Population Density And Mortality Of Adult Bighorn Sheep In Hells Canyon

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

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

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

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STUDY AREA

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

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

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

METHODS

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

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

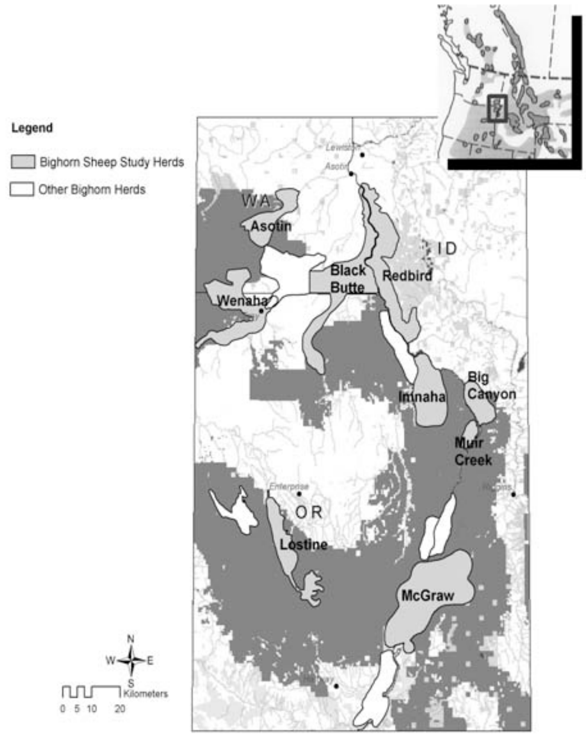

Figure 1. Hells Canyon Study Area and bighorn sheep herds.

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

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

We located all radio-collared sheep from the ground or from a fixed-wing aircraft at least bi-weekly, and often several times per week during the spring and summer. Over 95% of locations were visual. Sheep were located systematically to the greatest extent possible in order to obtain equal numbers of locations of individuals.

Radiocollars were equipped with a 4-hour delay mortality switch. When the mortality sensor was activated, we conducted a site investigation and collected the sheep where possible for evaluation at the Washington Animal Disease and Diagnostic Laboratory (WADDL) at the Washington State University Veterinary School in Pullman, WA. Where this was not possible, we conducted a field necropsy and collected tissue for gross and histological investigation at WADDL. Survival rates of radiocollared sheep were calculated using staggered entry Kaplan-Meier analysis (Kaplan and Meier 1958, Pollock et al. 1989).

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

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

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

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

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

RESULTS

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

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

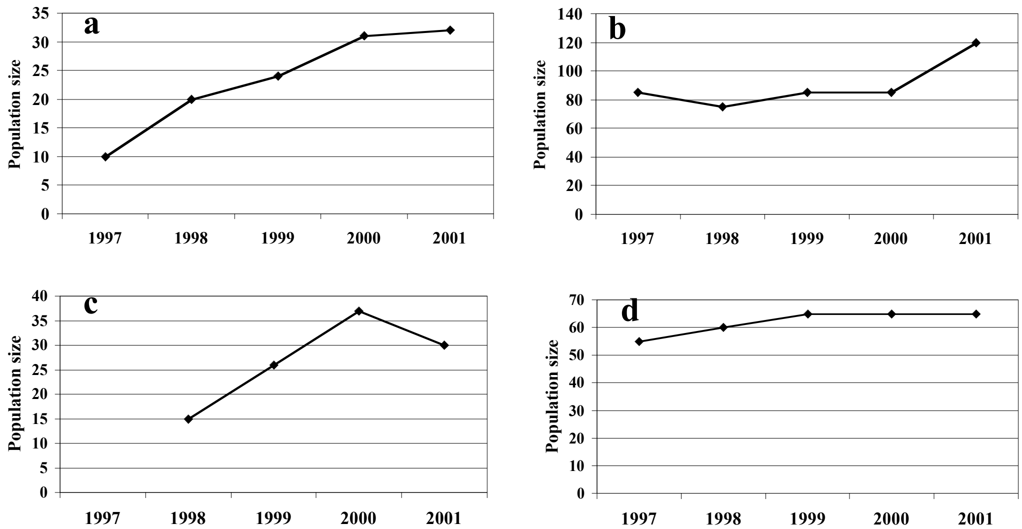

Figure 2. Bighorn sheep population dynamics 1997 – 2001 in 4 herds used in density analyses. Two herds experienced disease-related adult mortality and 2 did not. (a) Asotin, no disease; (b) Redbird, no disease; (c) Big Canyon, disease; (d) Wenaha, disease.

