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EVALUATION OF EWE VACCINATION AS A TOOL FOR INCREASING BIGHORN LAMB SURVIVAL FOLLOWING PASTEURELLOSIS EPIZOOTICS

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ABSTRACT: We conducted field and laboratory experiments to evaluate whether treating pregnant bighorn ewes with a combination of an experimental *Pasteurella trehalosi* and *Mannheimia haemolytica* (formerly *P. haemolytica*) vaccine and a commercially-available bovine *P. multocida* and *M. haemolytica* vaccine would increase lamb survival following a pneumonia epidemic. Three free-ranging bighorn herds affected by pasteurellosis outbreaks between November 1995 and June 1996 were included in the field experiment. Post-epidemic lamb survival was low in all three herds in 1996, with November lamb:ewe ratios of ≤8:100. In March 1997, thirty-six ewes (12/herd) were captured and radiocollared. Half of the ewes captured in each herd were randomly selected to receive both vaccines; the other half were injected with 0.9% saline solution as controls. Lambs born to radiocollared ewes were observed two or more times per week and were considered to have survived if they were alive in October 1997, about 6 mo after birth. Lamb survival differed among herds (range 22% to 100%), and survival of lambs born to vaccinated ewes was lower ($P = 0.08$) than survival of lambs born to unvaccinated ewes. Bronchopneumonia (pasteurellosis) was the dominant cause of mortality among lambs examined. We concurrently evaluated vaccine effects on survival of lambs born to seven captive ewes removed from the wild during the 1995–96 epidemic. Antibody titers were high in captive ewes prior to vaccination, and vaccines failed to enhance antibody titers in treated captive ewes. None of the captive-born lambs survived. These data suggest that, using existing technology, vaccinating bighorn ewes following pneumonia epidemics has little chance of increasing neonatal survival and population recovery.

Key words: Bighorn sheep, lamb mortality, *Ovis canadensis, Mannheimia haemolytica, Pasteurella multocida, Pasteurella trehalosi,* pasteurellosis, pneumonia, vaccine.

INTRODUCTION

Periodic pneumonia-related epidemics are common in bighorn sheep (*Ovis canadensis*), and have limited successful restoration and management of this species. Although a variety of agents may be associated with these epidemics, bacteria in the genus *Pasteurella* (some species now included in the genus *Mannheimia*) appear to be the most common (Miller, 2000). In addition to acute mortality in affected bighorn populations, pasteurellosis (here used to describe diseases caused by both *Pasteurella* spp. and *Mannheimia* spp.) epidemics are typically followed by periods of poor neonatal survival that may last for several years (Onderka and Wishart, 1984; Schwantje, 1986; Coggins, 1988; Festa-Bianchet, 1988). Typically, surviving bighorn ewes conceive and give birth, but lambs eventually succumb to pasteurellosis, presumably caused by bacteria transmitted from their dams (Foreyt, 1990; Miller, 2000). This extended period of low recruitment associated with pasteurellosis epidemics can have significant long-term impacts on bighorn sheep populations.

Numerous investigations into vaccination as a tool for preventing adult and lamb pasteurellosis have been conducted in domestic and wild sheep (Gilmour and Gilmour, 1989; Miller, 2000). Some vaccines simply failed to protect bighorn

sheep from pasteurellosis (Foreyt, 1992; Foreyt and Silflow, 1996), and others proved to be pathogenic in bighorns (Onderka et al., 1988). In contrast, more recent experimental vaccines containing leukotoxin and soluble cell surface antigens from *M. haemolytica* (formerly *P. haemolytica*) and *P. trehalosi* have offered significant protection against experimental challenge (Sutherland et al., 1989; Kraabel et al. 1998; Mosier et al., 1998). Miller et al. (1997) reported that vaccinating captive bighorn ewes increased leukotoxin neutralizing antibody titers for 12 to 16 wk and that vaccinating ewes 7 to 14 wk prior to parturition also appeared to elevate leukotoxin neutralizing antibody titers in colostrum. It follows that enhancing passive antibody transfer from vaccinated ewes to lambs through colostrum could potentially increase lamb survival by increasing immunity to *Pasteurella* spp. and *Mannheimia* spp. following pneumonia epidemics. Here, we describe field and laboratory experiments conducted to evaluate whether vaccinating free-ranging, pregnant bighorn ewes could increase lamb survival after a pneumonia epidemic.

