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COSTS AND EFFECTIVENESS OF METHODS USED FOR POPULATION ESTIMATES OF DESERT BIGHORN SHEEP IN DEATH VALLEY NATIONAL PARK

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Abstract: We evaluate cost effectiveness and relative accuracy of methods used since 1988 to estimate numbers of bighorn sheep in the Black Mountains of Death Valley. Methods included helicopter surveys, helicopter survey and mark-resample using paint pellets for marking, using radio-collared sheep as marked animals during helicopter survey, and using time-lapse camcorders at springs to record marked and unmarked individuals. Relative costs and accuracy of estimates are discussed. Time-lapse camcorder records with accumulative sampling over one or two summer months provided an accuracy of ± 10 percent for the population estimate (Krebs 1989).

Key Words:' desert bighorn sheep, time-lapse, camcorders, mark-resample, population estimates

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INTRODUCTION

This study was designed to gather ecological information on bighorn sheep in the Black Mountains of Death Valley, and to evaluate cost effectiveness of different survey methods and ways of estimating population size. Cost effectiveness of monitoring is becoming increasingly important as wages and equipment costs increase while management budgets decrease. Accurately estimating numbers of animals in a free-ranging population is one of the most difficult problems facing wildlife managers.

Population estimates derived from three different methods of survey were calculated and their accuracies compared. The objective of this study was to find the most cost-effective method that provides population estimates accurate enough for management purposes. Costs usually dictate the survey methods used, but it is not appropriate to opt for the least expensive method if it decreases accuracy of population estimates below that required for management needs. All population estimates consume funds, but inaccurate estimates are the most expensive; they both consume funds and are of little use to managers. This study addresses methods for determining absolute abundance (i.e., numbers of animals per unit area); relative abundance is not considered. Although a population index might someday suffice for long-term monitoring of Death Valley bighorn, such an index must be correlated with absolute abundance in order to be useful.

The Black Mountains comprise more than 1000 km^2 of rugged and precipitous desert terrain that supports a herd of approximately 100 bighorn sheep in three areas of concentration. Past efforts to survey the herd have consisted of waterhole counts, periodic helicopter surveys by the California Department of Fish and Game, and five helicopter surveys by the author (Charles L. Douglas). A mark-recapture experiment to obtain a population estimate was conducted in 1988 in conjunction with sheep surveys. Sheep were marked from a helicopter with paint pellets fired from a pellet rifle. This was the first population estimate for the Black Mountains to which a confidence interval could be applied. Subsequent efforts from 1990 to 1995 consisted of: 1) using time-lapse camcorders with infrared sensors at springs to record marked (radio-collared) and unmarked animals, 2) helicopter surveys using radio-collared sheep as the marked animals, and 3) paint pellet mark-resample. Costs and accuracy associated with these methods of estimating population numbers are compared.

METHODS

Population Monitoring

Aerial surveys were conducted using a Bell Jet Ranger Helicopter. We employed Landell's Aviation in 1990 and 1991; and Versatile Helicopter in 1988, 1993, and 1994. Locations of sheep seen on earlier surveys and during mark-recapture experiments in 1988 were used to establish boundaries of survey areas and flight comdors between areas. Survey areas were delineated based on bighorn distributionsrather than distance from springs. Insofar as possible, the same flight route was flown through survey areas each year. Surveys were conducted during summer months (except for the 1994 survey, which was conducted in October), at which time the majority of bighorn sheep were restricted in distribution to about 1.6 to 3.2 km from water sources (Douglas and Longshore 1995). All survey areas contained one or more springs used by bighorn sheep. Routes flown between survey areas were standardized and were essentially the shortest distance from the point of completion of one survey to the point of starting the next.

