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CHLAMYDIAL-CAUSED INFECTIOUS KERATOCONJUNCTIVITIS IN BIGHORN SHEEP OF YELLOWSTONE NATIONAL PARK

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ABSTRACT: An epizootic of infectious keratoconjunctivitis occurred in bighorn sheep (*Ovis canadensis*) in Yellowstone National Park during the winter of 1981–82. The causative organism was identified as *Chlamydia* sp. Mortality related to the epizootic was approximately 60% of an estimated 500 bighorn sheep in the northern range population. The infection probably affected all sex and age classes, but field surveys of live animals and mortality suggested that mature rams died disproportionately. Limited field observations the following winter on individuals having both normal and cloudy-appearing eyes suggested that half of the bighorns then present on the core units of winter range had contracted the disease and survived. By 1988, there were about 300 bighorn sheep in the population.

Key words: Bighorn sheep, *Chlamydia* sp., chlamydiosis, follicular conjunctivitis, infectious keratoconjunctivitis, *Ovis canadensis*, population consequences.

INTRODUCTION

The bighorn sheep (*Ovis canadensis*) population of the northern winter range of Yellowstone National Park (USA) (Fig. 1) is an important component of an ecological complex. Houston (1982) reviewed the population status from the 1890's through 1978; data suggested little change in the population 1955 to 1978. Subsequently, during the winter of 1981–82, an outbreak of infectious keratoconjunctivitis with resultant indirect mortality decimated this population. Thorne et al. (1982) defined infectious keratoconjunctivitis as a broad category of inflammatory changes confined to the eye and produced by an infectious agent. They reported sporadic occurrence of the condition in mule (*Odocoileus hemionus*) and white-tailed deer (*O. virginianus*), moose (*Alces alces*), and pronghorn antelope (*Antilocapra americana*) in Wyoming. These editors considered *Moraxella* sp., which was recovered from some affected animals, to be the most likely causative organism. A bighorn ewe was reported with keratoconjunctivitis in Colorado; the causative organism was not diagnosed (Bear and Jones, 1973). In domestic animals Fraser (1986) attributed infectious keratoconjunctivitis to *Moraxella bovis* (cattle), *Rickettsia* sp. (goats), and *Mycoplasma* sp., *Rickettsia* sp., or *Chlamydia* sp. (sheep). Baas (1981) described infectious keratoconjunctivitis in domestic sheep and goats, with *Chlamydia psittaci* and *Mycoplasma conjunctivae* as the most commonly isolated organisms. Kimberling (1988) described keratoconjunctivitis (follicular conjunctivitis, FC) as an acute, contagious, usually epizootic disease of domestic sheep, caused by a chlamydial organism. Shewen (1980) reviewed chlamydial-induced infection, including keratoconjunctivitis in various hosts. Among domestic animals, mortality from keratoconjunctivitis was not indicated, although economic losses resulted from reduced mobility, diminished capacity to find feed, weight loss, and cost of care (Kimberling, 1988).

A preliminary report presented information from first reported onset in December 1981 to early February 1982, described the behavior of afflicted animals and the course of the disease as observed during winter ground searches, and reported initial mortality (Meagher, 1982). This report documents the entire epizootic, provides laboratory diagnostic information, and assesses the resulting mortality and the population consequences.

METHODS

The obvious visual impairment of a number of bighorn sheep wintering near Gardiner, Mon-

tana (USA), generated great concern among area residents; this facilitated extensive inquiries during the epizootic for observations of afflicted animals and any circumstances that might provide relevant information.

Four blind and dying bighorn rams were killed at different dates and necropsied at the Montana Livestock Diagnostic Laboratory (Bozeman, Montana 59771, USA). Eyes and adnexal structures were removed, boxed in neutral buffered formalin, and processed for routine histologic examination. Excised eyes and adnexa of an additional ram and a ewe were also examined. Tissues were cultured for bacterial agents, virus isolations were attempted, and sera were sent to the National Veterinary Services Laboratory (Ames, Iowa 50010, USA) for additional tests. Complement fixation and microimmunofluorescent antibody techniques were used for organism identification.

Seven ground searches using three to six people were made of the Mt. Everts wintering use area (45°00'N, 110°40'W) from mid-December 1981 to late January 1982. We attempted to duplicate these searches for comparability, but weather conditions, snow depths, and terrain dictated the maximum area covered. Numbers, and sex and age determinations when possible, were recorded of live and dead bighorn sheep; appearance and behavior of individuals apparently afflicted with keratoconjunctivitis were noted. From mid-January to late February, efforts concentrated on monitoring the course of the disease in individuals recognizable by horn characteristics in combination with sex, size, color shadings, and scars. Limited movement by impaired individuals facilitated monitoring. Fourteen individuals (12 rams, two ewes) were photographed for future identification. Field observations continued into April. Additional mortality was recorded as carcasses or bones were located in early summer.

