POPULATION DYNAMICS OF BIGHORN SHEEP ON THE BEARTOOTH WILDLIFE MANAGEMENT AREA, MONTANA

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Abstract: A study of reintroduced Rocky Mountain bighorn sheep (*Ovis canadensis canadensis*) was conducted on the Beartooth Wildlife Management Area in west-central Montana between 1995 and 1998. Research included investigation of post-dieoff population dynamics and evaluation of a sheep augmentation program. Data were collected on sheep distribution and habitat use, reproduction and lamb recruitment, lamb and adult mortality, and general health. Particular emphasis was placed on assessing the role of mountain lion (*Felis concolor*) predation on adult sheep. Transplanted sheep (n = 39) were closely monitored to determine the effectiveness of herd augmentation. Results suggest that late summer lamb mortality and annual adult losses were responsible for a declining sheep population. Augmentation had no influence on herd productivity due to excessive loss of relocated sheep and limited annual reproduction. As a study in progress, statistical analyses have yet to be completed and conclusions are limited.

INTRODUCTION

The decline in distribution and abundance of Rocky Mountain bighorn sheep (*Ovis canadensis canadensis*) over the past century is well documented and has been attributed to a host of factors including overharvesting, loss of habitat, competition with domestic livestock, and disease (Buechner 1960). During their ascent of the Missouri River in 1805, Lewis and Clark noted bighorn sheep in many areas (Coues 1965) from which they were subsequently extirpated by the early 1900's (Couey and Schallenberger 1971). One such population, which historically inhabited the Gates of the Mountains area between Helena and Great Falls, Montana, was extirpated by 1935 as a result of overhunting and disease (Hilger 1989). Between 1971 and 1975, the State of Montana relocated a total of 113 sheep from the Sun River to the Beartooth Wildlife Management Area (BWMA) located adjacent to the Gates of the Mountains area and re-established a viable bighorn population (Rognrud 1983). Annual censuses conducted by the Montana Department of Fish, Wildlife and Parks (MDFWP) indicated a rapidly growing sheep population which approached 300 individuals by 1983, and a permit-only hunting season for 3/4 + curl rams was established in 1979 and continued through 1992. The population expanded its distribution beyond the release site and established seasonal migrations. A disease-mediated dieoff in 1984 decimated the herd and left only 51 survivors. Post-dieoff censuses between 1985 and 1994 indicated that the population had stabilized at approximately 70 individuals.

In an effort to stimulate population growth, MDFWP conducted an augmentation program in which sheep from Plains, MT (n=19) and Rock Creek, MT (n=20) were relocated to the BWMA in March 1995 and March 1996, respectively. I refer to the relocated sheep as "transplants" and to sheep previously inhabiting the BWMA as "natives" in this paper. Simultaneous with the augmentation program, a research project was initiated to investigate population dynamics of the BWMA sheep herd and to evaluate the effectiveness of herd augmentation. Specific study objectives included 1) documenting sheep distribution and habitat use, 2) quantifying and qualifying sheep reproduction, recruitment, and mortality, 3) evaluating general herd health and nutrition, and 4) monitoring transplant fates and reproductive success.

I wish to acknowledge MDFWP and Montana State University-Department of Biology for providing financial support. I thank Keith Aune and Dr. David Worley for laboratory assistance and Bob Michaelson and Terry Antonich for field assistance. Finally, I express sincere gratitude to mountain pilot extraordinaire Jim Lowe and houndsmen Gary and Scott Lankford.

STUDY AREA

The Beartooth Wildlife Management Area (BWMA) is located at the northern end of the Big Belt Mountains approximately 40 km. north of Helena, Montana (Figure 1). Purchased by the State of Montana in 1970 as elk winter range, the BWMA encompasses approximately 1,300 hectares and is annually closed from December 1 through May 15 to minimize disturbance of ungulates on winter range. Boundaries include the Missouri River and Holter Lake to the west, the Gates of the Mountains Wilderness Area to the south, and large private cattle ranches to the north and east (Figure 1). Elevations range from approximately 1100 meters along the western boundary to over 2400 meters at the southeastern corner.

Figure 1. Study area location map

Physiographic zones within the study area include 1) large flat plateaus and "bars" at lower elevations along the Missouri River with bunchgrass meadow (*Agropyron spicatum* and *Festuca idahoensis*) and Ponderosa pine parkland (*Pinus ponderosa* and *Agropyron spicatum*) communities, 2) rolling hills and rocky reefs at mid-elevations near the center of the study area with bunchgrass meadows and douglas fir (*Pseudotsuga menziesii*) communities, and 3) steep mountainous terrain at higher elevations along the southern edge of the study area with stands of douglas fir and aspen (*Populus tremuloides*) and extensive talus slopes and rock cliffs. A wildfire in 1990 burned 80% of the BWMA including much of the area currently occupied by bighorn sheep.

The general climate of the study area can be described as semi-arid with relatively hot, wet summers and cold, dry winters. Figure 2 presents monthly precipitation totals for the 3 year study period compared to the 30 year mean. Climatological data was obtained from the Holter Dam weather station located approximately 7 km northwest of the study area at an elevation of 1100 meters. Summer precipitation (May through September) accounts for 68% (21 cm) of the total annual precipitation. Figure 2 indicates 1994 and 1996 were particularly dry summers (50% of normal) and 1996 was a particularly wet summer (148% of normal). Southwesterly chinook winds are an important local climatic factor, moderating winter temperature extremes and keeping slopes with southerly aspects relatively snowfree throughout the winter.