MATERIALS AND METHODS

Efficacy of vaccination was evaluated concurrently in free-ranging and captive Rocky Mountain bighorn (*O. c. canadensis*) ewes that survived a pneumonia outbreak in the Hells Canyon area of Idaho, Oregon, and Washington, USA (Cassirer et al., 1996). Over 300 bighorn sheep died in this outbreak between November 1995 and June 1996. All-age mortality of free-ranging bighorns in three affected herds was estimated at 75% (165 sheep known dead) at Black Butte, Washington, USA (46°05′N, 116°55′W), 50% (60 sheep known dead) at Wenaha (Oregon, USA; 45°57′N, 117°30′W), and 5% (3 sheep known dead) at (Redbird, Idaho, USA; 46°16′N, 116°57′W) (Cassirer et al., 1996). Nearly all lambs born into these herds during May to July 1996 died, and November 1996 lamb : ewe ratios were 8:100 (2 lambs/25 ewes) in the Black Butte herd (BB), 7:100 (2 lambs/28 ewes) in the Redbird herd (RB), and 3:100 (1 lamb/33 ewes) in the Wenaha herd (WE).

Necropsies conducted during the epidemic diagnosed *Pasteurella* spp.- or *Mannheimia* spp.-associated bronchopneumonia as the cause of death in all cases examined (Cassirer et al., 1996). *Pasteurella multocida* was isolated from the lungs of 2 and *P. trehalosi* was isolated from the lungs of 4 of 11 pneumonic free-ranging sheep collected during the epidemic (Rudolph et al., 1999). Sixty-four of 72 bighorns captured in December 1995 and removed to a holding facility died in captivity with fibrinopurulent bronchopneumonia despite treatment that included oxytetracycline, penicillin, and ivermectin (D. Hunter, unpubl. data). *Pasteurella multocida* was isolated from the lungs of 42 and *P. trehalosi* was isolated from the lungs of 8 of 58 captive bighorns necropsied (Rudolph et al., 1999).

In our experiments, we used two vaccines in an attempt to provide broad protective immunity against bacteria that had been isolated from bighorns during the epidemic. For the field experiment, we used a split-plot design wherein individual bighorn ewes were randomly assigned to both treatment and control groups in each of three separate herds (BB, RB, and WE). Thirty-six adult ewes (12/herd) were captured by netgunning from a helicopter on 23 and 24 March 1997. Six ewes in RB and WE, and seven ewes in BB received experimental *P. trehalosi* and *M. haemolytica* vaccine (Miller et al., 1997; lot number 940902, no expiration date provided by manufacturer) injected into the right hind leg and commercially-available bovine *M. haemolytica*/*P. multocida* combination vaccine (PRESPONSE[7] H-M, Fort Dodge Laboratories, Inc.; lot number 376205A, expiration date 08/15/97) injected into the left hind leg; a full recommended dose (2 ml, delivered intramuscularly) of each vaccine was given to each vaccinated bighorn. The other six ewes in RB and WE and five ewes in BB received 2 ml intramuscular injections of 0.9% saline solution in each hind leg as controls. At capture, blood and fecal samples and oropharyngeal swabs were collected, general body condition was evaluated based on visual observation, external parasites were sampled with ear swabs and by visual observation and manual collection, and age was estimated based on tooth wear and replacement. Each ewe also was ear-tagged and equipped with a unique, mortality-sensing radiocollar.

Free-ranging bighorn ewes and their lambs were observed two or more times per wk through binoculars and 40× or 60× spotting scopes between April and October 1997. We estimated lamb production and survival by observing whether or not the ewe was lactating, and whether or not the ewe was seen with a lamb at heel (Miller et al., 2000). If a ewe was seen alone or not observed to nurse a lamb

over several observation periods, it was assumed the lamb had died. In cases where the lamb was not recovered, we estimated mortality date as the midpoint between when the lamb was last seen and when the ewe was first seen without the lamb. A lamb was considered to have survived if it was alive at the end of October.

Lamb health was assessed by looking for signs of respiratory disease including coughing, nasal discharge, drooping ears, anorexia, lethargy, and segregation from the herd. Dead lambs were located by observing ewe behavior (Akenson 1998) and scanning cliffs for carcasses. Necropsies were conducted at the Idaho Department of Fish and Game Wildlife Health Laboratory (Caldwell, Idaho, USA; IWHL), or at the Washington State University Animal Disease and Diagnostic Laboratory (Pullman, Washington, USA; WADDL). Histopathological examinations and ancillary diagnostic tests were conducted at WADDL and the University of Idaho Caine Veterinary Teaching and Research Center (Caldwell, Idaho, USA; CVTRC).