Survival

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

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

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

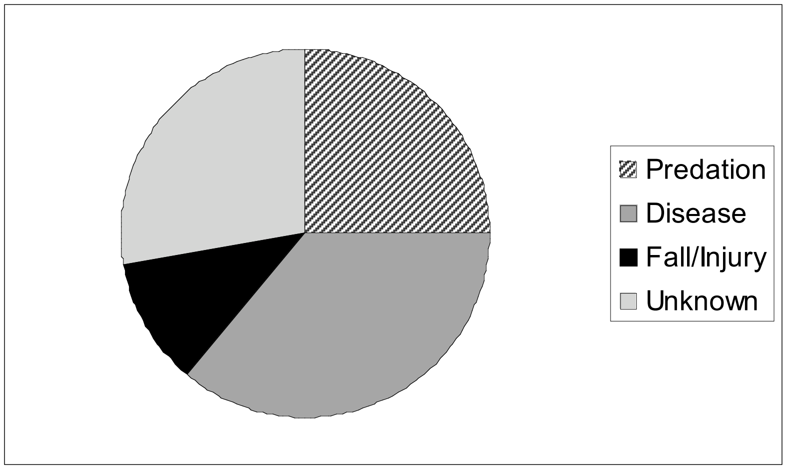

Figure 3. Causes of ewe mortality, 1997 – 2001 (n = 36).

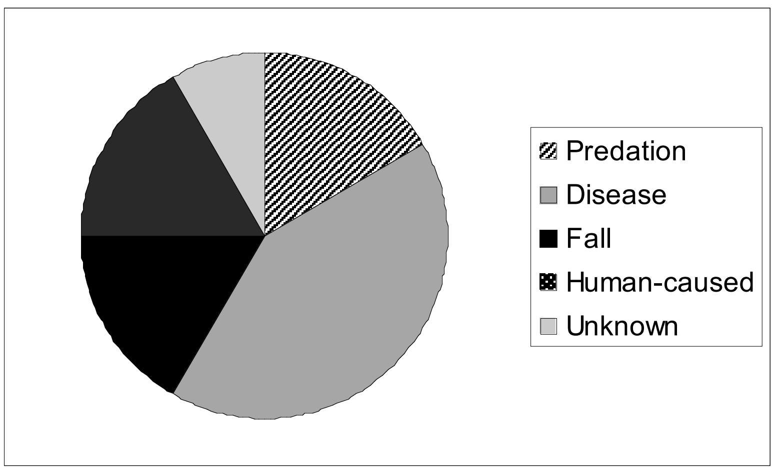

Figure 4. Causes of ram mortality, 1997 – 2001 (n = 12).

