THE ECOLOGY OF PENINSULAR BIGHORN SHEEP IN THE SAN JACINTO MOUNTAINS, CALIFORNIA

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INTRODUCTION

Natural history studies or case studies are important for problem solving and progress in conservation biology (Shrader-Frechette and McCoy 1993). For many species, empirical life history data needed for computer simulation modeling are lacking. Additionally, knowing the distribution, demography, survival, and recruitment of a population is fundamental to understanding the causes for a population decline and determining management options to restore a population (Caughley and Gunn 1996). In this study, we investigated a small population of desert bighorn sheep (*Ovis canadensis* cremnobates) to obtain baseline health and demographic information and to develop management recommendations aimed at regaining population viability.

Peninsular bighorn sheep range from the San Jacinto Mountains, California to the Santa Rosalia area of Baja California, Mexico, although the southern extent of their range is not well defined (Clark 1964, Jimenez et al. 1996). Peninsular bighorn within the U.S. were estimated to number 1,171 as recently as 1979 (Weaver 1979), but helicopter surveys conducted in 1996 by Bighorn Institute (BI) and the California Department of Fish and Game (CDFG) indicated that only approximately 280 adult bighorn remained. Peninsular bighorn have been listed as threatened by the State of California since 1972 and were proposed for Federal listing as endangered in 1992. A ruling on the proposed listing remains pending.

The San Jacinto Mountains (SJM) bighorn population comprises the northernmost deme of the Peninsular bighorn metapopulation and is a geographically peripheral population. In 1969, based on sight records and bighorn sign, it was estimated that 80 bighorn inhabited the SJM (Weaver and Mensch 1970). The population estimate was increased to 280 bighorn (Weaver 1979) after volunteers counted 285 bighorn at a 1973 water hole count. From 1974 to 1977, recruitment was high and the number of adult bighorn observed during summer water hole counts ranged from 94-131 (Society for the Conservation of Bighorn Sheep 1984); however, population numbers and recruitment declined thereafter. While 94 adult bighorn and 10 lambs were counted during a 1977 SJM waterhole count, only 45 adult bighorn and no lambs were counted in 1978 (Society for the Conservation of Bighorn Sheep 1984). Since 1977, the number of bighorn counted during annual waterhole counts or helicopter surveys in the SJM has failed to surpass 45 animals (Society for the

Conservation of Bighorn Sheep 1984, BI unpubl. data). A similar population trend was reported for the neighboring Santa Rosa Mountains (SRM), where a disease outbreak reportedly struck bighorn in the late 1970's (DeForge and Scott 1982, Wehausen et al. 1987, DeForge et al. 1995). This epizootic contributed to at least 13 years of poor recruitment and an 81% population decline in the SRM adult bighorn population between 1979 and 1996 (DeForge et al. 1995, BI unpubl. data). Here, we document a decline in the SJM bighorn population and examine the recent distribution, home range, survival, and reproductive rates of this population.

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STUDY AREA

The SJM of Riverside County are a northwest extension of the SRM, and constitute one of the Peninsular Ranges of California. In less than 12 km, San Jacinto Peak rises from 243 m to 3,294 m above sea level, creating the steepest escarpment in North America. Although the SJM are not a true desert range, the eastern-facing desert slopes are within the Colorado sub-division of the Sonoran Desert. Deeply cut canyons and steep arid slopes create desirable bighorn habitat. Weaver and Mensch (1970) used a modified version of Hansen's habitat evaluation technique and classified the SJM range as "important to bighorn." The rock mass of the SJM is classified as Mesozoic granite, but metamorphic rocks are common on the eastern slopes. Annual rainfall on the desert slopes of the SJM averaged 14.4 cm between 1982 and 1996 (data for the Palm Springs Airport from the Western Regional Climate Center). Vegetation within bighorn habitat is dominated by brittlebush (*Encelia farinosa*), creosote bush (*Larrea tridentata*), burro-weed (Ambrosia *dumosa*), catclaw (*Acacia* greggii), indigo-bush (*Psorothamnus* schotti), desert apricot (*Purnas fremontii*), barrel cactus (*Ferocactus cylindraceus*), cholla cactus (Opuntia spp.), and agave (*Agave* deserti). Most canyons within bighorn habitat have perennial water sources.

Land ownership within bighorn habitat is shared by the Agua Caliente Indian Reservation, USFS, BLM, and the private sector. The eastern edge of this range is bordered by City of Palm Springs. Within the central portion of this range, the Palm Springs Aerial Tram was constructed in Chino Canyon beginning in the mid 1950's and was completed in 1963.

METHODS

Helicopter surveys were conducted by BI in 1983, 1984, and then annually beginning in 1987, primarily to record population trends and range use. The range was flown south to north using a Hughes 500D or Bell Jet Ranger helicopter with 3 observers accompanying the pilot. The doors of the aircraft were removed for optimum visibility. Surveys were completed in 1.0-4.8 hours of flight time. Before 1993, we surveyed all bighorn habitat from Murray Canyon to Snow Creek. In 1993, a 4.8 hour census/search was conducted using radio-telemetry to assist in locating bighorn. Because the northern portion of this range appeared to have been abandoned after 1989, our 1994-1996 surveys were focused south of Blaisdell Canyon and the range north of this canyon was flown only cursorily. Data collected when bighorn were sighted included date, time, group size, group composition, location, and elevation. Bighorn locations were plotted on 1:62,500 topographical maps at the time of the sighting. Surveys were conducted in September-November, except for the May 1984 survey and a June 1994 flight conducted in addition to the fall 1994 survey.