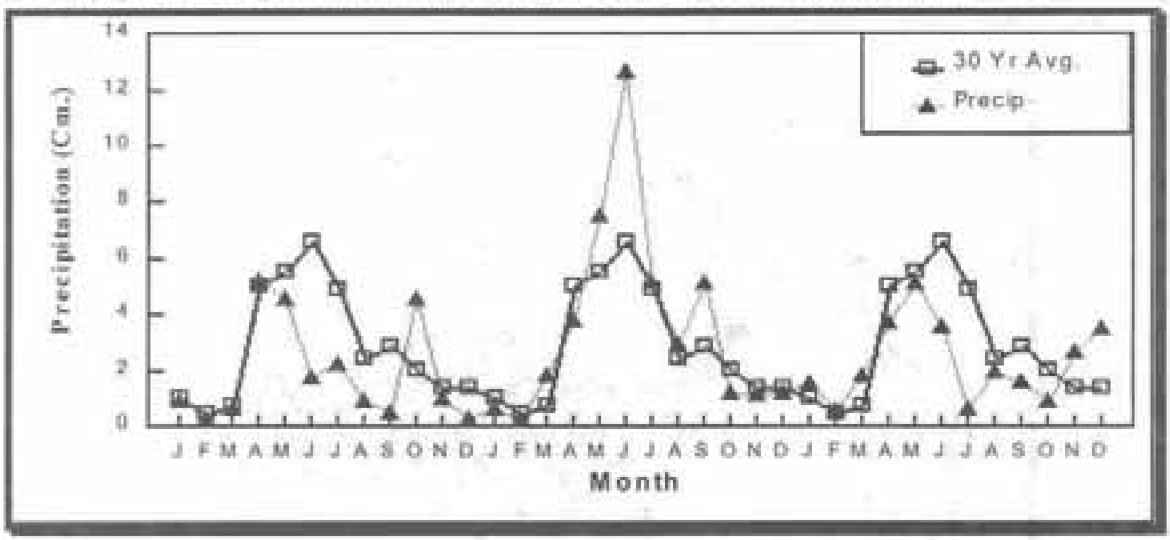

Figure 2. Monthly precipitation for January 1994 through December 1996 compared to the 30-year mean.

METHODS

Bighorn sheep (n=39) were captured via netgun by Helicopter Wildlife Management, Inc. and relocated to the BWMA. Samples (blood, nasal/pharyngeal swabs, and pellets) were obtained from each individual for health-related analyses by the MDFWP Research Laboratory and the Montana Department of Livestock Diagnostic Laboratory. All sheep were marked with numbered eartags and either a radiocollar (n=17) or an individually identifiable neckband (n=22). Mountain lions (*Felis concolor*) occupying bighorn sheep habitat were tracked and treed by trained hounds, immobilized, and fitted with radiocollars. Relocations of marked sheep and mountain lions were obtained via daily ground observations and 28 flights. Ground sightings and radio relocations utilized a Telonics receiver with a hand-held H-antenna, 8 x 42 binoculars, and a 40X spotting scope. Aerial relocations were made from a Piper Super Cub with a retractable, bottom-mounted, 3-element Yagi antenna. Relocation data were utilized to estimate sheep population size, to determine sheep dispersal and survival, and to evaluate sheep and lion distribution, habitat use, core ranges/territories. A modified Lincoln-Peterson estimator (Lancia et al. 1994) was utilized for estimating population size. The program CALHOME (Kie. Et al. 1994) was utilized to identify distribution and home range characteristics via the minimum convex polygon and harmonic mean methods. Lambing grounds were identified and monitored daily during lambing season to assess production and neonatal mortality. Sheep mortalities and lion kill sites were investigated to determine location, time, and cause of death. When possible, sheep carcasses were necropsied at the MDFWP Research Laboratory in Bozeman and samples submitted to the State of Montana Department of Livestock Diagnostic Laboratory for histological analyses.

Sheep pellet samples were collected from known individuals on a year-round basis and were obtained within 15 minutes of deposition to minimize potential contamination. Pellet samples were analyzed for lungworm via the modified Baermann technique (Beane and Hobbs 1983) and for fecal nitrogen via the Kjeldahl method (Horowitz 1980) performed at the Montana State University-Plant and Soils Analytical Laboratory.

Coyote (*Canis latrans*) and mountain lion scats were collected over the course of the study to augment predation analysis. Scats were airdried and washed and contents identified following Moore et. al (1974).

RESULTS

Sheep

1) Population size

Sheep population estimates were based upon MDFWP censuses for pre-augmentation years (1988-1994) and both census and sheep relocation data for post-augmentation years (1995-1998). MDFWP census results indicate a significant decrease following the fire in 1990, a relatively stable population between 1991 and 1995, and a decline in 1996 and 1997 (Table 1). Lincoln-Peterson estimates based upon relocation data also indicate a declining population during the study period, with the number of reproductive age ewes declining despite the addition of 29 transplant ewes.

	Total Population		Mature Ewes	
Year	MDFWP[1]	Relocation[2]	MDFWP[1]	Relocation[2]
1988	87	NA	53	NA
1989	84	NA	62	NA
1990	98	NA	69	NA
1991	56	NA	48	NA
1993	54	NA	33	NA
1995	45	69	41	54
1996	30	66	25	49
1997	20	40	10	27
1998	24	44	12	32

Table 1. Estimates of total population size and number of mature ewes based upon annual MDFWP census results[1] and Lincoln-Peterson estimates[2].

2) Distribution and habitat use

Sheep distribution was determined via construction of a 100% minimum convex polygon (MCP) utilizing all relocations excepting those associated with dispersal events. The 100% MCP indicates that total sheep habitat encompasses approximately 66 hectares and is limited to the western third of the BWMA (Figure 3). The polygon was modified to eliminate water from area calculations. Specific sheep activity areas were identified via the harmonic mean method. The 90% harmonic mean (Figure 4) reveals that the BWMA sheep population is comprised of 2 subgroups which occupy distinct portions of the study area (a northern and southern range). An 80% harmonic mean was utilized to more precisely delimit habitat use and identified 3 core activity areas within the southern subgroup range and 2 core areas within the northern subgroup range (Figure 4). These core areas are similar in that all are 1) located within lower elevations of the BWMA (<1550 m.), 2) associated with patches of escape terrain, and 3) utilized by sheep during all seasons. Although representing 80% of sheep use, these core areas encompass a total area of 12 and 8 hectares for the northern and southern subgroups, respectively. The BWMA bighorn sheep population is non-migratory and all core areas were occupied throughout the year. Several unmarked native rams (n=5) did migrate to unidentified summer range(s) outside the study area.