Mark-resample experiments were conducted in 1988 and 1990 by marking as many bighorn sheep as possible with paint pellets, then recounting marked and unmarked individuals at a later date. Paint pellets were fired from a pellet gun from the rear seat of the helicopter as it passed about 10 m above the sheep. An observer in the front seat recorded Loran coordinates of locations and sex and age classes of marked and unmarked animals. Animals usually could be marked without difficulty on the first pass. Sheep were not chased for long distances, and many marked sheep simply stopped and stared at the helicopter. Two days were used to mark animals and 1 day to resurvey for "resample" data. A major concern of mark-resample estimates of wildlife populations is that marked animals become randomly redistributed among unmarked animals before they are "resampled." It was determined in 1988 that marked and unmarked animals redistributed themselves within 24 hours. There were no groups of only marked or only unmarked animals, and no apparent clumping of marked animals. This rapid redistribution probably occurred because most animals were within 3.2 km of water sources (Douglas and Longshore 1995). Thus, resampling could be conducted the day following the last marking effort. This was a welcome discovery because holding the helicopter and crew for an extra day or rescheduling flights for a relatively remote location such as Death Valley can be prohibitively expensive. During the 1993 and 1994 mark-resample surveys, animals fitted with radio collars in 1992 were counted as the "marked" portion of the population. In addition to the 18 collars placed on bighorn sheep in 1992, one black marking collar had been put on a ewe in the Lemonade Spring area by the California Department of Fish and Game prior to our study. This individual was seen during each survey throughout the study.

Survey data were used to estimate population size and 95 percent confidence limits by means of the modified Lincoln estimate for sampling without replacement (Seber 1982). For determining 95 percent confidence limits of these estimates, we used Poisson confidence limits when the proportion marked was ≤ 0.10, and binomial confidence limits when the proportion marked was ≥ 0.10 (Krebs 1989). In 1991 to 1993, camcorders triggered by infrared sensing units were placed at springs by the Park's Resource Management Staff. The infrared sensor was placed near the spring so that the beam was broken by bighorn sheep watering there. When the infrared beam was broken, a radio signal activated the camcorder, turning it on for 30 seconds of filming. Solar panels recharged camcorder batteries; tapes were changed once a month throughout the summer. Tapes were analyzed by the authors, using an 8 mm VCR that permitted single-frame viewing on a Sony Professional Color Monitor.

Data from camcorders placed at Lemonade Spring, Willow Spring, and Scottys Spring, during the summer months in 1993 were used for calculating ewe population estimates. Data collected during the summers of 1991 and 1992 were not used for population estimates because collars were not placed on ewes until September 1992. Population estimates were calculated from camcorder data using Bailey's unbiased estimator for sampling-with-replacement following the method of Jaeger et al. (1991). This approach is accurate only for estimating ewe populations, and the following conditions must be met: 1) the number of live ewes wearing collars must be known; 2) springs should be point resources, not streams, allowing all bighorn sheep that drink at a water source to be recorded; 3) time-lapse camera data should be collected only during summer months, when most or all animals are using the springs; 4) the person(s) analyzing the videotapes must be able to classify sheep correctly (i.e., no yearling rams classified as ewes).

Because the intent of this study was to determine a cost-effective method for long-term monitoring of bighorn in Death Valley, expenses were projected for 5 years for each method used. Camcorders and radio collars have predictable life expectancies. Equipment and personnel costs, equipment losses, etc., experienced throughout our study are listed for the years in which they occurred and then projected for the remainder of the 5-year period.

RESULTS AND DISCUSSION

Surveys Using Paint Pellet Mark-Resample

A total of 41 adults (18 rams, 23 ewes) and 5 lambs was recorded during a rangewide survey of the Black Mountains in August 1988 during the initial marking. Of these, 36 were marked with paint pellets. During the resample survey, 27 adult sheep and 4 lambs were sighted of which 13 adults were marked. The population estimate for adults was 73 sheep, with 95 percent confidence limits of 53-130.

In contrast to the rangewide mark-resample in 1988, surveys in 1990 were confined to survey areas, which were defined based on sheep distributions in 1988. Mark-resample operations were conducted from July 30 through August 2, 1990. Twenty-nine animals were seen, 17 of which were marked (11 rams, 11 ewes, 4 lambs, 3 yearlings). During resampling, only 14 animals were sighted and only 2 rams had paint marks. The population estimate was 89 animals with confidence limits of 60-175.

Surveys in August 1991 were unsatisfactory; only 10 animals were seen in 6 hours of flying. Rain earlier in the summer allowed dispersal of animals away from springs, despite the fact that rain gauges recorded very little precipitation. The survey was terminated when it became apparent that bighorn were too difficult to locate to warrant the expense. Radio-collared animals were used as the marked portion of the population for surveys in 1993 and 1994. Eight rams, 22 ewes, and 2 lambs were seen in 1993. Three of these animals (2 ewes, 1 ram) had collars, resulting in a population estimate of 155 bighorn with 95 percent confidence limits of 10-188.