In 1992, a cooperative study with BI, CDFG, BLM, USFS, and USFWS was initiated. Between December 1992 and December 1996, 20 bighorn were captured (including 2 animals that were captured twice) via a net-gun fired from a helicopter for radio-collaring and/or biological sampling. Nine bighorn (4 M, 5 F) were captured in December 1992, 7 (4 M, 3 F) in December 1995, and an additional 4 animals (2 F, 1 M, and 1 lamb) were captured in November 1996. Upon capture, bighorn were blindfolded, hobbled, and approximately 120 cc of blood were collected by jugular venipuncture. Blood was transferred into 10-ml sterile integrated serum separator tubes for serum chemistry analysis and serology, into 3-ml heparinized tubes for bluetongue (BT) virus and epizootic hemorrhagic disease (EHD) virus isolation, into 3-ml liquid ethylenediaminetetraacetic acid (EDTA) (K_3) for hematological examination, and into 10-ml EDTA (K_3) tubes for genetic analysis. Serum chemistry panels were not conducted on bighorn sampled in 1992. Sera were evaluated for antibodies against BT, respiratory syncytial virus (RSV), border disease (BD), *Brucella ovis*, *Chlamydia*, contagious ecthyma (CE), EHD, infectious bovine rhinotracheitis (IBR), *Leptospira*, *Mycoplasma*, ovine progressive pneumonia (OPP), Parainfluenza-3 (PI-3), *Coxiella burnetii* (Q fever), *Toxoplasma*, and *Anaplasma*. Hair follicles and clots from whole blood were collected for mitochondria1 DNA sequencing and microsatellite DNA typing.

Nasal swabs were placed in modified Amies clear transport medium for aerobic bacterial culture and identification, although nasal swabs collected in 1992 were examined only for the presence of *Pasteurella* species. Additional nasal swabs were transferred into virus antibiotic media A for isolation of RSV, BD, IBR and PI-3 viruses. Pharyngeal swabs were collected for *Pasteurella* species culture and identification from animals sampled in 1992.

Fecal samples for ova and parasite examination were collected from each bighorn. Ticks and earswabs were collected and sent to the Department of Veterinary Pathology, Microbiology and Immunology, University of California, Davis, where ticks were identified and ear swabs were examined for *Psoroptes* mites. Test procedures and laboratories used are listed on Table 1. A total of 17 bighorn were fitted with ear-tags and Telonics MOD 400, 500, or 505 radio-collars with mortality sensors.

For each radio-collared bighorn, we obtained telemetry readings weekly and attempted to obtain either visual or fixed-wing telemetry locations a minimum of twice per month from the date of collaring through June 1997. Ground field work was supplemented by 30 fixed-wing telemetry flights. Data collected upon visual location of bighorn included animal identification, date, time, location (Universal Transverse Mercator coordinates), group size and composition, and animal health condition (McCutchen 1985). Records of the largest number of each age and sex class observed during ground field work were confirmed with helicopter survey data each year to determine annual population estimates, sex ratios, and recruitment.

Home range sizes were estimated for bighorn that were located on ≥25 independent occasions (locations >24 hours apart). Because of differences in monitoring intensity and an obvious visibility bias in the northern SRM as compared to the SJM, only locations of bighorn in the northern SRM (ram 560) that were >7 days apart were included in the home range analysis. We used the fixed kernel estimator in KERNELHR version 4.25 (Seaman and Powell 1996) to estimate the home range and core use areas, defined as the 95% and 50% utilization distributions (UD), respectively. As recommended by Worton (1989), least squares cross validation was used to determine the smoothing parameter for kernel estimates. Mann-Whitney U tests (Sokal and Rohlf 1995) were used to test for differences in home range size between sexes.

For the survival analysis, bighorn were considered at risk from the date of collaring until they died or until December 31, 1996. Bighorn detected on mortality mode were retrieved as soon as possible to determine the cause of death, which was classified as predation, capture-related, disease, or unknown. Annual survival rates based on a calendar year were calculated using the Kaplan-Meier method (Kaplan and Meier 1958, Pollock et al 1989).

RESULTS

Health Status

None of the bighorn captured or observed during ground field work displayed overt signs of illness. Overall, results from diagnostic testing of the SJM bighorn indicated limited disease exposure (Table 1). Of the bighorn tested, 66.7% (619) were seropositive for *Anaplasma*, but no anaplasma organisms were reported from stained blood smears submitted for hematology. Antibody titers (1:10 to 1:20) against Q Fever were reported in 54.5% (6111) of the bighorn, and 50% (10120) mere positive for EHD. Titers to Chlamydia, BT, RSV, and CE were also detected (Table 1). None of the 20 bighorn tested showed exposure to BD, IBR, *Leptospira*, OPP, or PI-3 virus. Eleven of 20 bighorn displayed eosinophilia (eosinophils comprised >10% of white blood cells), and 1 animal was monocytotic (monocytes comprised >6% of white blood cells). Two of 11 bighorn had creatinine phosphokinase (CPK) values >2,000 IU/l. All other hematology and serum chemistry values were within normal ranges established for desert bighorn sheep (BI unpubl. data).