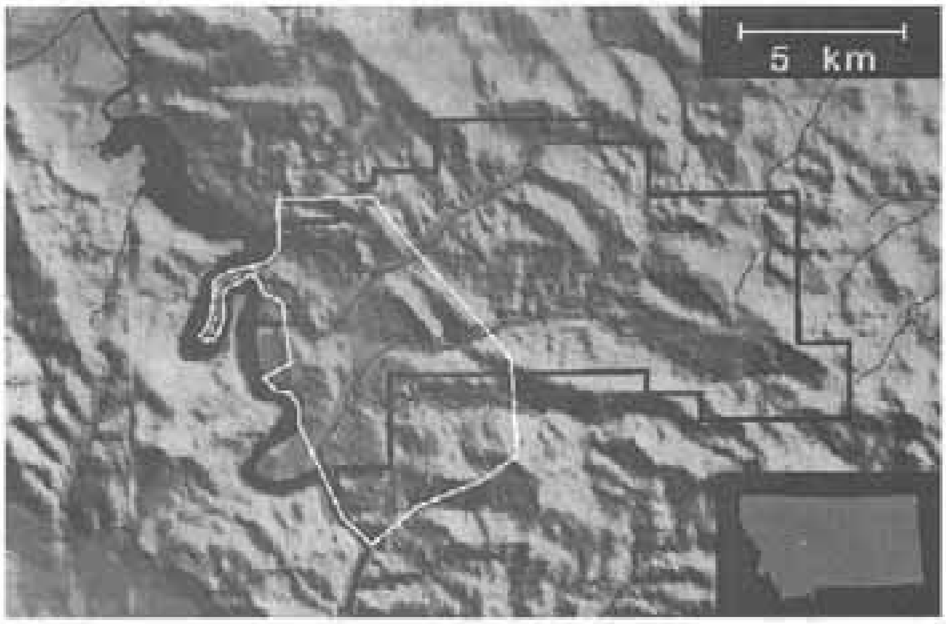

Figure 3. BWMA boundary (black line) and 100% MCP of sheep relocations (white line).

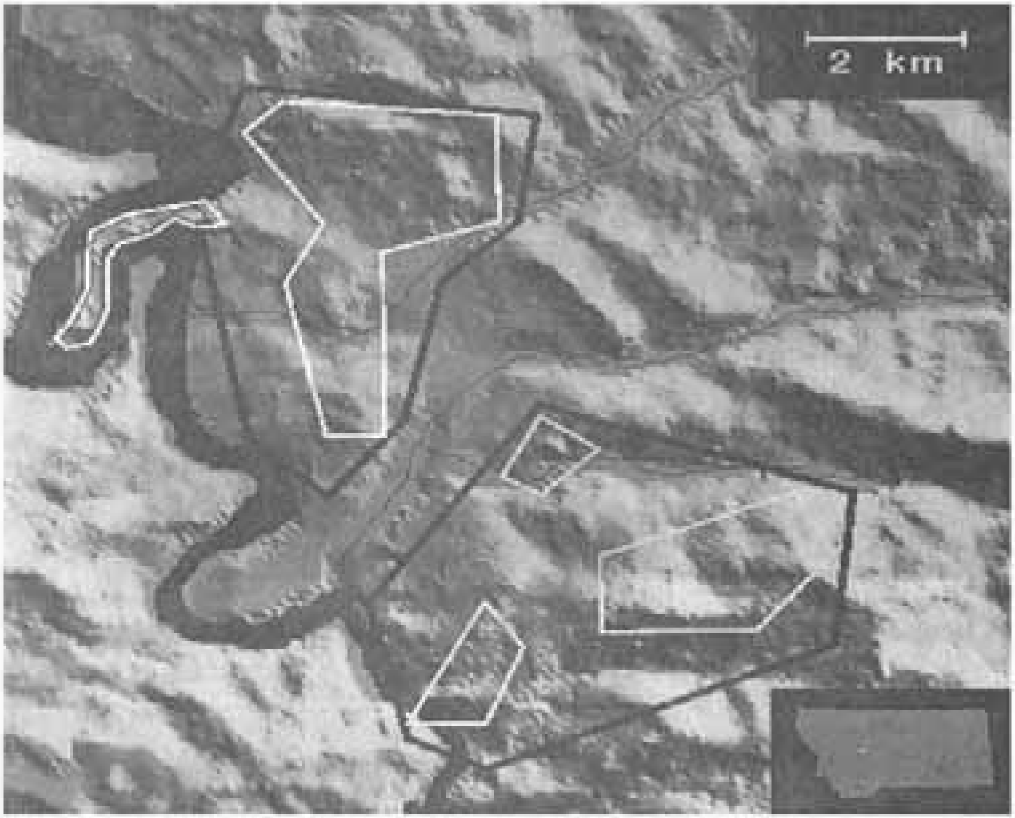

Figure 4. 90% (black lines) and 80% (white lines) harmonic means of sheep relocations.

2) Reproduction

Lambing peaked during the last week of May and extended into mid-June. In 1996, the transplant group released onto the BWMA in March 1996 lambed 3 weeks earlier than the native ewes. Lambing was generally synchronous between transplant and native ewes in 1997. Ewe production varied among years (Figure 5) with the highest production in 1996 (n=19) and lower production in 1995 (n=14) and 1997 (n=11).

Lamb survival patterns were similar for all 3 years, with most losses occurring between August 1 and September 15 (Figure 5). Little mortality occurred after this period and lambs surviving to October 1 were generally recruited into the population. Annual recruitment varied between 6 and 8 lambs and did not appear to be correlated with absolute lamb production. Lamb:ewe ratios never exceeded 40 lambs per 100 ewes, and spring ratios varied from 10 to 26 lambs per 100 ewes.

Lamb mortalities were difficult to locate and of 4 known mortalities, 2 were due to predation and 2 to disease. Both predation events occurred in 1997 while sheep were on lambing grounds and predator species could not be determined in either case. Coyotes (*Canis latrans*) are relatively common on the BWMA, yet no coyote-sheep interactions were observed over the course of the study and ewes with lambs were not overly concerned by the presence of coyotes. Golden eagles (*Aquila chrysaetos*) are extremely abundant but despite daily occurrences of eagles flying over/perching near lambs, no eagle-sheep encounters were observed and ewes were oblivious

