioneers herd and the Lost Creek herd prior to epizootics did not prevent respiratory disease. Both of these populations went through a serious epizootic event following attempts to reduce the population. These management adjustments may not have decreased population density sufficiently or in adequate time to provide a favorable effect and prevent disease. Special population management for the Rock Creek and Perma-Paradise herd units was implemented as well. It is difficult to say that reductions in the size of the Rock Creek and Perma-Paradise herd units reduced density sufficiently to prevent an epizootic but overall population trend for these herds has been more stable and neither population experienced an epizootic event following high population numbers. Thorne et al. (1982) indicated that population control to prevent overcrowding of sheep is important but reducing the concentration and amount of time sheep spend on critical range is more important. We did not examine density trends for these populations but agree that concentrating sheep for long periods may be the most significant factor predisposing sheep herds to respiratory disease. Measuring densities as well as total numbers of sheep on critical ranges among various herd units or between years within a herd unit may be the best population parameter for predicting risks for pneumonia epizootics.

Trends in lamb/ewe ratios were highly variable among different populations examined in this study but remained relatively stable within all populations except following epizootic events when they declined. Reduced lamb production and recruitment for 2 years following a pneumonia die-off has been reported in other study areas (Onderka and Wishart 1984, Coggins and Mathews 1992, Ryder et al. 1994).

Bighorn sheep herds in Montana are frequently managed to protect trophy quality rams. Healthy sheep herds and those experiencing epizootics in Montana reported between one and three rams per ewe. Although supportive data are not presented here we hypothesize that managing for high numbers of rams in bighorn populations could have significant disease implications. Rams are inclined to travel further, exhibit rutting behavior conducive to respiratory disease transmission, and are more likely to interact with domestic sheep during breeding season. In addition, a single pneumonic ram can associate with many ewes during one breeding season. In Montana at least 4 cases of young rams breeding with domestic sheep have been reported since 1990. These rams may be exposed to highly virulent pathogens and return to infect bighorn ewe/lamb groups. Further work is needed to evaluate the role of bighorn rams in the transmission of respiratory disease.

Bacterial pathogens commonly associated with pneumonia complex in bighorn sheep were ubiquitous in Montana. *Actinomyces pyogenes, Pasteurella haemolytica* and *Pasteurella multocida* were commonly found in bighorns during epizootics and also in healthy sheep. Other studies have indicated that these bacteria are commonly isolated from many ruminants whether respiratory disease symptoms exist or not (Siflow et al. 1994, Miller et al. 1991, Queen et al. 1994). *Actinomyces* and *Pasteurella* are recognized opportunists capable of causing disease if an animals immune system is compromised (Queen et al. 1994). Respiratory disease which involved these opportunistic bacteria where involved in three of the four epizootics we studied.

Pasteurella haemolytica along with stress factors has long been recognized as a significant component of pneumonia epizootics in bighorn sheep (Spraker et al. 1984, Miller et al. 1991). There are many identified strains of *Pasteurella haemolytica* with varying differences in virulence (Silflow et al 993). *Pasteurella haemolytica* bio-type T and various sero-types 3,4,10, and 15 were most commonly found in both healthy and diseased sheep in Montana. *Pasteurella haemolytica* A2 was identified in only one epizootic, occurring where domestic sheep are known to share habitat with bighorn sheep. *Pasteurella. haemolytica* A2 has been determined to be highly pathogenic to bighorn sheep (Foreyt and Silflow 1996, Silflow et al. 1994).

The respiratory viruses PI3, BVD, IBR and BRSV are found throughout Montana in a wide range of domestic and wild animals. In bighorn sheep we found serologic evidence for all four respiratory viruses but found that bighorn sheep were primarily exposed to PI3, BVD, and BRSV. Virus isolation from lung tissue prosected during mortality investigations indicates that PI3 and BVD were probably involved in some manner with two pneumonia epizootics in Montana bighorn sheep. The high sero-prevalence for BVD virus and isolation of the virus from numerous lung tissues implicate BVD, in concert with *Pasteurella* spp., as a significant pathogen in the Lost Creek epizootic. A cursory examination of the literature failed to locate any records implicating BVD in sheep pneumonia despite repeated evidence of serologic prevalence (Foreyt et al. 1996, Howe et al. 1966, Parks et al. 1974). Several studies have isolated PI3 from bighorn sheep with clinical disease (Parks et al. 1972, Jessup 1985). We isolated PI3 from bighorn sheep with clinical disease in the Quake Lake and Lost Creek herd units.

Parasites, in particular *Protostrongylus* spp., have often been implicated in pneumonia epizootics (Marsh 1938, Buechner 1960, Forrester and Senger 1964). Evidence presented in this study indicates that all herd units tested exhibited mild to moderately high lungworm loads. The Highland-Pioneers presented higher lungworm loads than other sheep herds in Montana prior to a pneumonia epizootic. However, of the seven herds tested, the lower Rock Creek herd unit exhibited the highest lungworm loads and has not experienced a recent pneumonia epizootic. Fecal samples from 15 sheep in the Lost Creek herd unit were negative for lungworm in 1988 (Roy 1992) and lungworms were not detected during gross examination or histopathology during a pneumonia epizootic in 1991. Lungworm burden alone did not predict the occurrence of pneumonia epizootics. Schwantje (1986) suggests that local reactions to focal injury from lungworms may increase the risk of bacterial infection by opportunistic pathogens. Bighorn sheep herd units with chronically high lungworm infections should be considered at risk for pneumonia. Lungworm larvae loads and prevalence as well as gastrointestinal parasites may be good indicators of crowding and could provide some insight into the susceptibility of a herd unit to pneumonia epizootics (Worley et al. 1988).