Pasteurella spp. were isolated from the nasal or pharyngeal swabs of 44.4% (8118) of the bighorn sheep sampled. Streptococcus *viridans* was the next most prevalent bacteria isolated from nasal or pharyngeal swabs (Table 2). No viruses were isolated from nasal swabs or blood. No ova or parasites were identified from fecal samples and no mites were recovered from earswabs. Ticks (*Dermacentor hunteri*) were found on 10120 bighorn. Results from genetic analyses will be presented elsewhere.

Distribution and Movements

We observed bighorn sheep at elevations from, 213-1,037 m. Deer (*Odocoileus* herniontw) were occasionally encountered in the upper elevations of bighorn habitat during helicopter surveys. No feral animals were seen within the bighorn range. During 1983-1988 helicopter surveys, bighorn were located in Hurricane, Blaisdell, Chino, or Tachevah canyons, whereas during 1990-1996 surveys, bighom were observed in southern Chino Canyon, and Tachevah, Tahquitz, Eagle, and Andreas canyons (Figure 1).

Most locations of radio-collared adult bighorn monitored in 1992-1997 were between southern Chino Canyon and northern Andreas Canyon. All radio-collared ewes were located within this area, however, multiple intermountain ram movements were recorded. A ram estimated to have been born in 1987 (ram 560) crossed to the adjacent SRM and joined a small herd of bighorn there for the rut in 1993-1996. Ram 560 was observed within the northern SRM bighom deme from September 20, 1993-November 13, 1993; September 6, 1994-November 5, 1994; August 6, 1995-November 2, 1995; and September 2, 1996-October 1, 1996. In 1996, a 9-year-old radio-collared ram from the SJM was found dead from unknown causes in Palm Canyon in the northern SRM.

Intermountain movements, or attempts thereof, by un-marked rams were also documented. An unmarked 4-year-old ram moving east toward the northern SRM was observed in the City of Palm Springs in October 1993. In 1995, 2 un-collared yearling rams from the northern SRM bighorn deme attempted to cross through Palm Springs toward the SJM, although traffic,

Table 1. Diagnostic test results for the presence of disease agents and internal parasites in bighorn sheep *(Ovis canadensis cremnobntes)* captured in the San Jacinto Mountains, California 1992, 1995, and 1996.

Infectious agent or disease	Test type	Test location	No. pos. **1992**	No. pos. **1995**	No. pos. **1996**	No. pos. total (percent)
Anaplasma	CARD test	CVDLS	6/9	nt	nt	619 (66.7)
Bluetongue	AGID, CF, ELISA	TEXAS, NVSL, CVDLS	419	2/7[a]	0/4	6/20 (30.0)
Bluetongue	VI	CSU-CVDL, PENN	0/9	0/7	0/4	0120 (0)
Border disease	SN	CVDLS	0/9	0/7	0/4	0120 (0)
Border disease	VI	PENN	0/9	0/7	014	0/20 (0)
Brucella ovis	ELISA	CVDLS	0/9	0/7	0/4	0/20 (0)
Chlamydia	CF	NVSL	3/9[c]	0/6	0/4	6/19 (31.6)
Contagious ecthyma	CF	NVSL	1/9[a]	1/6[d]	0/4	2/19 (10.5)
Coxiella burnetii (Q fever)	CF	NVSL	nt	3/7[e]	3/4[e]	6/11 (54.5)
Epizootic hemorrhagic disease	AGID	CVDLS	2/9	7/7	1/4	10/20 (50.0)
Epizootic hemorrhagic disease	VI	CSU-CVDL, PENN	0/9	0/7	0/4	0/20 (0)
Fecal parasites or ova	flotation/Baermann	PAL	0/9	nt	0/4	0/13 (0)
Infectious bovine rhinotracheitis	SN	CVDLS	0/9	0/7	0/4	0/20 (0)
Infectious bovine rhinotracheitis	VI	PENN	0/9	0/7	0/4	0/20 (0)
Leptospira	MAT	CVDLS	0/9	0/7	0/4	0/20 (0)
Mycoplasma	culture	CVDLS	nt	0/7	0/4	0/11 (0)
Ovine progressive pneumonia	AGID	CVDLS	0/8	0/7	0/4	0/19 (0)
Parainfluenza-3	HI	TEXAS, CVDLS	0/9	0/7	0/4	0/20 (0)
Parainfluenza-3	VI	CSU-CVDL, PENN	0/9	017	0/4	0120 (0)
Respiratory syncitial virus	IFA	CVDLS	2/9[b]	0/7	0/4	2/20 (10.0)
Toxoplasma	LAT	CVDLS	1/9[f]	0/7	0/4	1/20 (5.0)

AGID = agar gel immunodiffision; CF = complement fixation; ELISA = enzyme linked immunosorbent assay; VI = virus isolation; IFA = indirect fluorescent antibody; SN = serum viral neutralization; MAT = microagglutination test; HI = hemagglutination inhibition test; LAT = latex agglutination test: TEXAS = Texas A&M University, College Station, Texas; NVSL = National Veterinary Services Laboratory, Ames, Iowa; CVDLS = California Veterinary Diagnostic Laboratory System, Davis, California; CSU-CVLS = Colorado State University - Colorado Veterinary Diagnostic Laboratory; PENN = Animal Diagnostic Laboratory, The Pennsylvania State University, University Park, Pennsylvania: PAL = Professional Animal Laboratories, Inc., Irvine, California (now known as Antech Diagnostics); nt = not tested.