The field experiment was accompanied by a smaller study on seven surviving ewes captured at BB and transferred to captivity at IWHL during the 1995–96 pasteurellosis epidemic. Captive bighorns were held in 3 to 5 ha paddocks and fed rations of grass/alfalfa hay daily; fresh water and mineralized salt blocks were provided *ad libitum*. Two of these ewes lambed in captivity in 1996, but their lambs succumbed to pneumonia at about 4 wk postpartum. On 24 March 1997, four captive ewes were vaccinated with the two vaccines as described above, and three others were injected with saline as controls. Blood samples were collected at inoculation, 2 wk post-inoculation, and 11 wk post-inoculation. Blood samples were also collected from four captive-born lambs at 1 wk of age. Necropsies were conducted at the IWHL and diagnostic tests were conducted at CVTRC.

Levels of serum antibodies against *M. haemolytica* A1, A2, and *P. trehalosi* T10 serotype-specific surface antigens were measured using a direct microagglutination assay (Reggiardo, 1981) as described by Miller et al. (1997). Antibodies to serotype A1 and A2 antigens generally suggest exposure to *M. haemolytica* biogroup 1, and antibodies to serotype T10 generally suggest exposure to *P. trehalosi* biogroups 2 and 4CD (Ward et al., 1997; Jaworski et al., 1998); in all cases, some cross-reaction with other intraspecific serotypes may occur. Levels of leukotoxin neutralizing (LN) antibodies in bighorn sera were measured using a modified *in vitro* leukotoxin neutralization assay (Greer and Shewen, 1985; Shewen and Wilke, 1988; Miller et al., 1997). All serological tests for *Pasteurella* spp. and *Mannheimia* spp. antibody titers were conducted at the Department of Pathobiology, University of Guelph, Ontario, Canada; titers were reported as reciprocal $\log_2$ of endpoint dilutions for agglutination assays and as reciprocal $\log_2$ dilution that yielded $\geq$50% neutralization of toxicity for leukotoxin neutralization assays.

Oropharyngeal swabs were cultured and *Pasteurella* spp. and *Mannheimia* spp. isolates biotyped at CVTRC using standard techniques (Kilian and Fredericksen, 1981; Bisgaard and Mutters, 1986; Ward et al., 1986, 1999). Serologic tests were conducted for antibodies to bluetongue virus (BTV) (Agar Gel Immunodiffusion [AGID], VMRD, Inc. Pullman, Washington, USA), epizootic hemorrhagic disease virus (EHDV) (AGID: Veterinary Diagnostic Technology, Inc. Wheat Ridge, Colorado, USA), bovine respiratory syncytial virus (BRSV) (Serum neutralization [SN]: neg@1:4, National Veterinary Services Laboratories [NVSL,] Ames, Iowa; Testing Protocol 1998), parainfluenza-3 virus (PI-3) (SN:neg@1:4, NVSL Testing Protocol 1998), infectious bovine rhinotracheitis virus (IBRV) (SN: neg@1: 4, NVSL Testing Protocol BPPR02104.02, 1998), bovine viral diarrhea virus (BVDV) (SN: neg@1:4, NVSL Testing Protocol 1998), *Brucella ovis* (Elisa: Walker et al., 1985), serovars of *Leptospira interrogans* (Microaggultination: neg@1:50), and Anaplasma spp. (Complement fixation: neg@1:5) at the Idaho State Department of Agriculture Laboratory (Boise, Idaho, USA). Fecal samples from 18 free-ranging bighorns were screened for intestinal parasites using a sugar flotation technique (Foreyt, 1994); results were reported as ova or cysts per g fresh feces (opg). Abundance of lungworm larvae (*Protostrongylus stilesi* and *P. rushi*), reported as larvae per g dried feces (lpg), was estimated using a modified Baermann technique (Beane and Hobbs, 1983). Pregnancy-specific protein B (PSPB) was measured to determine pregnancy in all bighorn ewes (Sasser et al, 1986; Noyes et al., 1997).