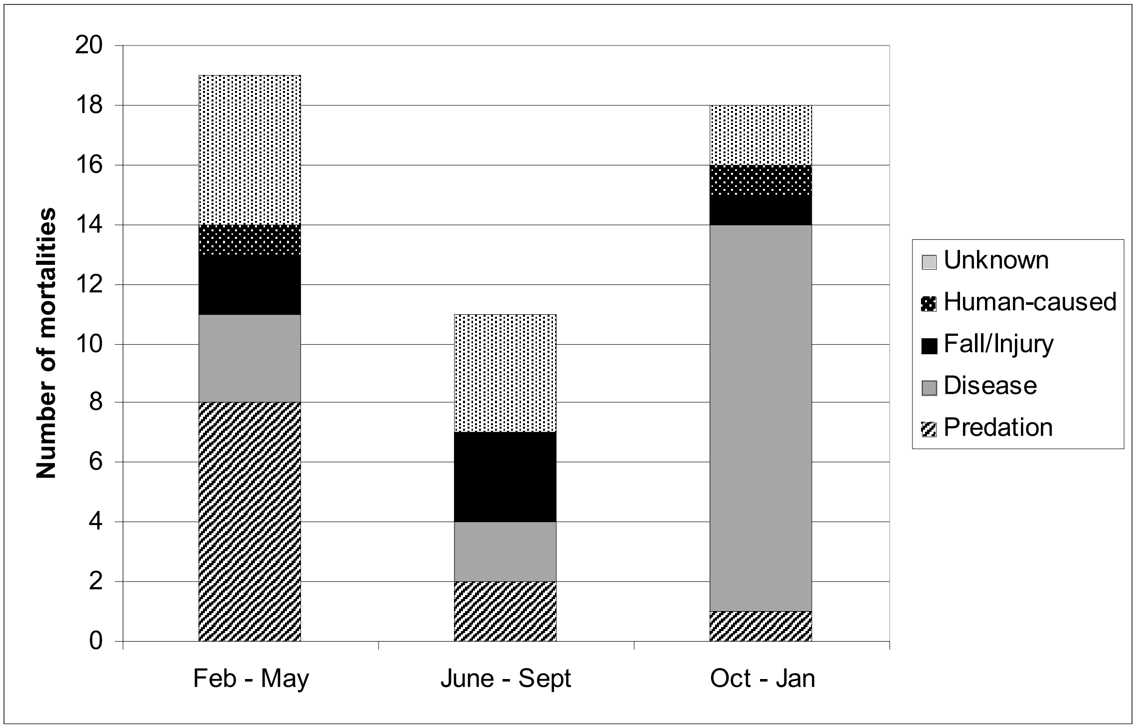

Figure 5. Seasonal occurrence of adult bighorn mortality, 1997 – 2001.

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

Population density

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

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

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

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

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

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

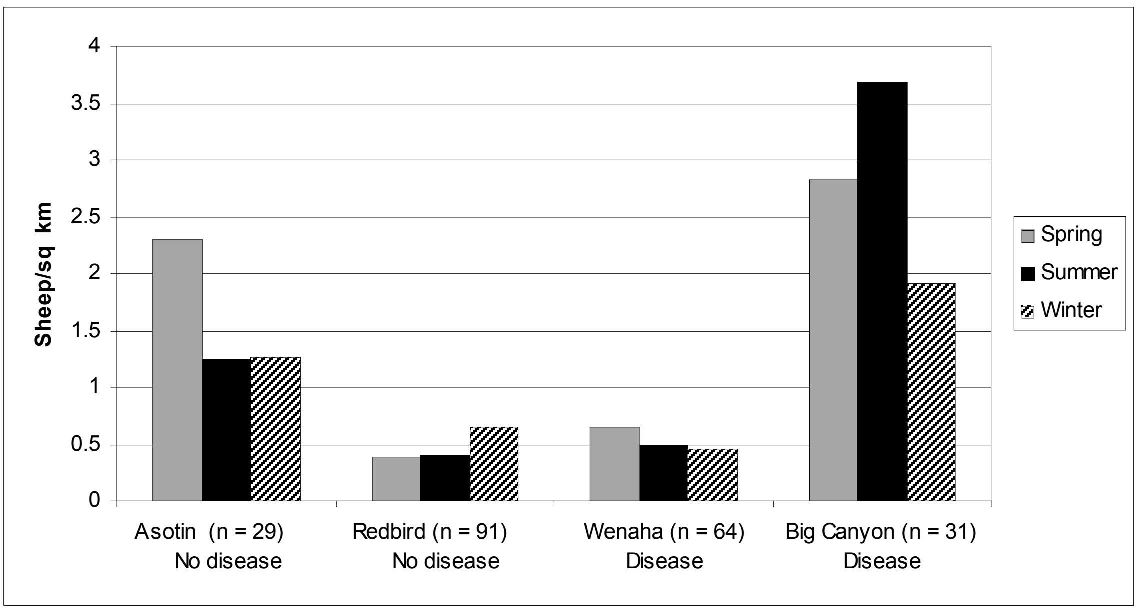

Figure 6. Average seasonal bighorn density in herds with and without disease-related mortality (100% MCP).