[a]Titer range: 1:20
[b]Titer range: ≥1:20
[c]Titer range: ≥1:40
[d]Titer range: 1:5
[e]Titer range: 1:10 to 1:20
[f]Titer range: 1:16

Figure 1. Locations of Peninsular bighorn sheep (*Ovis canadensis cremnobates*) seen during 1983-1996 helicopter surveys of the San Jacinto Mountains. Solid boxes represent locations of bighorn 1983-1988; open boxes are locations of bighorn 1989-1996. Map scale: 1 cm represents 1 km, 50 m contour interval.

Table 2. Bacteria cultured from nasal and pharyngeal swabs from bighorn sheep *(Ovis canadensis* cremnobates) captured in the San Jacinto Mountains, California, 1992, 1995, and 1996. Testing was conducted at Professional Animal Laboratories, Inc., (now known as Antech Diagnostics) Irvine, California.

Bacteria	No. positive **1992**	No. positive **1995**	No. positive **1996**	Total no. positive (percent)
Streptococcus *viridans*	nt	4/5	014	4/9 (44.4)
Klebsiella pneumoniae	nt	015	2/4	219 (22.2)
Bacillus spp.	nt	1/5	¼	2/9 (22.2)
Pseudomonm *aeruginosa*	nt	1/5	¼	219 (22.2)
Escherichia coli	nt	015	¼	1/9 (11.1)
Pasteurella spp.	7/9[a]	1/5	0/4	8/18 (44.4)
Staphylococcus aureus	nt	115	0/4	119 (11.1)

nt=not tested
[a]*Pasteurella* species were cultured from 719 pharyngeal swabs and 019 nasal swabs

animal control officers and police officers interfered with their movements. One ram returned directly to the northrn SRM, while the other ram was observed in Blaisdell Canyon of the SJM 7 days later, before he also returned to the northern SRM.

Lambs were observed in Andreas, Eagle, Tahquitz, Tachevah, and Chino canyons. Young lambs (<1 month of age) were observed primarily in Eagle and Tahquitz canyons, but also in Andreas and Tachevah canyons.

Demographics

The total number of adult bighorn observed during helicopter surveys ranged from 0 in 1989, to 17 bighorn in both 1993 and 1994 (Table 3). Because helicopter surveys were cursory and marked animals were not available for capture-recapture estimates prior to 1993, we did not calculate population estimates from helicopter surveys alone. Catch per unit effort (CPUE), or the number of adult sheep (≥ 1 year) seen per rotor hour, declined between 1984 and 1987 then remained low until 1993. An average of 81.7% of the collared animals were observed during the 1993-1996 flights. Between 1992-1996, ground field work corroborated helicopter survey results indicating the adult bighorn population remained relatively stable at approximately 19 adult bighorn (Figure 2); however, the sex ratio became increasingly skewed in favor of males. Excluding yearlings, we estimated that there were 8 adult ewes in 1993, and 6 adult ewes in 1994-1996. The average ram to ewe ratio between 1992-1996 was 135.4 rams/100 ewes (SD=33.8).

Excluding 1989 and 1992, when no ewes were observed, the number of lambs/100 ewes from helicopter surveys averaged 72.7 (SD=71.0). Although lamb:ewe ratios were highest between 1987-1990, the actual number of lambs observed in each helicopter survey increased after 1993. Between 1992-1996, lambing began in February or March each year and recruitment, as recorded from ground and helicopter surveys, averaged 71.8 lambs/100 ewes (SD=26.7). In 1993, 2 lambs and their radio-collared dams were killed by mountain lion (Felis concolor), but we were unable to document the cause of death for any other lambs. The sex ratio of 1992-1996 lambs recruited to yearling age was 167 males/100 females.