A total of 26 adult bighorn sheep (12 rams, 14 ewes) and 4 lambs were sighted during the survey of September 1994; 3 of these (2 rams, 1 ewe) had collars, yielding a population estimate of 127 bighorn sheep with 95 percent confidence limits of 9-150 animals.

The above survey results reflect some of the difficulties inherent in attempts to derive estimates of a small bighorn population distributed over several areas of concentration in a large mountain range. Although the population estimates are surprisingly similar, the accuracy of the estimates is unacceptably low. It is important to consider relative costs of different methods of survey and population estimates in relation to accuracy of the estimates.

The costs shown in Table 1 are based on the most recent costs for marking Death Valley bighorn sheep in late summer in each of three survey areas, as opposed to marking throughout the entire mountain range.

The costs in Table 1 do not include paint pellets and compressed gas, which were supplied by the NBS Cooperative Unit. Four hours of helicopter ferry time are included. The assumption in this 5-year projection is that the mark-recapture population estimate would be repeated at regular intervals. Five year projected costs are $24,018 or an average of $4,804 per year. This would increase if surveys were conducted more frequently than every third year.

Surveys Using Camcorders and Radio-Collared Animals

This method uses radio collars in conjunction with fixed-wing flights to relocate individual bighorn and to determine seasonal movements and habitat use. Camcorders are then used to record sheep use at selected springs during summer. Camcorders have been used at selected springs in the Black Mountains since 1992 to monitor bighorn sheep and to derive population estimates based on numbers of marked and unmarked sheep recorded during summer. Although radio collars are more expensive than marking collars, the increased information from being able to locate animals and monitor movements more than offsets the added expense. Sheep equipped with radio collars are counted as marked animals when recorded on tape. The number of live, radio-collared animals in the population must be known prior to camcorder surveys.

The costs in Table 2 were those experienced during our study, and are predicated on a 2-year life expectancy for radio transmitters. By reducing the number of signals per minute, transmitter life can be extended for another year or two. However, reduced signal rate can increase the difficulty in locating animals, which may also increase flight time when ascertaining whether individual animals are still alive. Radio collars should be marked so that individuals can be recognized in the field or on camcorder tapes. Radio collars were not replaced, and were used as marking collars after their batteries died. Equipment replacement costs are included to simulate loss from theft that occurred in summer 1993. Averaged over 5 years, the project would cost about $25,016 per year. Radio collars permit an enormous increase in the amount of ecological and behavioral data useful for management that can be obtained; this method is optimum when funding permits. Savings could be effected by reducing numbers of flights, but there would be a commensurate loss of information.

The Biological Technician's salary is based on 4 months, GS-5, with a 4 percent annual cost-of-living adjustment. Cost savings could be effected by assigning monitoring duties to a staff person rather than hiring a seasonal for the project.

Surveys Using Camcorders and Collared Animals

Table 3 shows estimated costs of capturing and equipping animals with marking collars (not radio-collars), as well as costs for camcorders and the associated equipment needed. These costs are projected over 5 years, assuming equipment failure and loss similar to that experienced since 1992.

Averaged over 5 years, this approach would cost $13,432 per year, and about half of that if a staff person serviced the camcorders and analyzed the tape. Marking collars should last more than 5 years; marking collars lasted for about 10 years in the River Mountains, Nevada (personal observation by the authors). Likewise, barring loss from theft, time-lapse camcorders should last 10 or more years. They should be used only in summer when sheep are concentrated around water. Relatively few Black Mountain sheep used water sources during nonsummer months and the erratic data were not useful in calculating population estimates. Recording sheep usage at springs in nonsummer months exposes the equipment to additional weathering and increases the risk of vandalism or theft.

The number of marked and unmarked animals seen is directly related to accuracy of the population estimate, irrespective of the method used. Resampling should be increased until the accuracy of the population estimate is within the necessary probability limits (Krebs 1989).

Population estimates based on cumulative samples of ewes at springs and from data gathered during helicopter surveys in 1988, 1993, and 1994 are shown in Table 4. Population estimates from camcorder data were calculated for July and August separately and combined as a single sample.