Population status before and after the epizootic was assessed by using pre-lambing total winter range counts of bighorn sheep made from a Piper Supercab fixed wing aircraft during April from 1981 through 1988, conditions permitting. To maximize comparability, these surveys were flown by the same pilot (D. Stradley) who flew 58 bighorn surveys 1968 to 1978 (Houston, 1982). Supplemental aerial observations of the movements of disturbed bighorn sheep that were suggestive of impaired vision and of dead animals allowed assessment of the geographical extent of the epizootic in otherwise inaccessible pockets of winter range.

RESULTS

The epizootic apparently began among bighorn sheep along the Yellowstone River east of Mt. Everts (45°02'N, 110°39'W), just north of the park. A blind ewe was seen there in late October 1981 (Meagher, 1982) and three dead bighorn (½ curl ram, ewe, lamb) were found together there in early December. We do not know if these animals brought the condition with them as they moved from summer to winter range or whether they represented the location of initial infection and were among the first to die.

The source of infection remained unknown but the epizootic appeared to be a natural occurrence. Extensive inquiries failed to locate afflicted livestock, and the affected bighorn sheep had limited opportunity for such contact. Known summer range for these bighorn is mostly within the park and no livestock grazing allotments existed in the Absaroka Wilderness immediately adjacent to the north boundary of the park. A few domestic sheep were penned just north of the park near Gardiner, Montana, and a ranch adjacent to the Cinnabar winter range (Fig. 1) first pastured 330 domestic sheep in November 1981. Other ranches had only cattle and horses.

Gross examination of the four intact carcasses and two sets of excised eyes revealed a keratoconjunctivitis in all cases. No other significant lesions were evident. Microscopic examination of the eyes and adnexal structures indicated the keratoconjunctivitis to be of an acute to subacute duration and characterized by necrosis and a mixed leucocytic infiltrate. Macchiavello's stain revealed intracytoplasmic bodies consistent with chlamydia. Fluorescent antibody tests on conjunctival smears from one ram were positive for *Chlamydia* sp.; egg inoculation was unsuccessful. The consistency of the keratoconjunctivitis as observed in both the field and laboratory and the lack of other apparent etiologic agents led to the diagnosis of *Chlamydia* sp. as the causative agent of the keratoconjunctivitis. *Streptococcus* sp. and *Staphylococcus* sp. were isolated from eye exudate but were considered secondary. Two of the four carcasses showed a moderate verminous

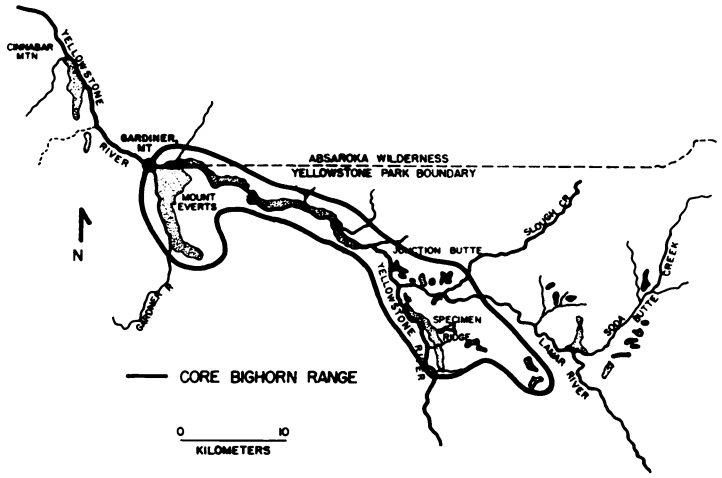

FIGURE 1. Bighorn sheep winter range in and adjacent to northern Yellowstone National Park.

pneumonia with ova, larvae, and mature nematodes identified as *Protostrongylus* sp.

Maximum numbers of bighorns observed (117), rams (46), and affected rams (30) were seen on the first search (Table 1). A number of bighorn sheep with affected eyes could be observed easily and sometimes approached to about a meter's distance. The course of the infection appeared as follows: 1 to 2 wk of intense irritation of the eyes with copious discharge (the eye or eyes were partially to completely closed, sometimes with obvious swelling of the lids); corneas of affected eyes appeared cloudy and milky blue-white, and eyes were generally open, but sometimes less so in bright light. Discharge later decreased and sometimes the cornea ruptured, or the healing process began. Eyes that appeared to be healing had noticeable dense white scar tissue which sometimes could be seen to shrink in extent almost daily; eyes would take on a purplish cast, presumably as vascularization proceeded. Progression of the infection commonly was observed to be in different stages in the two eyes of an individual.