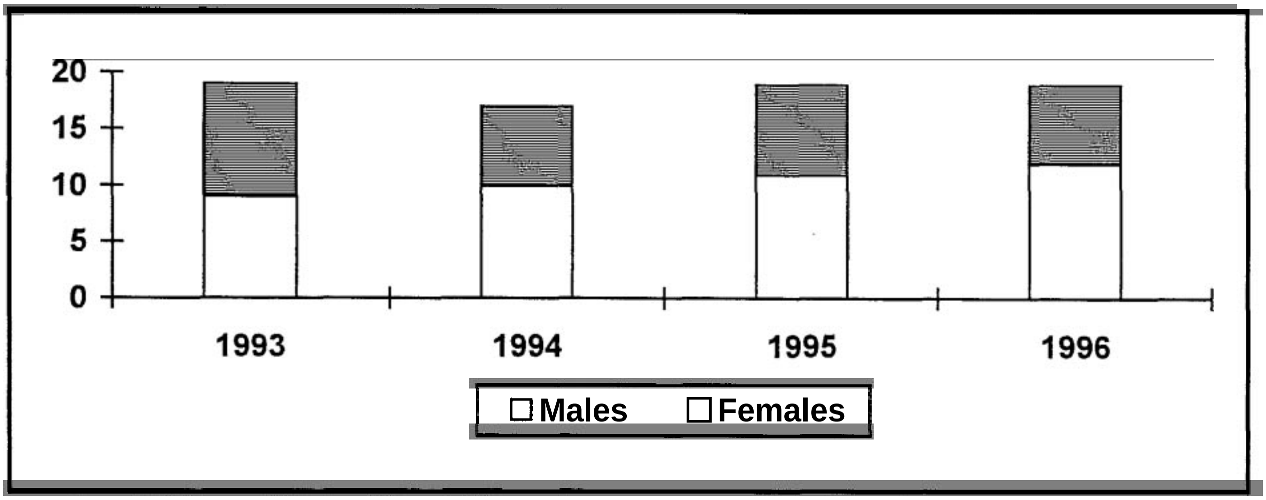
Six mortalities of radio-collared adult bighorn were recorded between 1992 - 1996. Three

Table 3. **Results from helicopter surveys of bighorn sheep (Ovis canadensis *cremnobates*) in the San Jacinto Mountains, California. All surveys were performed in September-Novemberunless otherwise indicated.**

Year	Flight time (hours)	Total adults	Rams	Ewes	Lambs	Yrlg. Males	Yrlg. Females	Rams/100 Ewes	Lambs1100 Ewes	Yrlgs/100 Ewes	Adult bighorn/ helicopter hour (CPUE)
1983	1.50	15	4	11	0	0	0	36.4	0	0	10.0
1984[a]	1.25	14	5	8	1	1	0	62.5	12.5	12.5	11.2
1987	1.50	4	2	1	2	1	0	200.0	200.0	100.0	2.6
1988	1.00	5	3	2	2	0	0	150.0	100.0	0	5.0
1989	1.00	0	0	0	0	0	0	0	0	0	0.0
1990	2.00	5	1	2	2	2	0	50.0	100.0	100.0	7.5
1991	1.50	4	3	1	0	0	0	300.0	0	0	2.6
1992	2.00	1	1	0	0	0	0	0	0	0	0.5
1993	4.80	17	6	7	2	2	2	85.7	28.6	57.1	3.5
1994[b]	2.50	13	4	7	4	1	1	57.1	57.1	28.6	5.2
1994	1.10	17	7	5	4	3	2	140.0	80.0	100.0	15.4
1995	1.30	15	7	6	5	0	2	116.7	83.3	33.3	11.5
1996	1.75	16	6	5	3	4	1	120.0	60.0	100.0	9.1

[a] **Survey conducted in May** 1984
[b] **Survey conducted in June** 1994

Figure 2. Population estimates of Peninsular bighorn sheep (*Ovis canadensis cremnobates*) in the San Jacinto Mountains. Estimates were obtained using data from both ground field work and helicopter surveys.



bighorn ewes were killed by mountain lion. Two 9-year-old rams and a 3-year-old ewe died from unknown causes. A 6-year-old ewe captured in 1992 died of capture-related complications within 30 minutes of release and was therefore eliminated from the survival analysis. Annual survival of radio-collared bighorn averaged 0.7986 for 1993-1996 (Table 4). Our small sample sizes prohibited testing for differences in survival caused by gender or season.

Home Range

Eight radio-collared bighorn had ≥25 locations for home range analysis. Four sheep died less than 1 year after collaring, and 5 of the sheep were regularly monitored, but had <25 locations. Fixed kernel home range size averaged 25.47 km^2 (SD=3.28, range 22.78-30.24 km^2) for rams and 20.05 km^2 (SD=2.00, range 17.93-21.91 km^2) for ewes (Table 5). Core use areas averaged 7.0 km^2 (SD=0.43) for rams and 5.04 km^2 (SD=0.73) for ewes. Both average home range and core use areas were significantly larger for males than females.

DISCUSSION

Health Status

Seropositive results among the SJM bighorn were highest for *Anaplasma* spp. Anaplasmosis is an infectious, noncontagious intraerythrocytic, rickettsia1 disease of ruminants. Both *A. ovis* and *A. marginale* can cause disease in wild and domestic ruminants, but infonnation on the epizootiology of Anaplasmosis in bighorn sheep is lacking. *Dermacentor hunteri* ticks, as found on the SJM bighorn, can transmit both *A. ovis* and *A. marginale* to bighorn sheep under experimental conditions (D. Stiller, unpubl. *in* Goff et al. 1993). *Annplnsmn ovis* has been isolated from wild desert bighorn sheep (Goff et al. 1993) and *A. ovis* can cause severe anemia, icterus, and lethargy when inoculated into healthy, captive bighorn sheep (Tibbitts et al. 1992). Although *A. marginale* may replicate in bighorn sheep, there is no evidence of naturally or experimentally occurring infection (Goff et al. 1993).