Mild to relatively high lungworm and enteric parasite loads were identified in several Montana bighorn sheep herd units (Hoar et al. 1996, this study). Most of the parasites identified have been previously reported in bighorn sheep from North America (Becklund and Senger 1967, Worley and Seesee 1992). Dorsal spined larvae, probably larvae from the muscle worm *Paralaephostrongylus odocoileus,* were found in bighorns captured in 1997 from Lower Rock Creek. This parasite has not been previously reported in Montana bighorn sheep. However, recent examinations of mule deer from similar areas in northwestern Montana have also identified dorsal spined larvae (MDFWP unpublished data). Coccidiosis was evident in sheep from the Upper Rock Creek herd, but no known mortalities attributed to coccidiosis have occurred. Although no recent pneumonia epizootics have been observed, the Rock Creek bighorn sheep herds demonstrated parasite loads that may cause clinical disease and at high sheep density may increase the risk for pneumonia.

Each pneumonia epizootic in Montana we evaluated demonstrated unique characteristics and yielded a complex of pathogens that resulted in respiratory disease (Table 8). The Lost Creek herd pneumonia epizootic resulted from a combination of bacterial and viral infections without evidence of a significant parasitic infection. This was contrasted to the Highlands-Pioneers pneumonia epizootic which was preceded by significant parasitism which likely predisposed these sheep to opportunistic bacterial infections. The Highlands-Pioneer pneumonia epizootic was also characterized by a unique infection with the highly pathogenic *Pasteurella haemolytica* type A2 as well as the more common type, T-3,4. It is likely that the cytotoxic A2 isolate originated from domestic sheep that share habitat with these bighorn sheep yearlong. Several reports of bighorn rams breeding with and mingling with domestic sheep ewes were recorded prior to the pneumonia outbreak. Domestic sheep have been implicated in the development of bighorn sheep pneumonia in several studies (Callan et al. 1991, Foreyt et al. 1994). Domestic sheep and bighorns coexisted in the Highlands-Pioneers for nearly 20 years before a pneumonia outbreak. However, this population of bighorns had dramatically increased recently, improving the probability of transmission.

Table 8 Summary of findings for 4 bighorn sheep epizootics in Montana, 1990-1997.

Herd Unit	P. mult.	P. haemo.	Other Pathogens	Factors	Mortality*
Lost Creek	Yes	T-3,4,10	BVD, Mild Lungworm Range Condition	Density	>150 (55%)
Tendoys	Yes	No	IBR, Mild Lungworm	Unknown	>100 (75%)
Highlands	Yes	T-3,4,10,15 A-2	Lungworm	Density Domestic Sheep	>300 (87%)
Quake Lake	Yes	T-3,4	PI3	Winter Malnutrition	>50 (60%)

* Indicates the approximate number of mortalities followed by the percentage of the herd mortality in parenthesis.

The Quake Lake pneumonia epizootic occurred during a very severe winter resulting in greater than average snowpack on winter ranges. Bighorn sheep in this unit were forced to low elevations and were frequently obstructing traffic along a highway. This epizootic occurred during the middle of a severe winter which sets it apart from the other recent pneumonia epizootics that developed during the fall. Diagnostic evidence indicated that various combinations of bacterial and viral pathogens acted opportunistically following the winter stress and chronic malnutrition. Malnutrition was evidenced by the significant decline in kidney fat indexes.

Recent pneumonia epizootics were documented in supplemented native herds as well as herds established through transplant programs. Two herd units discussed, Quake Lake and Upper Rock Creek, supported a few native sheep before they were supplemented with transplants. All other bighorn herd units were established through the introduction of transplanted sheep. The source stock for these herd units was variable and did not come from herds with evidence of respiratory disease. Pneumonia epizootics in Montana were not restricted to long established herd units but affected newly established herd units such as the Tendoy Mountain herd which had been established for only 10 years.

In conclusion, our investigation supports previous work indicating that clinical respiratory disease in bighorn sheep results when the right pathogens, susceptible hosts and an appropriate environment combine. We found many opportunistic bacterial and viral pathogens causing pneumonia in Montana sheep. Parasitic infections in Montana bighorns also periodically cause low level chronic stress depending on population size and density, predisposing sheep to pneumonia (Worley et al. 1988). In addition to the wide variety of pathogens associated with respiratory disease, there were many different habitat and environmental factors uniquely affecting each individual herd unit in Montana, creating complex and variable stresses on bighorn populations. Annual standardized population surveys, environmental monitoring and detailed health data from each herd unit provided a relatively complete picture of specific factors that may increase the risk for pneumonia epizootics and may lead to preventative management. We recommend expanding this preliminary program of population and health monitoring to additional herd units to improve risk management for respiratory disease and prevent the tremendous loss of bighorn sheep due to pneumonia epizootics.

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