Population estimates obtained from both helicopter surveys and cumulative time-lapse samples from camcorders are relatively similar, as are the 95 percent confidence limits. The best estimate from the camcorder data (smallest confidence interval) occurred when both months were combined. The goal of a mark-and-sample population estimate is to accurately estimate the proportion of the population that is collared (Krebs 1989). To obtain even moderate (25 percent) accuracy in population estimation, it is often necessary to mark 50 percent or more of the individuals in the population (Krebs 1989). Confidence intervals for population estimates of the Black Mountain bighorn sheep were relatively large because the number of animals marked and the number of marked animals sighted during resample flights were low. On average, 95 percent confidence limits will cover the true population size, but to be within a certain range of the true number of animals, sample size charts for Lincoln-Peterson population estimates can be used to determine how many animals must be marked and how many must be sighted during the resample survey to obtain an accurate population estimate (Krebs 1989:25). We compared accuracy of population estimates obtained from helicopter surveys and from cumulative time-lapse camcorder samples using the sample-size charts. Based on recommendations by Robson and Regier (1964; in Krebs 1989), the charts use three standard levels of accuracy and have a 0.05 probability of not achieving the desired accuracy (A), where:

$$A(\%) = \pm 100 \text{ [(estimated population size - true population size)/true population size]}.$$

The three standard levels of accuracy are:

1. Preliminary surveys: A = ± 50 percent, where a rough idea of population size is needed.

2. Management work: A = ± 25 percent, when a moderate level of accuracy is desired.

3. Research work: A = ± 10 percent, when accurate data on population size are needed.

The population estimate for ewes from the initial mark-resample survey in 1988 was 52, of which 21 were marked. To achieve 25 percent accuracy, approximately 30 ewes needed to be seen during the resample flight (the actual number of ewes resampled was 16). When the number of ewes with marking or radio collars was 9, approximately 45 ewes needed to be sighted during the resample survey. The rough terrain and relative low density of animals in this mountain range makes it very difficult during helicopter surveys to see the number of bighorn sheep required to achieve this type of accuracy. The only time a large number of ewes were "resighted" was when the estimate was calculated using cumulative sampling from time-lapse camcorder data in August 1993 and when data from July and August 1993 were combined, (57 ewes recorded in August 1993 and 92 ewes recorded in July and August 1993) resulting in 10 percent accuracy. Cumulative sampling from helicopter, while possible, may not be cost-effective. Our budget did not permit it.

Advantages and Disadvantages of Different Methods of Population Estimation

1. Mark-Resample using paint pellets and helicopter surveys.

Advantages:

- Quick
- Short time commitment
- Provides some information on animal use areas
- Can be conducted in remote and difficult terrain

Disadvantages:

- It is difficult in some years to locate animals
- The method is dependent upon hot, dry weather concentrating animals near water sources
- May have low level of accuracy if sample size of marked or resampled animals is small
- High cost of helicopter may preclude repeat sampling to increase sample size
- Permits gathering only limited kinds of data
- Resampling may be complicated by animal avoidance or change in weather.

2. Use of radio collars, aerial monitoring, and camcorders at springs.

Advantages:

- Higher level of accuracy than number 1 for population estimates
- Permits study of habitat use in conjunction with fixed-wing location flights
- Provides seasonal movement, home range, and demographic data
- Provides ecologically relevant information for management
- Optimum method for amount of information that can be gathered.

Disadvantages:

- Longer time commitment
- More labor intensive
- More expensive than other methods

3. Use of marking collars and camcorders at springs.

Advantages:

- Less expensive than use of radio collars
- Higher level of accuracy than number 1 for population estimates
- Eliminates expense of fixed-wing monitoring

Disadvantages:

- Provides less information than number 2
- Assumes springs can be reached to install camcorders
- Assumes springs are point water sources.

SUMMARY STATEMENT

Obtaining accurate population estimates of large, free-ranging mammals is fraught with difficulties and remains a challenge for wildlife researchers and managers. The methods selected will always be based on economic realities. Regardless of the method selected, marked animals are a prerequisite, because population estimates with management levels of accuracy (25 percent) cannot be achieved without them.