Anaplasma spp. have also been isolated from apparently healthy bighorn (Jessup and Boyce

Table 4. Annual adult survival of bighorn sheep (Ovis conadensis *cremnobates*) in the San Jacinto Mountains, California, monitored January 1993 - December 1996. Annual survival averaged 0.7986 for the four year period; however, refer to the test for an explanation of the recommended average estimate of annual survival between 1993-1996 (0.7478).

Year	Survival	95% CI	No. collared	No. mortalities
1993	0.7500	0.4499-1.0000	8	2
1994[a]	1.0000	1.0000-1.0000	6	0
1995	0.6667	0.2895-1.0000	6	2
1996	0.7778	0.5062-1.0000	9	2

[a] The population estimate for the SJM adult bighorn decreased in 1994, therefore our data suggested that adult mortalities did occur in 1994.

Table 5. Fixed kernel home range estimates (km^2) for bighorn sheep (Ovis conadensis *cremnobates*) in the San Jacinto Mountains, California, monitored January 1993 - June 1997.

Sex and ID	95% utilization distribution	50% utilization distribution	**No.** data points
EWE040	20.32	5.02	36
EWE295	17.93	4.32	74
EWE360	21.91	5.78	38
RAM200	24.06	7.69	27
RAM310	27.45	7.66	26
RAM450	22.78	6.90	50
RAM560	30.24	7.02	51
RAM850	22.82	6.81	32

1993). Eight of 9 desert bighorn sheep populations sampled in California between 1992-1995 were seropositive for *Anaplasma* sp. (n=160), with seroprevalence within populations ranging from 14-97% (Crosbie et al. 1997). Recovered animals may serve as lifetime carriers of the disease and exhibit positive antibody titers to *Anaplasma* spp. without detectable parasitemia (Blood et al. 1986).

Results from sampling 7 SJM bighorn in 1983-1985 (Clark et al. 1985) indicated that 57% of the sheep had titers against RSV (>1:5), 57% were positive for EHD (AGID), and 42% were positive for BT, compared to positive results for 10%, 50%, and 30% of the animals sampled in 1992-1996 for these diseases, respectively. While the percentage of animals seropositive for RSV, EHD, and BT declined between the 2 testing periods, titers against CE were found in 10% of bighorn sampled in 1992-1996, but in none of the animals sampled in 1983-1985 (Clark et al. 1985). Detecting antibodies to known bighorn diseases in these adult sheep through serology testing indicated 1 of 3 possibilities: 1) current infection, 2) previous infection to which the host is now immune, or 3) cross-reaction with shared antibodies from another infection. A rise in specific antibody titer from 2 sampling dates (paired samples) would provide a more definitive diagnosis.

Overall, hematology and serum chemistry results were un-remarkable. Eosinophilia is generally associated with parasitic infestation and/or allergic states; however a sustained rise in eosinophils could occur in a wide variety of conditions. Monocytes appear briefly in circulating blood, and then enter the body tissues where they are transformed to macrophages. The significance of monocytosis in our study is unknown. Creatine phosphokinase is a leakage enzyme that generally indicates muscular damage when serum levels are increased. Short-term increased values can occur after excessive exercise or contusions, while prolonged increases in CPK may indicate muscle necrosis or other serious muscle disease.

Although we found evidence of exposure to a number of infectious agents, we found no indication that disease operated as a limiting factor for the SJM bighorn population between 1992 and 1996. Anecdotal reports of respiratory ailments among SJM bighorn in the early 1980's (Society for the Conservation of Bighorn Sheep 1984) correspond with disease symptoms reported in the neighboring SRM bighorn population during this time period (DeForge and Scott 1982, DeForge et al. 1982). The impact of infection on host animals is a function of both host and parasite density, as well as the nutritional and stress level of the host. Disease may be a density dependent mechanism analogous to predation or resource limitation in its ability to regulate population growth (Anderson and May 1979). Although observations and diagnostic testing indicated that bighorn in the SJM are not currently experiencing disease, we cannot reject the hypotheses that disease played a primary role in the decline of the SJM bighorn population after 1977, or that the current population density is below the threshold at which disease will persist (Anderson and May 1979).

Distribution and Movements

Desert bighorn sheep populations are generally structured by female groups which have relatively stable home ranges, while males usually range wider and often move between ewe groups (Geist 1971, Festa-Bianchet 1986, Bleich et al. 1996). Accordingly, while the ewe range in the SJM was restricted to the area between and including Andreas and Chino canyons during our 1992-1997 telemetry study, rams frequently moved beyond these boundaries. The domain of concentrated sheep use during our study was significantly reduced from recent historical descriptions that indicate bighorn ranged from Snow Creek to Palm Canyon and concentrated in Blaisdell, Chino, and Tachevah canyons (Weaver and Mensch 1970).