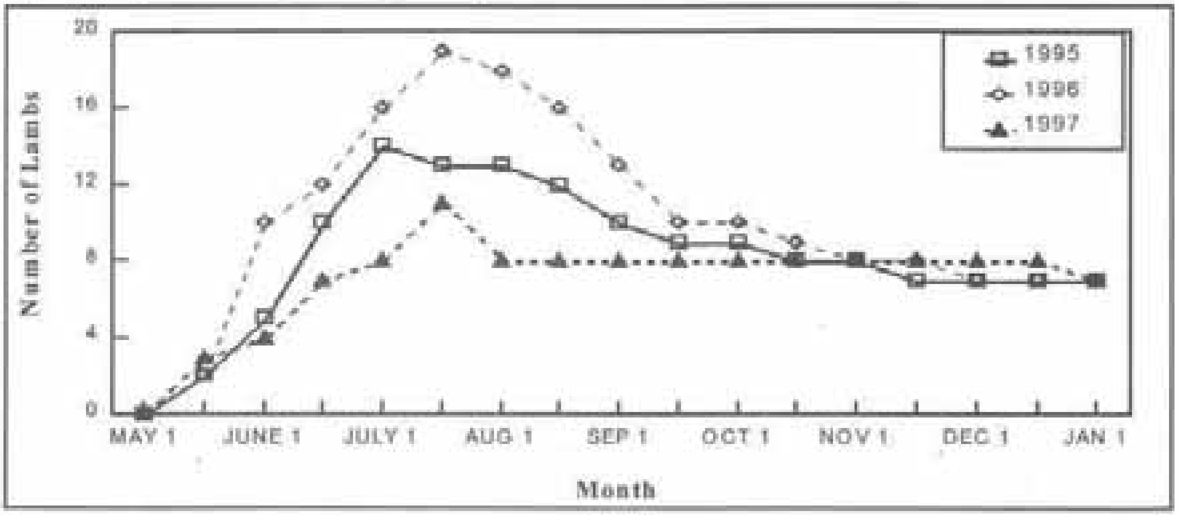

Figure 5. Lamb production and survival for the study period.

to their presence. Two disease-related lamb mortalities were discovered in July and August of 1996, 1 of which was necropsied and diagnosed as pneumonia (see necropsy results). These 2 mortalities were coincident with 1) observations of severe coughing among lambs and ewes and 2) the disappearance of numerous other lambs.

3) Adult sheep losses

Losses of marked sheep resulted from dispersal, mortality, and disappearances. Table 2 summarizes the fates of the 39 transplanted sheep. Only a third are currently alive on the BWMA, with dispersal and mortality accounting for 76% of the losses. While "random" dispersal did occur, most dispersers swam across the Missouri River and joined a small sheep herd on the opposite side. Fates of all marked sheep regardless of dispersal status are also presented in Table 2. Approximately 50% of the transplants are alive, 31% are dead (21% predation and 10% disease), and 19% have disappeared. Of 17 radiocollared sheep, 41% (n=7) are alive, 48% (n=8) were killed by mountain lions, and 12% (n=2) died from disease.

Fate	Number of sheep[1]	Number of sheep[2]
Alive	14 (on BWMA)	19
Dispersed	12	NA
Predation Mortality	4	8
Disease Mortality	3	4
Unknown	6	8

Table 2. Fates of transplanted sheep including dispersal[1] and without regard to dispersal[2]

4) Health

Results of serological tests, nasal and pharyngeal cultures, and Baermann and Lane analyses indicated that sheep transplanted to the BWMA in 1996 carried various gastrointestinal parasites and lungworm. While none of these individuals tested positive for *Pasteurella* spp., several other sheep obtained during the same capture operation did test positive. All sheep appeared to be in good health at the time of capture and there were no incidents of capture myopathy.

Two sheep carcasses (1 lamb and 1 ewe) were discovered in summer 1996 in a condition which permitted necropsy and both were diagnosed as pneumonia-related mortalities. Table 3 summarizes necropsy results for these individuals as well as previous necropsies of BWMA sheep. In all cases the diagnosis was pneumonia, individuals were in poor to fair nutritional condition with low lungworm loads, and mortalities occurred in late summer/early fall.

Another transplant ewe and lamb were discovered in late July 1996, but their condition prohibited necropsy. The ewe had dispersed from the BWMA and died in a domestic sheep pasture with no evidence of predation, trauma, or injury. The lamb died under circumstances similar to the necropsied lamb and had no visible trauma or injury. Additionally, we monitored 2 ewes during fall and winter of 1996 that were in extremely poor health. Both ewes were coughing with nasal discharge and rough pelage when last observed in late November and neither was observed again despite extensive searches.

Date	Age/Sex	Lungworm	Nutrition	Isolates	Diagnosis
09/20/84	3 Yr. ram	Few	Poor	P. hemolytica, E.coli	Pasteurellosis
09/25/84	5 Yr. ram	Many	Poor	P. multocida, E. coli	Verminous pneumonia
07/24/91	lamb	None	Fair	Streptococcus spp.	Streptococcal pneumonia
07/31/96	lamb	None	Fair	NA	Unspecified pneumonia
10/22/96	5 Yr. ewe	Few	Poor	Streptococcus spp.	Streptococcal pneumonia

Table 3. Necropsy results for sheep found within the study area

Results of Baermann analyses indicated that 97% of the adult pellet samples contained lungworm larvae. Mean monthly larval counts (expressed as larvae per gram-LPG) were relatively high and exceeded 100 LPG during several months with individual samples approaching 550 LPG (Figure 6). Lamb samples were negative for lungworm until August, at which time low shedding rates (~10 LPG) were observed.

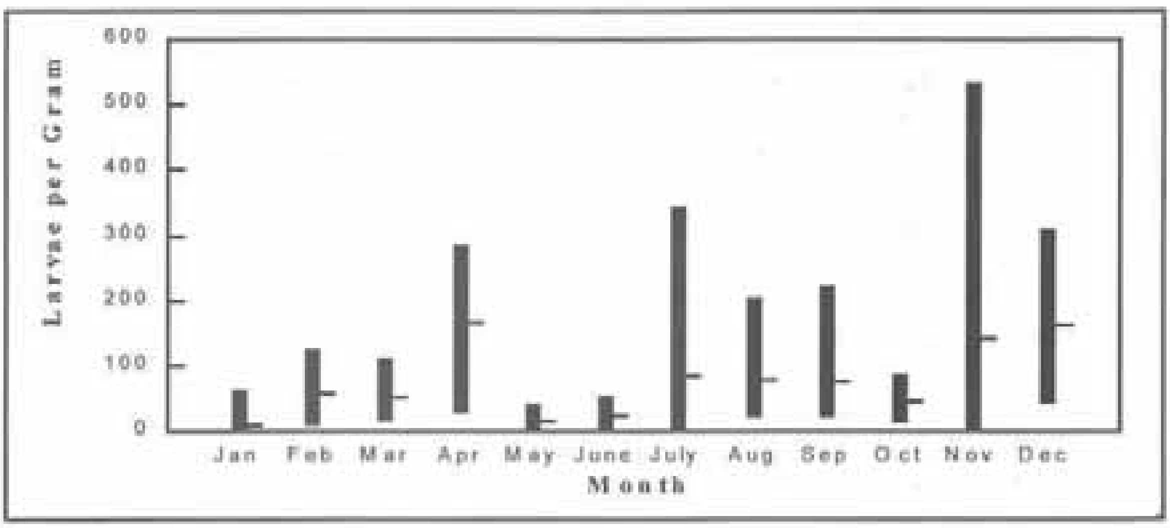

Figure 6. **Baermann results on adult pellet samples with monthly ranges (horizontal bars) and means (vertical bars).**