If funding permits, the recommended steps are as follows: First conduct a paint pellet mark-resample population estimate. Resampling via helicopter surveys can be conducted following marking and continued on subsequent days until an acceptable sample size is achieved. In addition to information on numbers of animals, these surveys provide important information about animal distribution. Knowing what areas of the range animals are using is important for reducing helicopter flight time for capture operations. Following the mark-resample, radio collars should be placed on 20-30 individuals, divided between the sexes. Periodic monitoring of radio signals will yield important data about seasonal home range, habitat use, lambing, and management concerns. There is no question that information from telemetered animals can provide vital management information that cannot be gathered by other means. In addition, time-lapse camcorders should be placed at key springs in summer to gather sufficient data on marked and unmarked individuals for a more accurate population estimate.

If funding is limited, population estimates can be obtained by the following: A paint pellet, mark-recapture population estimate should be conducted. Animals should then be captured and fitted with numbered marking collars (not radio collars). Depending upon circumstances, it might be possible to use apple mash as bait and a drop net to capture the animals rather than the more expensive method using a net-gun and helicopter. Again, time-lapse camcorders should be placed at key springs in summer to gather data on marked and unmarked individuals.

If funding is almost nonexistent, population estimates cannot be calculated, but limited habitat and spring use can be determined. Habitat use can be evaluated by having staff personnel hike a predetermined route through bighorn habitat, noting numbers and locations of unmarked animals (Wehausen 1992). This would be possible in some mountain ranges in Death Valley, but not in others. Camcorders could be placed on springs to demonstrate use or nonuse by sheep.

Problems that thwart efforts to conduct population estimates include: changeable weather during mark-resample efforts, too many water sources for the number of camcorders available, water sources too difficult to reach, linear water sources, difficulty catching or marking enough sheep, and difficulty obtaining sufficient samples of marked and unmarked animals when resampling.

Table 1. *Costs associated with population estimates of desert bighorn sheep in the Black Mountains, Death Valley, California, using mark-resample techniques with paint pellets fired from a helicopter.*

ITEM	Year 1	Year 2	Year 3	Year 4	Year 5
Helicopter 21 hrs	$ 10,437	0	0	$ 10,500	0
Service Truck	$ 646	0	0	$ 650	0
Per Diem 6 person days	$ 432	0	0	$ 432	0
PI per diem GSA Truck	$ 405 $ 51	0 0	0 0	$ 410 $ 55	0 0
TOTALS	$ 11,971	0	0	$12,047	0
PROJECT TOTALS	$ 24,018				

Table 2. *Five-year expenses using aerial surveys and camcorders at springs to monitor radio-collared bihorn sheep in the Black Mountains, Death Valley National Park, California.*

ITEM	Year 1	Year 2	Year 3	Year 4	Year 5
Camcorders	$ 14,000	0	$ 3,500*	0	0
Solar Panels	$ 720	0	$ 180*	$ 180	0
IR Units	$ 720	0	$ 180*	0	$ 180
Tapes	$ 132	$ 132	$ 132	$ 132	$ 132
PIR Receiver	$ 400	0	$ 100*	0	0
Sony Video Player	$ 300	0	0	0	0
Monitor	$ 1,000	0	0	0	0
Bio. Tech.	$ 6,212	$ 6,460	$ 6,718	$ 6,986	$7,265
Helicopter	$ 11,000	0	0	0	0
20 Telemetry Collars	$ 6,000	0	0	0	0
Aerial Monitor 5 hrs bimonthly	$ 26,160	$26,160	0	0	0
TOTALS	$ 77,404	$ 32,884	$ 10,810	$7,298	$7,577
PROJECT TOTAL	$ 135,973				

* Denotes replacement of stolen equipment

Table **3.** *Costs associated with using camcorders and associated equipment to monitor collared and noncollared bighorn sheep drinking at water sources in the Black Mountains, Death Valley, California.*

ITEM	**Year 1**	**Year 2**	**Year 3**	**Year 4**	**Year 5**
Camcorders	$ 14,000	0	$ 3,500"	0	0
Solar Panels	$ 720	0	$ 180*	$ 180	0
IR Units	$ 720	0	$ 180"	0	$ 180
Tapes	$ 132	$ 132	$ 132	$ 132	$ 132
PIR Receiver	$ 400	0	$ 100*	0	0
Sony Video Player	$ 300	0	0	0	0
Monitor	$ 1,000	0	0	0	0
Bio.Tech.	$ 6,212	$ 6,460	$ 6,718	$ 6,986	$ 7,265
Helicopter	$ 11,000	0	0	0	0
20 Marking Collars	$ 400	0	0	0	0
TOTALS	$34,884	$ 6,592	$ 10,810	$ 7,298	$ 7,577
PROJECT TOTAL	$67,161				

* Denotes replacement of stolen equipment.