Afflicted animals tended to move in circles when disturbed. Some undisturbed animals also circled; apparently they wished to move but could not see to travel. Animals also used a rather stilted "testing" walk, especially down slopes. Blind individuals with sighted bighorns moved more easily, apparently using their hearing ability.

During the fall and early winter of 1982–83, limited field observations in the Mt. Everts area suggested that about half of 25 bighorn sheep observed had had the infection and survived. With close observation in good light, the two eyes of some individuals appeared to be different. One eye showed the typical golden brown color of a healthy bighorn sheep eye; the other appeared somewhat cloudy with a less distinct pupil. None was seen with obvious scar tissue.

A blind ram treated with eye patches and fed hay in a corral by a local rancher survived. Two identifiable mature rams

TABLE 1. Live bighorn observed and (number affected) during ground searches 15 December 1981 to 29 January 1982.

Date	Rams	Ewes	Lambs	Total
Dec. 15	46 (30)	26 (3)	6 (0)	117 (33)[a]
Dec. 19	26 (13)	58 (3)	10 (1)	94 (17)
Dec. 22	27 (19)	59 (5)	21 (3)	107 (27)
Dec. 26	8 (2)	46 (4)	14 (0)	68 (6)
Dec. 29	20 (16)	53 (13)	13 (3)	86 (32)
Jan. 12	7 (4)	26 (5)	1 (1)	34 (9)
Jan. 29	15 (7)	16 (5)	9 (2)[b]	40 (14)

[a] Includes 39 unclassified, no apparent infection.
[b] Includes yearlings.

TABLE 2. Spring aerial counts of bighorn sheep on the northern range of Yellowstone National Park 1978 to 1988.[a]

Year	Bighorn winter range			
	Northwestern area	Core	North eastern area	Total
1978	70	371	30	471
1981	62	382	43	487
1982	56	68	35	159
1983	61	89	26	176
1984	—	90	28	118[b]
1985	—	90	32	122[b]
1986	62	119	44	225
1988	86	136	51	273

[a] No counts 1979, 1980, 1987. Count made 1978 by D. B. Houston.

[b] Northwest areas not counted.

that had a serious infection in both eyes at the same time survived. When one of these rams died in 1985, the necropsy noted that the right cornea contained a 3 mm diameter central clouded area and a slight thickening of the epithelial layer. The appearance was consistent with a prior episode of keratoconjunctivitis.

We recorded the remains of 99 bighorn sheep from December to July: 40 rams, 40 ewes, 10 lambs/yearlings, and nine of unknown sex and age. Of these, 61 died apparently where bedded, 25 died in accidents (mainly falls from cliffs), 12 were killed by park rangers and state wardens, and one lamb was taken by coyotes.

Aerial surveys (Table 2) suggested that total mortality approximated 60% of an estimated 500 northern range bighorn total population, and 80% of the core winter range.

DISCUSSION

Laboratory findings and field observations both appeared to indicate ocular involvement only, although Shewen (1980) reported a frequent occurrence of chlamydial-associated conjunctivitis with polyarthritis or pneumonia in domestic sheep. Chlamydiae were associated with polyarthritis in bighorn sheep of Wyoming (E. T. Thorne, pers. comm.) and with respiratory problems in bighorn sheep in Colorado (T. Spraker, pers. comm.); ocular involvement did not occur but ocular lesions consistent with a chlamydial-caused keratoconjunctivitis have been seen.

Initially, the infection appeared to be most prevalent in the Mt. Everts area of the winter range. Also, more rams than ewes appeared afflicted (Table 1), but this may have been deceptive for the epizootic as a whole. More rams may have acquired the infection earlier because of breeding season social interaction during November and December. Also, mature rams were classified more easily by less experienced observers, and perhaps the condition of their eyes was observed more readily. There was no apparent reason for this infection to be selective within the population as a whole. Visual impairment would have decreased foraging and sheltering ability for all afflicted animals, and otherwise caused accidental deaths or vulnerability to predators.