Kjeldahl results for adult sheep samples revealed a typical seasonal pattern of fecal nitrogen levels (Figure 7). Fecal nitrogen declined rapidly from June to October 1996, at which time they leveled off at approximately 1.3% TKN and remained at that level until April 1997. Nitrogen levels increased in May 1997 and then started to slowly decline during the summer months.

Lamb samples also revealed a seasonal trend, although lamb fecal nitrogen levels were generally higher than adult levels during late summer and fall months.

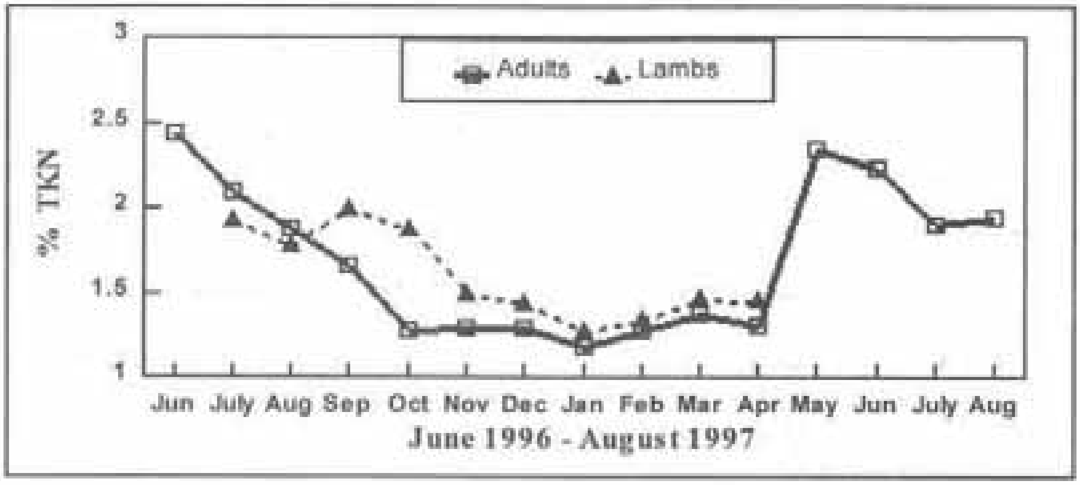

Figure 7. Monthly Kjeldahl results for adults and lambs

5) Transplant ewe productivity

Timing of the transplant events was such that ewes were bred in their indigenous habitats (Plains, MT and Rock Creek, MT) and lambed on the BWMA during 1995 and 1996. Although lambing was not monitored in 1995, data indicate that transplant ewe production varied considerably in 1996 and 1997. In 1996, 38% of the 1995 ewes and 78% of the 1996 ewes produced lambs. Proportions were reversed in 1997, with 73% of 1995 ewes and 25% of 1996 ewes producing lambs. Over this 2-year period, the 29 transplanted ewes produced total of 16 lambs on the BWMA (9 in 1996 and 7 in 1997). Data will be collected during the 1998 lambing season to augment productivity analyses.

Lions

1) Distribution and habitat use

A total of 8 mountain lions were captured and radiocollared. Mountain lions were widely distributed throughout the BWMA and principally utilized Douglas fir and ponderosa pine habitats. Relocation data and kill site analyses indicated that they relied on both vegetative cover and topographic complexity (i.e. rocky reefs and steep terrain) for traveling and stalking prey. Backtracking revealed that mountain lions were not averse to crossing large open meadows and on several occasions individuals were tracked for > 2 km. through open habitats.

Mountain lion territories significantly overlapped with occupied sheep range (Figure 8), largely due to a female territory which encompassed 4 of the 5 sheep core areas. Elk (*Cervus elaphus*) and mule deer (*Odocoileus hemionus*) winter on the BWMA and migrate to higher elevation summer ranges. Mountain lions tended to follow seasonal ungulate migrations and were therefore seasonal occupants of bighorn sheep range. Drawn by winter ungulate concentrations on the BWMA during winter months, individual mountain lion territories overlapped and it was not uncommon for several different lions, including adult males, to travel through the same drainage during a single week. As a result of mountain lion concentrations and reduced territoriality, we identified 12 different lions that spent time in occupied sheep habitat.

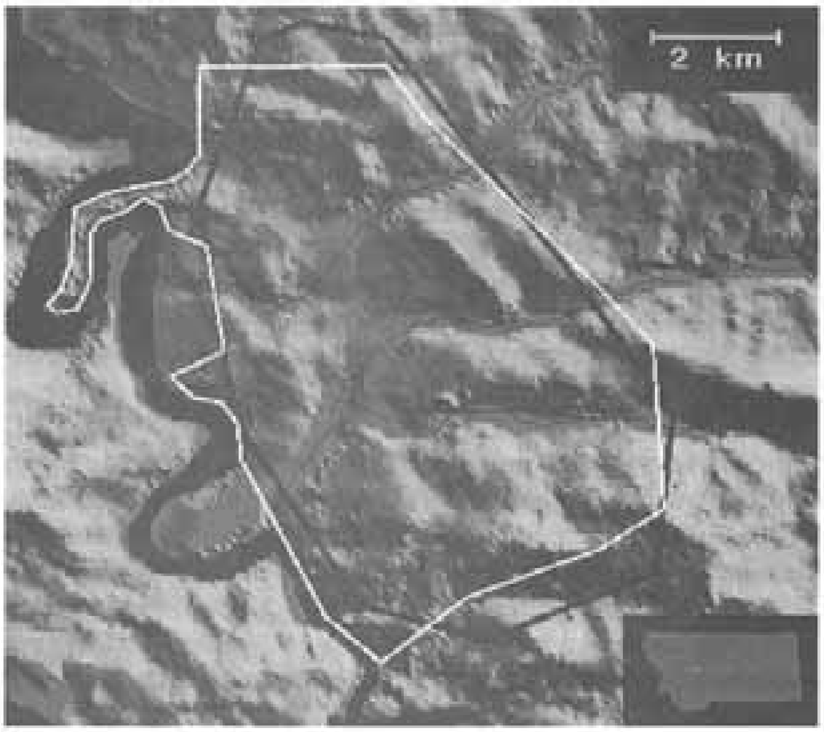

Figure 8. 100% MCP's of mountain lion F1 (black line) and bighorn sheep (white line).