Table 4. *Mark-resample population estimates (N) for ewes in the Black Mountains, Death Valley National Park, California. Estimates are based on data from helicopter surveys in 1993 and 1994, and from camcorders placed at Lenzonade, Scottys, and Willow Springs in 1993.*

Survey	No. in Sample	Percent Marked	95% C.L.	Total Marked	N	95% C.L.
Aerial						
1988	16	0.37''	0.15-0.65	21''	52	36-158
1993	22	0.09	0.34-6.69	9	76	29-170
1994	14	0.07	0.05-5.32	8	67	20-127
Camera						
July 1993	35	0.14	0.04-0.32	9	54	28-225
August	57	0.15	0.06-0.28	9	58	32-150
July + Aug	92	0.14	0.08-0.23	9	64	39-123

* = animals marked with paint pellets

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DISTRIBUTION, MOVEMENTS, AND MORTALITY OF ROCKY MOUNTAIN BIGHORN SHEEP IN ARIZONA

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Abstract: Seventeen Rocky Mountain bighorn sheep were radio collared in two adjacent subpopulations in southeastern Arizona and monitored for 26 months to document distribution, degree of interchange, survey observation rate, and mortality. Marked sheep were located outside of their subpopulation only 4.2 percent of the time. However, sheep moved freely between two hunt units prompting a change in the hunt unit boundary. Five sheep also moved across the Arizona-New Mexico state line. Average annual mortality rate during the study was 5.5 percent. Blood samples revealed no vitamin or mineral deficiency but some exposure to epizootic hemorrhagic disease (6 of 7), blue tongue (4 of 7), and contagious ecthyma (2 of 5). Average observation rates of marked bighorns were 29 percent for rams and 81 percent for ewes for 2 years of October helicopter surveys. It appears that rams are not seen in the same proportion as they occur in the population.

Key Words: observation rate, Ovis c. canadensis, mining, mortality, Rocky Mountain bighorn sheep, telemetry.

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INTRODUCTION

In 1826, explorer James Ohio Pattie reported "multitudes" of bighorn sheep on the cliffs of the San Francisco River near it's confluence with the Gila River (Davis 1973). Like many other sheep populations in the Southwest, sheep along the San Francisco and Gila Rivers were extirpated around the turn of the century, probably as a result of the introduction of domestic livestock and unregulated market hunting.

In 1964, the New Mexico Department of Game and Fish released 10 (2M:8F) Rocky Mountain bighorn sheep (Ovis canadensis canadensis) from Banff National Park, Canada, into Turkey Creek, 27 km northeast of Glenwood, New Mexico. Six months later, 16 (3M:13F) additional sheep were released along Sheridan Ridge, about 11 km southeast of Glenwood, New Mexico. These sheep came from the Sandia Mountains in New Mexico, which had been stocked with sheep from Banff in 1939 and 1940 (Ogren 1957). Two additional rams from the Sandias were released at Frisco Hot Springs in July 1965. By 1967, the sheep released along Sheridan Ridge had moved into the side drainages of the San Francisco River, not far from the Arizona-New Mexico border (Larsen 1971).

The first postextirpation Rocky Mountain bighorn were reported in Arizona in 1971 on the upper Blue River and the San Francisco River near the Arizona-New Mexico border (Apache County News 1971).

In May 1979, the Arizona Game and Fish Department (AGFD) transplanted eight (2M:6F) Rocky Mountain bighorn sheep from Rocky Mountain National Park in Colorado to Bush Creek along the upper Blue River of eastern Arizona (Figure 1). Twelve (5M:7F) additional sheep from Colorado were released near Bush Creek the following March. Lambs were observed in the first year and the population expanded in both size and distribution over the next several years.