The change in the pre- and post-1989 bighorn distribution as shown by our helicopter data (Figure 1) can be interpreted either as range contraction, range shift, or the extirpation of a sub-population. The northern extent of the regularly used bighorn range has clearly been reduced and now extends into Chino Canyon, rather than Snow Creek. Historical information (Grinnell and Swarth 1913, Goodman and Knudsen 1963, Blong 1967. Weaver and Mensch 1970) suggests that during our early surveys, bighorn may have been present in the southern canyons, but were not observed. Thus, the changes in bighorn distribution shown by our helicopter survey data appear to be a result of both range contraction in the northern end of the bighorn range, and low sheep numbers and sampling error in the southern areas.

Human disturbance, habitat fragmentation, and density dependent mechanisms including disease may all explain the recently reduced SJM bighorn distribution. Range contraction is an inherent result of severe population declines. However, past accounts of the SJM bighorn distribution (Weaver and Mensch 1970) reported that sheep were primarily concentrated in Tachevah, Chino, and Blaisdell canyons, an area now almost void of sheep. Disturbance and habitat fragmentation may be principal causes for the current limited use of sheep habitat north of Chino Canyon. Roads and traffic are known to inhibit bighorn movement and habitat use (DeForge 1972, Jorgensen 1974) and construction of the Tram Road through Chino Canyon in 1963 was reported to severely reduce bighorn movement (Blong 1967). Human disturbance, habitat loss, and habitat fragmentation are serious and long-standing problems for the SJM bighorn deme

(Tevis 1959, Weaver and Mensch 1970) that must be addressed for the recovery of this population.

In November 1997, ram 560 moved north of Chino Canyon into the area that appeared to have been abandoned by the current SJM ewe group. Although only a single radio-collared ram was observed north of Chino Canyon in 1997, tracks and feces along the northern edge of the canyon indicated that other bighorn (including a lamb or yearling) had crossed the canyon within the month. Monitoring of radio-collared bighorn as well as bighorn sign is continuing.

Because bighorn habitat in the SJM is a narrow belt between the valley floor and chaparral, preservation of all remaining bighorn habitat, both occupied and unoccupied habitat, is essential to obtaining a viable population. Our study corroborates other findings (Ough and deVos 1984, Bleich et al. 1996) that suggest inter-mountain ram movements are common, and reaffirms the importance of preserving corridors (Bleich et al. 1990). Although we did not record ewes outside of the Andreas-Chino canyon area, the resolution of our tracking may have failed to detect brief inter-mountain movements by ewes. Palm Canyon serves as a critical corridor linking the SJM deme to the northern SRM bighorn deme, and Chino Canyon is a vital corridor connecting the northern and southern halves of the SJM bighorn range. The geographic location of this population in relation to the metapopulation underscores the importance of the corridor in Palm Canyon, but blocking either of the Palm or Chino canyon corridors would significantly impact the long-term viability of the SJM bighorn population.

Demographics

Both the total number of bighorn seen and the CPUE from our helicopter surveys indicate the SJM bighorn population declined between 1984 and 1987. We attribute the increase in CPUE and number of animals observed in 1993-1996 surveys primarily to our increased knowledge of bighorn distribution, rather than an actual population increase to the degree indicated by the data.

The SJM and the adjacent SRM bighorn populations declined sharply following 1977 and had depressed recruitment for ≥ 7 years aftenvard (Society for the Conservation of Bighorn Sheep 1984, CDFG unpubl. data, DeForge et al. 1995). Because ≤ 2 ewes were observed during each of the 1987-1992 SJM helicopter surveys, the increase in lamb/ewe ratios following 1987 is questionable. However, the 1993 yearling/ewe ratio indicated that recruitment in the SJM population had clearly improved by 1992. This also roughly corresponds with the increased recruitment documented in the SRM in 1991 (DeForge et al. 1995). Correlated dynamics, as displayed by the SJM and SRM bighorn demes, tend to reduce metapopulation persistence times (Hanski 1989, Bleich et al. 1996).

Annual adult bighorn mortality rates generally range from 5 to 22% (Cunningham and deVos 1992, Wehausen 1992, Heffelfinger et al. 1995). Our estimate of adult bighorn survival in the SJM is likely to be biased high because of the small number of collared animals (*n*=6) and because no collared animals died in 1994. Survival measured from radio-collared animals in 1994 was 1.0000, but the number of adult ewes in the population declined during 1994 (Figure 2). This suggests that our 1994 sample of collared animals was not representative of the population. Furthermore, the population's relative stability over the 4 year period when recruitment averaged 71.8 lambs:100 ewes also indicates adult survival may be lower than 0.7986. Average annual survival was 0.7640 during the 2 years when 8 collared animals were monitored, and survival based on the average of the 3 years when mortalities were recorded is 0.7315. We propose the average of these 2 numbers (0.7478) as a more accurate overall estimate of annual adult bighorn survival for the calendar years of 1993-1996. While the data reflect a large amount of variation in annual survival rates, the large confidence intervals on annual estimates (Table 4) are a result of small sample sizes.