2) Diet

Evaluation of 33 mountain lions kill sites within occupied sheep range indicated that deer accounted for nearly 80% of the prey base. Bighorn sheep (18%) and elk (2%) represented lesser components of mountain lion diets. Deer kills were found in all seasons while sheep kills were generally limited to spring (March and April) and early winter (November and December) periods. All sheep kill sites were located either in riparian corridors or adjacent to escape terrain. A total of 10 sheep kills (8 transplants and 2 natives) were discovered during this study when including dispersers.

Large ungulates remains were found in 100% of mountain lion scats analyzed (n=23). Sheep hair was identified in 22% of the scats (n=5), however this number may be biased due to the collection of scats at sheep kill sites. Coyote scats (n=153) were also analyzed and sheep hair was identified in 11% of the samples. Sheep hair was primarily found in coyote scats collected during winter months, and of scats collected between the months of May and November, only 3 contained sheep hair.

DISCUSSION

1) Sheep distribution and habitat use

Bighorn sheep on the BWMA are limited in distribution to small, widely dispersed core areas of low elevation, winter range-type habitats. Core area locations are largely determined by the presence of escape terrain. Sheep on the BWMA are skittish, unapproachable, and easily disturbed, a behavior likely due to 13 years of hunting pressure on the BWMA as well as hunting in the indigenous habitats of transplanted sheep (Geist 1971). The result is that sheep are frequently disturbed and subsequently flee over relatively long distances to the nearest escape terrain. Such flight often necessitates travel through "vulnerable" terrain, including riparian corridors, which increases the risk of mountain lion predation. Several kill sites were located in riparian communities. This behavioral response also represents a potential stressor, requiring expenditure of significant energy which may affect sheep health and reproductive fitness (Geist 1979)

Precipitation is critically important to promoting plant growth in semiarid habitats (Sinclair 1977) and production of quality forage is highly correlated with precipitation during the growing season (Smoliak 1986). Herbivore populations are strongly limited by their food supply and particularly by the relative quality of available forage rather than absolute abundance (Schwartz and Hobbs 1985). Many bighorn sheep populations in the Rocky Mountain region have established seasonal migrations as a behavioral response to external environmental cues, including forage availability (Geist 1971). Sheep relocated to the BWMA in the early 1970's established a seasonal altitudinal migration, an atypical characteristic of reintroduced herds (Geist 1971) which might have been due to the migratory traditions of the Sun River source herd (Erickson 1972, Frisina 1974). Seasonal migrations ceased subsequent to the 1984 die-off with the exception of a small ram group. The low elevation, non-migrational BWMA population is largely dependent upon summer precipitation which determines the temporal availability of quality forage.

2) Reproduction

Lamb production and survival on the BWMA appears to be correlated with summer precipitation and associated forage quality. The nutritional status of individual ewes, based upon the availability of quality forage, dictates the reproductive component of sheep population dynamics and appears to be critical to the BWMA sheep population. Ewe production in domestic sheep has been demonstrated to be correlated with nutritional status, particularly the periods immediately preceding conception and birth (Edey 1970). Production was low over all 3 years and ranged between a maximum of 19 lambs in 1996 (following a particularly wet summer) and a minimum of 11 lambs in 1997 (following a particularly dry summer). The observed annual variability in lamb production was likely a function of the ewes' ability to obtain adequate energy reserves necessary for viable estrus and ovulation and to support fetal growth (Gunn 1983). A significant decrease in the 1997 lamb crop also occurred on a domestic sheep ranch adjacent to the study area which experienced a 30% decline in lamb production despite supplemental feeding during winter months. The rancher attributed low productivity to the lack of precipitation and associated forage quality in summer 1996 (S. Blackman, pers. comm.). The data indicate that only 35% of all BWMA ewes produce lambs in a given year, and transplant ewe production patterns are suggestive of an alternate year reproduction which is common among "low quality" herds (Heimer 1978). Results of Kjeldahl analysis support a nutritional stress hypothesis as fecal nitrogen levels decreased rapidly during the dry summer of 1996 and likely prevented ewes from attaining body condition necessary for successful reproduction in 1997.

Lamb survival was low in all 3 years and data indicate high rates of late summer mortality. Lamb survival and recruitment is critical to bighorn population dynamics (Geist 1971) and lamb mortality has been subject to numerous investigations (Woodard et al. 1974, Spraker and Hibler 1977, Festa-Bianchet and Samson 1984, Douglas and Leslie 1986, Akenson and Akenson 1992). Studies have generally concluded that lamb mortality was due to either predation (Hass 1986, Scotton, pers. comm.) or disease (Marsh 1938, Woodard et al. 1974, Spraker and Hibler 1977, DeForge et al. 1982, Cook et al. 1990). Coyotes and golden eagles have both been implicated in populations with high rates of lamb predation (Hass 1986, Scotton, pers. comm.), which are often characterized by significant neonatal/early summer losses (Hass 1986). These studies noted regular predator-sheep interactions and observed specific ewe behavioral responses to the presence of predators. Two cases of lamb predation during this study occurred as sheep departed lambing grounds in early July 1997, which is similar to the findings of Akenson and Akenson (1992). No other known predation events/attempts were observed during this study, and ewes with lambs did not exhibit any behavioral responses when coyotes or eagles were present.