We analyzed differences in lamb survival among herds with a Pearson chi-square statistic and vaccine effect on lamb survival using the Cochran-Mantel-Haenzel chi-square statistic (SAS Institute, Inc., 1995). Differences in pre-existing antibody titers to *Pasteurella* spp. and *Mannheimia* spp. at capture among free-ranging bighorn ewes were analyzed via two-way analysis of variance (ANOVA) with subsequent treatment assignment and herd as main effects; student's *t*-tests were used for pairwise comparisons. Student's *t*-tests also were used to

TABLE 1. *Pasteurella* spp. and *Mannheimia* spp. biogroup variants isolated from oropharyngeal swabs collected from 27 free-ranging ewes in Idaho, Oregon, and Washington, March 1997.

Successful[a] ewes			Unsuccessful ewes		
Biogroup	Hemolysis	*n*	Biogroup	Hemolysis	*n*
2	+	3	2	+	2
2^{B}	−	5	2	−	2
3^{AE}	−	2	2^{B}	−	3
9^{ABL}	−	1	2^{BCD}	−	1
10^{B}	−	3	2^{BD}	−	1
4^{BLS}	−	2	2^{D}	−	1
1	+	1	2^{D}	+	2
U^{AEL}	+	1	2^{G}	−	1
U^{L}	+	2	4^{B}	−	1
			4^{BS}	−	1
			U^{BLX}	−	1
P. multocida A		2	*P. multocida* B		1

[a] Successful or unsuccessful at raising a lamb May to October 1997.

compare titers between ewes with surviving lambs (successful) and ewes with lambs that died (unsuccessful). Differences in antibody titers in captive ewes before and after vaccination were evaluated with a paired *t*-test statistic (SAS Institute, Inc., 1995). Differences in macroparasite abundance in successful and unsuccessful ewes were evaluated with a Wilcoxon rank-sum statistic (Conover, 1980). Based on *a priori* calculations of experimental power ($1 - \beta$), we used $\alpha = 0.1$ in assessing significance in all foregoing analyses.

RESULTS

Seventeen biogroup variants of *P. trehalosi* and *Mannheimia* spp. (originally reported as *P. haemolytica*) were isolated from oropharyngeal samples of 27 of 36 free-ranging bighorns. Seven biogroups occurred in more than one ewe: T^{2B}, T^{2} (hemolytic and nonhemolytic), T^{2D}, T^{4BLS}, 3^{10B}, 3^{3AE}, and A^{UL}. *Pasteurella multocida* serotypes A (2 ewes) and B (1 ewe) also were isolated. Although most isolates were nonhemolytic (Table 1), hemolytic strains of both *P. trehalosi* and *Mannheimia* spp. were identified. No *Pasteurella* spp. or *Mannheimia* spp. were isolated from nine free-ranging bighorns sampled. *Mannheima haemoytica* (5 of 9 samples) and *Pasteurella* spp. and *Mannheimia* spp. biovariants T^{4BLS}, 3^{10B}, and 3^{3AE} were only isolated from the Redbird herd where all ewes successfully recruited a lamb. *Pasteurella trehalosi* biovariant T^{2B} occurred in all herds and biovariant T^{2} occurred only in BB and WE. No discernable differences in the occurrence of *Pasteurella spp.* or *Mannheima spp.* strains were observed between ewes that were ultimately successful or unsuccessful in recruiting lambs (Table 1).

TABLE 2. *Pasteurella* spp. and *Mannheimia* spp. biogroup variants isolated from oropharyngeal swabs collected from seven captive bighorns at the Idaho Wildlife Health Laboratory (Caldwell, Idaho), March 1997.

Biogroup	Hemolysis	Number
2	−	1
2^{B}	−	7
2^{CDES}	+	1
4^{ACDE}	−	1
9^{B}	−	1
U^{ABELX}	+	2
U^{AL}	−	1
P. multocida		1
P. multocida A		1

Seven biogroup variants of *Mannheimia* spp., *P. trehalosi*, and *P. multocida* were isolated from seven captive ewes (Table 2).