By the mid-1980s, sheep were seen along the length of the San Francisco River from the New Mexico border to the town of Clifton (Figure 1). Small numbers of sheep also began appearing along Eagle Creek, which joins the Gila River 4 km west of it's confluence with the San Francisco (Figure 1). The number of sheep observed along Eagle Creek steadily increased, allowing the issuance of one permit tag in 1984. No more than 65 sheep were observed during surveys prior to 1990; however, during the October 1994 survey, 136 sheep were observed along approximately 25 km of the creek (AGFD files). During this period, fewer sheep were being observed along the San Francisco River (from 113 in 1988 to 56 in 1994).

Presently, the Eagle Creek and San Francisco River drainages represent two distinct areas of sheep occurrence. Corridors of interchange between these two areas include along the Gila River, which connects them, or through the Phelps-Dodge Mine, which lies directly between the two drainages (Figure 1). It is not uncommon for sheep to be observed using the cliffs and talus slopes created by the mining activity. The Phelps-Dodge Mine is the world's largest copper mine.

The Eagle Creek and San Francisco River subpopulations are in different AGFD administrative regions and, except for 15 percent of the Eagle Creek drainage that is part of the San Francisco River area, are hunted separately.

Objectives of this study were to: 1) document the amount and frequency of interchange between the two subpopulations, 2) determine the frequency of interchange across the Arizona-New Mexico border, 3) determine mortality rates and causes, 4) sample sheep for vitamin and mineral deficiencies and exposure to common livestock diseases, and 5) estimate survey observation rates of sheep in this river canyon habitat type.

We thank the Arizona Desert Bighorn Sheep Society for partial funding of the project; pilots Terry Amalong, Dave Hunt, Basil Coffman, Steve Sunde, and Bill David; and wildlife biologists Devin Skinner, Juan Romero, Mike Pruss, Mike Holloran, John Holcomb, Jim Hinkle, Sharen Adams, and Bob Vahle for their assistance with the capture and monitoring of radio-collared sheep. Ed Comaduran and Gary Jones of Phelps-Dodge Morenci, Inc. provided valuable assistance with access to mine property and mine information. Ron Olding and Mike Holloran reviewed the manuscript. The GIS mapping expertise and efficiency of Matt Alderson was much appreciated.

STUDY AREA

The study area was located in Graham and Greenlee counties in southeastern Arizona along the Arizona-New Mexico border. The area lies within the Basin and Range Physiographic Province in the transition zone between the Sonoran and Chihuahuan biotic communities, resulting in a diverse association of flora and fauna (Bureau of Land Management 1994). Rainfall is highly variable. Average annual rainfall varies from 17.8 cm to 40.6 cm, with most falling in the late summer months (Bureau of Land Management 1991).

The study area encompassed the Gila, Blue, and San Francisco rivers and Eagle Creek. These drainages are perennial and subject to periodic "scouring" during high rainfall events. The cliffs along these drainages are comprised of sedimentary, basalt, or volcanic tuft material and provide ideal escape cover for bighorn sheep (Bureau of Land Management 1993). Many cliffs along the Gila River rose over 300 m above the river. Elevation ranged from 1025 m at the confluence of the San Francisco and Gila rivers to 2374 m above the upper Blue River.

METHODS

Eight sheep (2M:6F) along Eagle Creek and nine sheep (3M:6F) along the San Francisco River, from the town of Clifton to the New Mexico border, were captured and radio-collared October 26-27, 1992, in 7.5 hours of helicopter time. Each animal was marked in the right ear with a numbered, red duflex tag. Ages ranged from 1 to 6 years. Biweekly telemetry flights from November 1992 to January 1995 yielded 620 telemetry locations.

Latitude/longitude coordinates determined from telemetry locations were recorded using a Global Positioning System (GPS) and then entered into a Geographic Information System (GIS). Distribution and home range for all marked sheep were analyzed with GIS. Each collared sheep yielded a sample of that individual's range. We also calculated occurrence of sheep outside the subpopulation it was captured in and movements into New Mexico.

Population surveys were conducted by helicopter each October. The entire study area was flown in 4 or 5 days each year. The rate of helicopter coverage averaged approximately 21 km^2 per hour.

Telemetry flights were conducted prior to or immediately following annual helicopter surveys in October to determine which radio-collared sheep were in the area surveyed and thus available to be sighted.

Mortality rates were determined using MICROMORT, a software package which calculates cause-specific and seasonal mortality rates based on radio-days gathered from telemetered animals (Heisey 1985, Heisey and Fuller 1985).