Results of scat analysis suggests that lamb predation is limited. The absence of sheep hair in coyote scats collected between May and November indicates that lambs are not a significant prey item. The majority of coyote scats having sheep hair were collected during winter months, corresponding to the peak of lion predation upon adult sheep and therefore possibly representing scavenging by coyotes. Mountain lions, whose presence on the BWMA is limited during summer months, did not prey upon lambs.

Pneumonia is often the proximate cause of disease-mediated lamb mortality and suggested ultimate causes have included loss of winter range (Woodard et al. 1974), lungworm loads (Festa-Bianchet and Samson 1984), temperature (DeForge and Scott 1982), precipitation (Douglas and Leslie 1986) and nutritional stress (Akenson and Akenson 1992). Losses resulting from disease-mediated lamb mortality typically occur in late summer and early fall (Akenson and Akenson 1992) and such timing is thought to be associated with weaning (Dr. Mike Miller, pers. comm.). Studies have also noted high rates of lamb mortality in years subsequent to a die-off event (Ryder et al. 1994). Evidence suggests that lamb mortality on the BWMA is disease-related. The majority of lamb losses (77%) occurred between late July and September 15. Two lambs that died of pneumonia were discovered in late July and early August 1996 and coincided with coughing in ewe-lamb groups. No lamb-predator interactions were observed after ewe/lamb groups departed lambing grounds. Necropsy results indicate the presence of pneumonia-inducing pathogens in this population. Sources of such pathogens could include a long-term residual effect of the 1984 die-off, *Pasteurella* spp. carried by transplanted sheep, known contact with domestic sheep and goats, and seasonal migrations of native rams.

Potential stressors resulting in lamb susceptibility to pathogens include inadequate nutrition and lungworm burdens. Lamb survival may be correlated with precipitation levels during their first summer, with 73 % survival during the wettest summer (1997) and 42% survival in the driest summer (1996). Forage quality mediated through summer precipitation affects lamb survival through both maternal nutritional status and lamb physiological condition. Low quality forage in dry years likely results in reduced lamb vigor and development and inadequate ewe milk production (quantity and quality) which results in earlier weaning and increased lamb reliance on poor quality forage. The initial appearance of lungworms in lambs in August could augment nutritionally-induced physiological stress. Several surviving lambs were relatively small as yearlings which is indicative of inadequate nutrition levels during development and which may result in reduced survivorship and lifetime reproductive potential (Gunn 1983). The production and survival rates of BWMA lambs results in very low annual recruitment levels which are inadequate for a growing or stable population (Lawson and Johnson 1982).

3) Adult mortality

Adult mortalities were associated with mountain lion predation and disease. Predation represented a significant source of mortality relative to the small sheep population (10 sheep). Other studies have found sheep to be an important dietary component for mountain lions (Williams 1992, Ross et. al 1996). Mountain lions were generally winter occupants of sheep range and sheep predation can be characterized as seasonal and opportunistic. The timing of sheep kills indicates that sheep are seasonally utilized as a supplemental dietary item while elk and deer migrations are in progress and preferred prey is unreliable. Locations of sheep kill sites suggest sheep were taken opportunistically while crossing riparian areas. Topographic features representing sheep escape terrain were also utilized by mountain lions. The use of similar landscape features by both species resulted in significant spatial overlap and increased sheep vulnerability.

Disease-related mortality of adult sheep was also seasonal, occurring in late summer and early winter months. This timing suggests that nutritional deficiencies play a role in increasing susceptibility to pathogens and the resultant pneumonia. Mortalities followed a particularly dry summer during which fecal nitrogen levels declined sharply, a factor which suggests that sheep relied on low quality forage. A necropsied ewe had a full rumen yet was in poor nutritional condition in October 1996. Bone marrow evaluation on all mortalities indicated sheep were in good nutritional status and suggests a relatively short-term decline in health as would be expected with pneumonia. Lungworm loads likely represented an additional stressor for sheep of poor nutritional status. Physiological stress resulting from poor quality forage and lungworm burdens, in the presence of *Pasteurella* spp. and other pathogens, was likely the proximate cause of these mortalities.

4) Augmentation

The primary goal of the bighorn sheep augmentation program was to stimulate population growth by increasing the herd's reproductive potential (annual lamb production). Augmentation was unsuccessful in attaining this goal due to high rates of transplant dispersal and mortality and limited transplant ewe production. Disease-mediated mortalities and predation have accounted for the loss of 32% of the transplants. Of the 39 sheep relocated in 1995 and 1996, only 38% (11 ewes and 4 rams) are currently alive on the BWMA and in 3 years transplant ewes have produced a total 16 lambs. Not only has augmentation not improved herd reproductive rates, but population estimates indicate a 20% *decline* subsequent to augmentation. This decline is attributable to a low herd productivity, limited lamb survival, and relatively high rates of adult mortality

SUMMARY

Disease-mediated dieoffs are relatively common in bighorn sheep populations, often reducing herds by >70% and expressing residual effects for several years. When reduced to low numbers, the ability of such herds to recover and attain pre-dieoff densities depends largely upon a variety of stochastic factors. Relatively small changes in annual reproduction and survival rates can dramatically influence population dynamics and determine the ultimate fate of such populations. The BWMA bighorn sheep population, reduced to approximately 50 individuals in 1984, is currently regulated primarily by limited reproduction and recruitment and secondarily by annual adult mortality. This low elevation, non-migrational population is constrained to "winter-range" type habitat throughout the year and access to quality forage during summer months is largely determined by summer precipitation levels. Nutritional stress resulting from low quality summer forage is likely the proximate cause late summer/fall mortality of lambs and adults. While winter is considered *the* critical season for bighorn sheep inhabiting the Northern Rockies, it appears that summer is the critical period for non-migrational populations limited to low elevation ranges.

Mountain lion predation accounted for significant transplant mortality and plays a significant role in the current sheep population dynamics. Results suggest that escape terrain may not provide adequate protection from predation in environments where mountain lions represent the primary predators. Given expanding mountain lion populations in the Rocky Mountain region, it may be necessary to re-evaluate "escape terrain" and sheep-predator dynamics in ecological settings similar to the BWMA.

Augmentation programs are utilized by many states and provinces as a management tool to increase productivity of bighorn sheep populations. Although relatively expensive, augmentation projects are often not evaluated with respect to the fate of relocated individuals and their ultimate effectiveness in improving population dynamics. The BWMA augmentation program was not successful in stimulating population growth. Transplant losses due to dispersal (31%) and mortality (33%), in conjunction with limited lamb production, prohibited population growth. Additionally, transmission of pathogens between transplants and natives may have resulted in adult mortalities and a declining post-augmentation population. Results suggest that prior to conducting transplant operations, managers should evaluate 1) the specific factors influencing population dynamics and 2) transplant health.