In comparison to data reported elsewhere (Miller et al, 1997; Kraabel et al., 1998), prevaccination agglutinating titers to *M. haemolytica* serotype A2 and *P. trehalosi* serotype T10 were relatively high, as were leukotoxin neutralizing titers. Prevaccination agglutinating titers to serotype T10 and leukotoxin neutralizing titers differed among free-ranging herds (Table 3), but neither mean agglutinating antibody titers nor leukotoxin neutralizing titers differed ($P > 0.50$) between ewes that were subsequently assigned to treatment and control groups. Prevaccination antibody titers among captive ewes were similar to those in the free-ranging herds, except that titers to serotype A2 were lower in captive ewes ($P < 0.01$). Prevaccination agglutinating antibody titers to *P. trehalosi* serotype T10 and leukotoxin neutralizing

TABLE 3. Average agglutinating and leukotoxin neutralizing antibody titers to *Pasteurella* spp. and *Mannheimia* spp. prior to vaccination in three free-ranging and one captive bighorn sheep herds.

	Bighorn herd				
	Black Butte	Redbird	Wenaha	P[a]	Captive
LN[b]	8.00 (0.47)A[d]	7.46 (0.47)A	10.04 (0.47)B	0.002	7.50 (0.66)
Serotype A1[c]	nd[e]	nd	nd		4.17 (0.61)
Serotype A2[c]	7.91 (0.18)A	8.25 (0.17)A	7.92 (0.17)A	0.180	5.83 (0.24)
Serotype T10[c]	9.36 (0.32)A	8.67 (0.30)A	10.67 (0.30)B	0.001	9.50 (0.42)

[a] P value for ANOVA comparing herd effects on mean antibody titers among the three free-ranging herds.
[b] Leukotoxin neutralizing antibody titers ($1/\log_2$).
[c] Agglutinating antibody titers ($1/\log_2$).
[d] Means (SE) followed by different letters are significantly different.
[e] Not done.

titers were lower ($P < 0.05$) in free-ranging ewes that succeeded in recruiting a lamb than in unsuccessful ewes (Table 4). Vaccination of captive ewes did not significantly increase leukotoxin neutralizing or agglutinating titers at 2 or 11 wk after vaccination ($P > 0.18$) (Fig. 1). Average antibody titers of captive lambs at one week of age (A1 = 5, A2 = 6.75, T10 = 4, LN = 4.63) were 46 to 88% lower than those observed in ewes prior to vaccination.

All free-ranging ewes were negative for antibodies to BRSV, BTV, EHDV, and IBRV. One successful ewe had an antibody titer to BVDV (1:64), four ewes that reared lambs had *Leptospira interrogans* serovar *autumnalis* antibody titers (1:50), and three WE ewes that failed to raise lambs tested positive for antibodies against *Anaplasma* spp. (1:10). Ten free-ranging ewes had significant antibody titers to PI-3 (range 1:16 to 1:64), and seven of these were successful at raising lambs. Five of seven captive ewes also had significant PI-3 antibody titers (range 1:32 to 1:64). All other serologic tests were negative in captive ewes.

TABLE 4. Comparison of average prevaccination *Pasteurella* spp. and *Mannheimia* spp. antibody titers in free-ranging bighorn ewes successful and unsuccessful at raising lambs during May to October 1997.

	Successful	Unsuccessful	P
LN[a]	7.89 (0.44)[c]	9.18 (0.46)	0.051
Serotype A2[b]	8.16 (0.14)	7.88 (0.13)	0.145
Serotype T10[b]	9.16 (0.29)	10.06 (0.32)	0.044

[a] Leukotoxin neutralizing antibody titers ($1/\log_2$).
[b] Agglutinating antibody titers ($1/\log_2$).
[c] Standard error.

Median abundance of *Nematodirus* spp. (3 opg), *Protostrongylus* spp. (13 lpg), and strongyles (0 opg) in free-ranging bighorns did not differ between successful and unsuccessful ewes. *Skrjabinema* spp. (median 15 opg) were found in samples from three bighorns. *Psoroptes* spp. mites were detected in four free-ranging ewes, and mild to moderate lesions but no mites were observed on another seven ewes.

Median lambing date was 20 May (range 30 April–26 July) for free-ranging bighorns and 28 May (range 21 May–30 June) for captive bighorns. We observed marked differences in lamb production and survival among the free-ranging herds ($P < 0.01$) (Table 5). Fourteen of 34 free-ranging pregnant ewes and all pregnant captive ewes either lost or failed to produce lambs. One pregnant captive ewe and one pregnant free-ranging ewe died before or during lambing and one captive ewe had twins. Five pregnant free-ranging ewes were never seen with a lamb and were assumed to have had stillborn lambs or lambs that died within 48 hr of birth. Mortality dates for lambs lost by the remaining eight free-ranging ewes were between 20 June and 12 October. Median age at mortality was 47 days for free-ranging lambs and 25 days for captive lambs.