Although our small sample sizes prohibit testing for differences in survival rates between sexes, other data suggest that survival of females was lower than males during the study period: (1) the adult sex ratio, and (2) that only 2 of the 6 mortalities recorded from 16 collared animals (8 F, 8 M) were rams, and the rams most likely died from old age. The male biased sex ratio of lambs recruited (yearlings) may be a result of demographic stochasticity, a higher mortality rate for female lambs, nutritional stress (Verme 1965), or possibly inbreeding depression (Lacy et al. 1993, Lacy and Homer 1997). Further study of recruitment, nutritional levels, and the genetic diversity within this deme is needed.

Home Range

Home range estimates for bighorn sheep have often been calculated using the Mohr's (1947) minimum convex polygon method (Ough and deVos 1984, Krausman et al. 1989, Longshore and Douglas 1995). While this method is non-parametric and easy to calculate, it is also sample size biased (Krausman et al. 1989, Boulanger and White 1990). Only home range estimates calculated using the same software, sample size, and parameters are comparable (Lawson and Rogers 1997); consequently, no published studies are available for valid comparison to the results reported here. The fixed kernel estimator using least squares cross validation has been shown to be the most accurate (Seaman and Powell 1996) and least biased (Worton 1995) home range estimator for multi-modal and non-normal data, provided the proper smoothing parameter is chosen. However, because kernel estimators using small samples may overestimate home range size (Seaman and Powell 1996), our home range size estimates may be slightly inflated.

In our study mean total home range size of ewes is between 17 and 29 km^2, while ram home ranges are larger and more variable. The size of an animal's home range is dependent upon a number of factors: the population density, habitat quality and heterogeneity, and the animal's energy requirements, age, and social status (Jewell 1966, Krausman et al. 1989). Several studies (Krausman et al. 1989, Longshore and Douglas 1995) have shown that bighorn in higher quality habitat maintained smaller home ranges than bighorn in less desirable habitat. However, the relative importance of factors influencing intraspecific variation in the home range size of ungulates is not well understood (Tufto et al. 1996).

As expected, male bighorn in the SJM used significantly larger areas than female bighorn. Bleich et al. (1997) found support for the hypothesis that because of their larger size, male bighorn are able to exploit nutritionally superior areas, while female bighorn and their offspring are limited to habitats with fewer predators and more opportunities to escape predation. It is probable that predation pressure influences ewe habitat use and home range size in the SJM. Furthermore, movement of males from the female range in order to create sexual segregation also explains the larger home range of male bighom (Bleich et al. 1997).

CONCLUSION

The SJM herd has declined precipitously since the late 1970's (Table 6) and remains a precariously small population. Although these bighorn appear healthy and have high recruitment rates, adult survival is low. The current distribution of bighorn in this range is greatly reduced from pre-1989 levels, with only the central and southern portions of the bighorn range currently used. There appear to be ample exploratory movements to suggest that if the population increased, range expansion into the formerly occupied habitat north of Chino Canyon is likely. This indicates the importance of preserving historical habitat and movement corridors to allow recovery to occur.

Current limiting factors for the SJM bighorn population include loss of habitat, human disturbance, the high male sex ratio, and

Table 6. Data from water hole counts (WHC) or helicopter surveys (HS) of bighorn sheep (Ovis canadensis *cremnobates*) in the San Jacinto Mountains, California. Counts were conducted by the California Department of Fish and Game (California Department of Fish and Game unpublished data) or the Society for the Conservation of Bighorn Sheep (1984).

Year	Data source and survey type	Total adults	Rams	Ewes	Lambs	Yearlings	Rams1100 Ewes	Lambs1100 Ewes	Yrlgs/100 Ewes
1973	SCBS-WHC	226	63	129	59	34	48.8	45.7	26.4
1974	SCBS-WHC	105	57	82	37	18	69.5	45.1	22.0
1975	SCBS-WHC	126	41	70	34	15	58.6	48.6	21.4
1976	SCBS-WHC	131	50	79	12	2	63.3	15.2	2.5
1977	SCBS-WHC	94	40	50	10	4	80.0	20.0	8.0
1978	SCBS-WHC	45	10	35	0	0	28.6	0	0
1979	SCBS-WHC	13	4	9	0	0	44.4	0	0
1979	CDFG-HS	20	5	15	0	0	33.3	0	0
1980	SCBS-WHC	7	0	7	0	0	0	0	0
1980	SCBS-HS	25	na	na	1	na	na	na	na
1980	CDFG-HS	44	na	na	Na	na	na	na	na
1981	SCSB-WHC	1	0	1	0	0	0	0	0
1982	SCSB-WHC	0	0	0	0	0	0	0	0
1983	SCSB-WHC	22	4	18	0	0	22.2	0	0

na=data not available

mountain lion predation. The skewed sex ratio of both lambs and adults in this herd may be caused by demographic stochasticity, a higher mortality rate for females than males, nutritional stress, or inbreeding depression. Mountain lion predation accounted for 50% (3/6) of the radio-collared bighorn mortalities in 1993-1996. Habitat loss and/or human disturbance leading to an avoidance reaction may cause the loss of lambing or watering areas that are critical for survival, resulting in yet higher mortality rates within this deme. Augmentation to increase the number of females in the population and provide additional genetic variation is recommended. However, augmentation will only be effective if adequate habitat is preserved. All remaining occupied and un-occupied bighorn habitat must be preserved, including the Palm Canyon and Chino Canyon corridors.

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