LITERATURE CITED

Akenson, J.J. and H.A. Akenson. 1992. Bighorn sheep movements and summer lamb mortality in central Idaho. Bienn. Symp. North Wild Sheep and Goat Council 8: 14-27.

Beane, R.D. and N.T. Hobbs. 1983. The Baermann Technique for estimating *Protostrongylus* infection in bighorn sheep: effect of laboratory procedures. Journal of Wildlife Diseases. 19(1): 7-9.

Buechner, H.K. 1960. The bighorn sheep in the United States: its past, present, and future. Wildlife Society Monograph #4. 174 pp.

Cook, J.G., E.B. Arnett, L.L. Irwin, and F.G. Lindzey. 1990. Population dynamics of two transplanted bighorn sheep herds in southcentral Wyoming. Bienn. Symp. North Wild Sheep and Goat Council 7: 19-30.

Coues, E. 1965. History of the expedition under the command of Lewis and Clark. Vol. II. Dover Publishing, New York. 265 pp.

Couey, F. and A. Schallenberger. 1971. Bighorn sheep. Pages 97-107 *In* T.W. Musschl and F.W. Howell, Eds. Game management in Montana. Montana Fish and Game Department, Helena, Montana. 238 pp.

DeForge, J. and J. Scott. 1982. Ecological investigations into high lamb mortality. Trans. Desert Bighorn Council 26:65-76.

_______., D. Jessup, and C. Jenner. 1982. Disease investigations into high lamb mortality of desert bighorn in the Santa Rosa Mountains, California. Trans. Desert Bighorn Council 26:76-81.

Douglas, C. and D. Leslie. 1986. Influence of weather and density on lamb survival of desert bighorn sheep. Journal of Wildlife Management 50(1):153-156.

Edey, T. 1970. Nutritional stress and pre-implantation mortality in Merino sheep. Journal of Agricultural Science 74:193-198.

Erickson, G.L. 1972. The ecology of Rocky Mountain bighorn sheep in the Sun River area of Montana with special reference to summer food habits and range movements. Masters Thesis, Montana State University, Bozeman, Montana. 50 pp.

Festa-Bianchet, M and J. Samson. 1984. Lamb survival in relation to maternal lungworm load in Rocky Mountain bighorn sheep. Bienn. Symp. North Wild Sheep and Goat Council 4: 364-371.

Frisina, M.R. 1974. Ecology of bighorn sheep in the Sun River area of Montana during fall and spring. Masters Thesis, Montana State University, Bozeman, Montana. 68 pp.

Geist, V. 1971. Mountain sheep: a study in behavior and evolution. University of Chicago Press, Chicago, Ill. 383 pp.

_______. 1979. Life strategies, human evolution, and environmental design. Springer-Verlag, New York.

Gunn, R. 1983. The influence of nutrition in the reproductive performance of ewes. pp. 99-110 in W. Haresign ed. Sheep production. Butterworths Inc., London. 214 pp.

Hass, C. 1986. Play behavior and dominance relationships of bighorn sheep on the National Bison Range. Masters Thesis, University of Montana, Missoula, Montana. 53 pp.

Heimer, W.E. 1978. Alternate year reproduction in a low quality, declining dall sheep population. Bienn. Symp. North Wild Sheep and Goat Council 2:30-40.

Hilger, B. 1989. Building the herd. Tailight Studio, Helena, Montana. 142 pp.

Horowitz, J. 1980. Official methods of analysis of the Association of Official Analytical Chemists. 13th. ed. Assoc. Off. Anal. Chem., Washington, DC.

Kie, J.G., J.A. Baldwin, and C.J. Evans. 1994. CALHOME- Home range analysis program electronic user's manual. U.S. Forest Service; Fresno, California. 18 pp.

Lancia, R., J. Nichols, and K. Pollock. 1994. Estimating the number of animals in wildlife populations. Pp. 215-553 *In*: Research and management techniques for wildlife and habitats. 5th ed. Ed. T. Bookhout. The Wildlife Society, Bethesda, Maryland.

Lawson, B. and R. Johnson. 1982. Mountain sheep. Pages 1036-1055 *In* J. Chapman and G. Feldhammer, Eds. Wild mammals of North America. Johns Hopkins University Press, Baltimore, Maryland.

Marsh, H. 1938. Pneumonia in Rocky Mountain bighorn sheep. J. Mamm. 19: 214-219.

Rognrud, M. 1983. Final Report: General wildlife restocking in Montana: 1941-1982. Federal Aid in Wildlife Restoration Final Report. 55 pp.

Ross, P.I. and M.G. Jalkotzy. 1992. Characteristics of a hunted population of cougars in southwestern Alberta. Journal of Wildlife Management. 56(3): 417-426.

Ryder, T.J., E.S. Williams, and S.L. Anderson. 1994. Residual effects of pneumonia on the bighorn sheep of Whiskey Mountain, Wyoming. Bienn. Symp. North Wild Sheep and Goat Council 9: 15-19.

Schwartz, C.C. and N.T. Hobbs. 1985. Forage and Range Evaluation Pp. 25-52 *In* R. Hudson and R. White, Eds. Bioenergetics of Wild Herbivores. CRC Press, Boca Raton, Florida. 314 pp.

Sinclair, A.R.E. 1977. The African buffalo: A study of resource limitations of populations. University of Chicago Press, Chicago, Ill.

Smoliak, S. 1986. Influence of climatic conditions on production of Stipa-Bouteloua prairie over a 50 year period. Journal of Range Management 39: 100-103.

Spraker, T.R. and C.P. Hibler. 1977. Summer lamb mortality of Rocky Mountain bighorn sheep. Transactions of the Desert Bighorn Council, pp. 11-12.

Williams, J.S. 1992. Ecology of mountain lions in the Sun River area of northern Montana. Masters Thesis, Montana State University, Bozeman, Montana. 79 pp.

Woodard, P.M., R. Gutierrez, and W. Rutherford. 1974. Bighorn lamb production, survival, and mortality in south-central Colorado. Journal of Wildlife Management 38(4): 771-774.