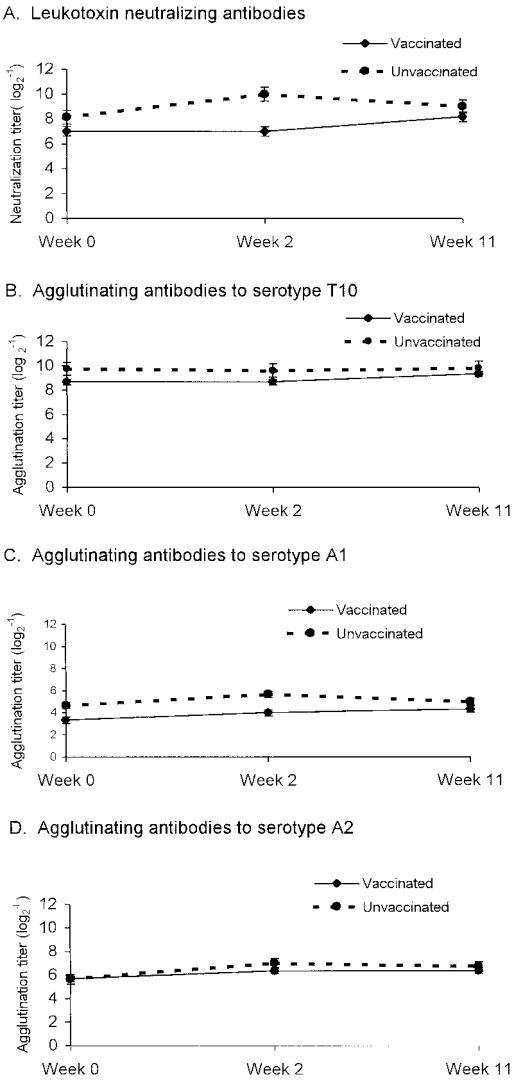

FIGURE 1. Antibody titers in response to vaccination in seven captive bighorns. Vertical lines are ± 1 standard error of mean observations.

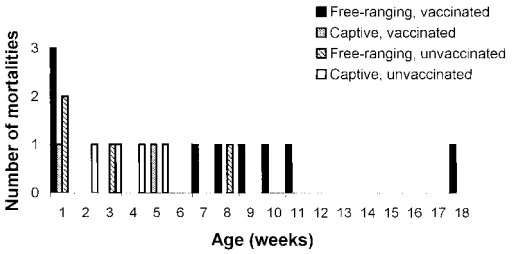

FIGURE 2. Age at death of free-ranging and captive bighorn lambs.

There was no difference in longevity of free-ranging lambs born to vaccinated or unvaccinated dams ($P = 0.13$), although median age at mortality in lambs from vaccinated dams ($n = 9$) was 57 days, whereas median age at death of lambs from unvaccinated dams ($n = 4$) was 10 days (Fig. 2). Overall, lamb survival was lower in vaccinated than unvaccinated free-ranging ewes ($P = 0.08$, Table 5).

Four of 13 dead free-ranging lambs (three from WE and one from BB) and the six dead captive lambs were collected and necropsied. Three of four free-ranging and five of the six captive lambs were diagnosed with acute bronchopneumonia. The remaining captive lamb died of starvation. The remaining free-ranging lamb was diagnosed with chronic bronchopneumonia complicated by traumatic peritonitis probably caused by aggression from an adult ewe; this ewe was observed butting the lamb repeatedly in the side prior to its death. *Pasteurella* spp. biotypes isolated from the lungs of five captive lambs and three free-ranging lambs included 2, 2^B, *P. multocida* A and *P. multocida galli.* No

TABLE 5. Ewe pregnancy and lamb survival rates in three free-ranging and one captive bighorn herd, March to October 1997.

Herd	Pregnant (%)	Number ewes observed with lambs (%)	Number surviving lambs (%) from all ewes	Number surviving lambs (%) from vaccinated ewes
Black Butte ($n = 12$)	12 (100)	8 (67)	5 (42)	2 (29)
Redbird ($n = 12$)	12 (100)	12 (100)	12 (100)	6 (100)
Wenaha ($n = 12$)[a]	10 (83)	7 (64)	2 (22)	0
Captive ($n = 7$)[a]	6 (86)	5 (83)	0	0

[a] One pregnant Wenaha ewe and one pregnant captive ewe died before or during lambing.