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

Interactions

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

DISCUSSION

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

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

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

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

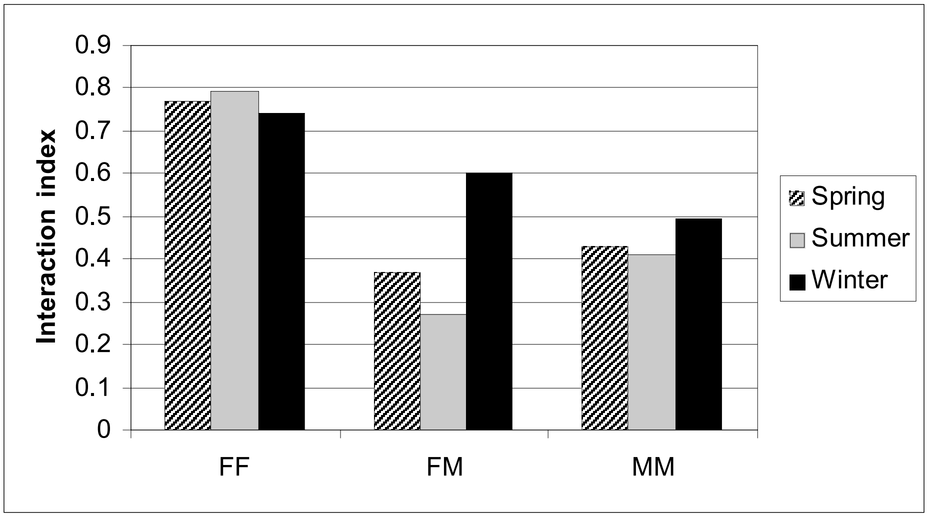

Figure 7. Seasonal interaction indices for females (F) and males (M).

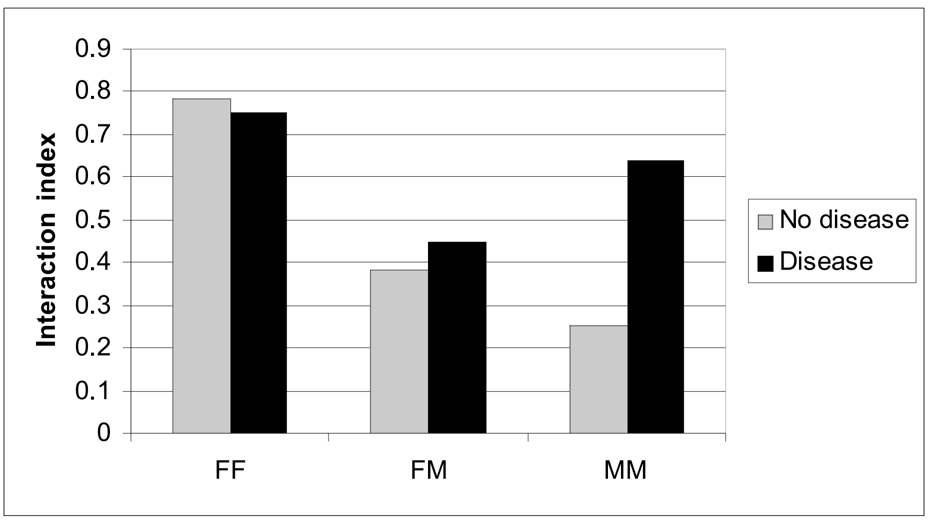

Figure 8. Female-female (FF), female-male (FM), and male-male (MM)[1] interaction indices in herds with and without disease-related mortality.

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

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

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

CONCLUSIONS

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

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