Nearly all recorded mortality occurred in and near Mt. Everts and Junction Butte, although the aerial surveys documented a major decrease in population throughout the core winter area. This probably reflected accessibility, level of search effort, and numbers of animals wintering in these locations rather than indicating a higher prevalence of infection. Lamb, yearling, and perhaps ewe mortality was probably under-recorded because the smaller remains of these animals were more difficult to locate or may have disappeared entirely. Searches during the epizootic also failed to locate mortality that apparently occurred in unexpected places when blind sheep moved up slopes and drainages rather than down, as weakened animals otherwise commonly do, because during the summer, bones were found at the upper elevation fringes of the Mt. Everts wintering area. Although we could not be certain such individuals had all had keratoconjunctivitis, we assumed that most finds represented afflicted animals, because

winter conditions were about average when compared to long-term weather records, because recorded mortality is infrequent most years, and because we were able to observe the presence of the infection in eyes, the physical decline in condition, and eventual death of identifiable individuals.

While the infection may have been nonselective for sex and age, mortality apparently selected disproportionately against mature rams. Of the 40 ram mortalities recorded during the epizootic, 26 were Class III from 6 to 8 yr of age (Geist, 1971) and larger. These rams expend considerable energy during the rut, which coincided with the epizootic. The cumulative energy reserve loss of rutting activity and impairment of foraging and sheltering ability could account for this disproportionate mortality. The mean early winter population composition in 1981 was probably comparable to that recorded for 1971 to 1979 in the Mt. Everts area (Houston, 1982), with 24 ± 6% males, 54 ± 4% ewes, 6 ± 3% yearling females, and 16 ± 5% lambs. Ewe mortality may have occurred in approximately the same proportion (40 of 99 dead bighorn) as their live presence of roughly 50% in the population since some of the mortalities recorded in the yearling/ewe and unknown categories were probably ewes.

Mortality selection against mature rams was further suggested by subsequent air and ground surveys; few large males were seen. Also, approximately two dozen Class III and larger ram skulls appeared suddenly in commercial markets shortly after the epizootic (J. Scrafford, pers. comm.); they were believed to have been gathered illegally in the park from locations we could not search during the epizootic. Finding these remains in remote locations is otherwise an infrequent occurrence.

Although the initial impression was that the epizootic occurred mostly in the Mt. Everts area, mortality assessed from aerial surveys indicated that all the core areas (Fig. 1) were hard hit. Houston (1982) believed that these units represented a population continuum with considerable contact and interchange; the epizootic appeared to confirm this. This core of areas totaled nearly 400 bighorn sheep in spring 1981; after the epizootic perhaps less than 100 bighorn remained (Table 1). The very low count of 68 in the core area in spring 1982 also may have reflected more than usual difficulty in locating bighorn sheep, perhaps due to smaller group size and social group disruption, as well as actual mortality. Those bighorn that apparently had the infection and survived may have had only one eye, or one eye at a time, affected.

The extent of the ocular infection in Yellowstone Park may be related to the social behavior of bighorn. At the time the infection apparently began, bighorn were moving to winter ranges and the onset of rut was not far off. Not only were the animals aggregating, but bighorn engage in a great deal of social interaction at this season (Geist, 1971), including the rubbing of the preorbital glands among individuals. This behavior would undoubtedly exacerbate this particular infection.

Houston (1982) also believed that pockets of winter range located northeast of the core area (Fig. 1) were more discrete. These outlying units were inaccessible except by aerial survey, but no animals were observed from the air to exhibit the circling movement of disturbed blind animals. The consistency of the numbers of sheep counted (Table 2) also suggests that no infection occurred, and indicates these locations are discrete from the core winter range, at least after the onset of winter.

Keating (1982) documented some interchange of bighorn sheep between the winter range at Cinnabar Mountain and Mt. Everts, but this apparently occurred infrequently or at a time of year that precluded spread of infection. The Cinnabar sheep were closely observed from a road during and after the epizootic; no cases of keratoconjunctivitis occurred.

Houston (1982) analyzed the surveys prior to 1979, noting that northern range

bighorn counts could be highly variable. The highest aerial count on record of 487 was made the spring of 1981. Using Houston's survey guidelines we believed this to be a very good count, based on excellent conditions and the long-term experience of the same sharp-eyed pilot for nearly two decades. Three aerial surveys from 1982 through 1985 suggested a population of approximately 200 after the epizootic. By 1986, recovery of the bighorn sheep population could be detected and a continuing increase was shown by the 1988 survey. These increases appeared to be real when compared to the previous several counts rather than an artifact of counting conditions, since the surveys showed more bighorn sheep in locations from which they had been few-to-absent after the epizootic.

The bighorn sheep population will continue to be monitored as conditions and availability of suitable personnel allow. The occurrence of the epizootic as a natural event has not changed park management in allowing such to run its course. However, the concern for possible adverse human-caused impacts has increased in the wake of the population crash.

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