Mannheimia spp. were cultured from the lungs of the dead lambs. No lungworm lesions were observed at necropsy and feces of one lamb tested were negative for all parasites. Signs of respiratory distress, especially coughing, lethargy, and isolation from the herd were recorded in most free-ranging lambs that died but could not be collected. In contrast, lambs at RB (where no lamb mortality occurred) were rarely observed to be lethargic, and were never observed coughing during 6 mo of field observation.

DISCUSSION

Two yr after an all-age pneumonia epizootic, lamb survival was much lower in two free-ranging bighorn herds (BB, WE) that experienced high mortality rates (50 to 75%) during the epidemic than in a herd (RB) where estimated mortality was low (5%) during the epidemic. Similarly, captive bighorn ewes that survived an epidemic where mortality rates were high (89%) were completely unsuccessful at raising lambs 2 yr later. Pneumonic pasteurellosis appeared to be the predominant cause of mortality of both free-ranging and captive bighorn lambs. Several lambs recovered had *P. multocida* or *P. trehalosi* biovariants in the lungs that were not found on oropharyngeal swabs collected from their respective dams prior to lambing. It is possible that these strains were present but not detected in the ewe; alternatively, they may have been transmitted to the dam after sampling but prior to parturition or transmitted from another ewe or lamb to these lambs and/or their dams after parturition. None of the *Pasteurella* spp. strains isolated from the lungs of dead lambs appeared to have been introduced: all had been recovered from one or more ewes in their respective populations prior to parturition. Moreover, these isolates represented biovariants commonly found in the tonsils and nasal passages of clinically healthy bighorn sheep elsewhere (Queen et al., 1994, Jaworski et al., 1998), and some ewes carrying these biovariants successfully raised lambs in this experiment. However, no other likely initiating pathogens were found during necropsies or in the ewes sampled at capture.

Vaccinating pregnant ewes 5 to 12 wk prior to parturition was safe, but had no beneficial effect on lamb survival. In both free-ranging and captive ewes studied here, prevaccination leukotoxin neutralization titers were at or above postvaccination titers reported during previous vaccine studies on captive bighorns in Colorado, USA (Miller et al., 1997; Kraabel et al., 1998). The failure of vaccination to increase antibody titers in captive ewes may have been due to preexisting high antibody levels; similar unresponsiveness in individuals with high preexisting antibody titers has been reported in other *Pasteurella* spp. and *Mannheimia* spp. vaccine studies in bighorn and domestic sheep (Ward et al., 1999: Fig. 4C) and cattle (Hodgins and Shewen, 1994). If our observations are representative of antibody titers and likely responses in bighorn ewes following epidemics, then vaccination would be more effective in stimulating immunity in naive populations.

Antibody titers to *Pasteurella* and *Mannheimia* spp. in ewes, although high, apparently were not sufficient to enhance lamb survival. In fact, differences in agglutinating titers to serotype T10 and in leukotoxin neutralizing titers (Table 4) suggested that ewes with lower prevaccination antibody titers were actually more likely to be successful in recruiting lambs. This finding, although initially counterintuitive, is consistent with previous observations of interference between passive immunity and development of acquired immunity in a variety of animal species, including domestic sheep and cattle (Gilmour et al., 1980; Kiorpes et al., 1991; Hodgins and Shewen, 1994; Gershwin et al., 1995; Tizard, 1996). It follows that vaccinating ewes actually may have exacerbated such interference, thereby offering a plausible underlying mechanism for observed re-

duction in survival among lambs born to vaccinated ewes.

Free-ranging lambs appeared especially vulnerable to pasteurellosis from 6 to 11 wk of age, near the time that passively-acquired agglutinating and leukotoxin neutralizing antibody levels wane (Miller et al., 1997); however, one lamb succumbed to pasteurellosis in October, long after passive immunity would be expected to be protective. Thus, even if vaccination can initially enhance passive immunity to pasteurellosis, lambs still may eventually succumb in herds where virulent strains of *Pasteurella* spp. and/or *Mannheimia* spp. are circulating. Based on our findings it appears that, given existing technology, vaccinating bighorn ewes following pneumonia epidemics has little chance of increasing neonatal survival, and may be contraindicated as a management intervention.

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