Blood samples were taken from each animal. Sera for serological studies was drawn and heparinized for vitamin and mineral analysis. Clots were sent to Montana for DNA analysis. Serum samples were tested for exposure to blue tongue (BT), epizootic hemorrhagic disease (EHD), contagious ecthyma (CE), infectious bovine rhinotracheitis (IBR), bovine viral diarrhea (BVD), bovine respiratory syncytial virus (BRSV), and brucellosis.

RESULTS

Sheep captured in one subpopulation (Eagle Creek or San Francisco River) generally stayed in that area. Of the 321 locations of the eight Eagle Creek sheep, only four (1.3 percent) locations (from two of the sheep) were in the San Francisco River drainage. Of the nine sheep radio-collared along the San Francisco, six were located at least once in Eagle Creek, but only 22 of 299 (7.4 percent) locations of San Francisco sheep occurred in Eagle Creek. Overall, marked sheep (n=17) were located outside their subpopulation of capture only 4.2 percent of the time.

Some sheep captured in Eagle Creekmoved between the two portions of that drainage that were in different hunt areas. All eight sheep captured in Eagle Creek moved back and forth across the boundary between Game Management Units 27 and 28, which are hunted as separate populations. All eight sheep were captured in the Unit 28 portion of Eagle Creek, but 14 percent of the locations were in the Unit 27 portion.

Six marked sheep were located within the perimeter of the mine. Forty-five locations (7.3 percent) occurred within the mine perimeter, with half of these locations being of a single 6-year-old ewe.

Five of nine sheep captured along the San Francisco River were located across the state line in New Mexico. Three ewes (#12, #15, and #17) captured on the San Francisco River were located at least once near Glenwood, New Mexico, approximately 32 river km into New Mexico between November 14 and April 20. The other two sheep making interstate movements were never located further than 6.4 km from the Arizona-New Mexico border. The longest distance between two locations recorded during the study was 52.8 km for a 5-year-old ram.

The limited number of radio-collared individuals precluded a detailed analysis of sex-specific, cause-specific, and seasonal mortality rates. The average annual mortality rate for all marked sheep was 5.5 percent during the study. Only two mortalities, a 5-year-old ewe from Eagle Creek (cause of death unknown) and a 3-year-old ram from the San Francisco River (killed by a mountain lion - *Felis concolor),* were recorded in 12,876 radio days.

Eight blood samples were taken at capture and tested for vitamin and mineral deficiencies and disease titers. Vitamin levels were very good. Serum copper (Cu) and whole blood selenium (Se) showed considerable individual variation but were all within the levels reported for domestic animals (Table 1). Positive exposure to BT (4 of 7 samples), EHD (6 of 7), and CE (at least 2 of 5) was detected (Table 2). Serum neutralization tests for IBR, BVD, and BRSV, as well as the Brucella plate test, were all negative.

Estimates of animals seen during annual October helicopter surveys ranged from 73 percent to 90 percent for ewes and 25 percent to 33 percent for rams (Table 3). During the 1993 surveys, average size of ewe groups was 5.7, while ram groups averaged 2.2 (AGFD files). Observation rates for all sheep were 73 percent and 64 percent in 1993 and 1994, respectively.

DISCUSSION

Early observations of Rocky Mountain bighorn sheep in Arizona indicate that the sheep now in the Eagle Creek and the San Francisco River areas are descendants of sheep transplanted into both New Mexico and Arizona. Five of nine sheep that were radio-collared in the upper reaches of the San Francisco moved freely across the Arizona-New Mexico border. Once in Arizona, whether by transplant or immigration, the sheep population increased. The high lamb production and low natural mortality undoubtedly enabled Rocky Mountain bighorns to expand in both abundance and distribution.

In the mid-1980s, sheep undoubtedly from the San Francisco River population became established in the Eagle Creek drainage. As the Eagle Creek population continued to increase in abundance, the population along the San Francisco appeared to decrease.

The number of lambs in October has always been consistently high in the Eagle Creek subpopulation, averaging 53 lambs:100 ewes from 1989 through 1994. The relatively high reproduction and low mortality suggests that much of the recent increase in the Eagle Creek subpopulation is due to a positive recruitment:mortality ratio rather than to immigration. Trends in survey data show that this subpopulation continues to increase and sheep are now being found in areas they did not previously use, such as along the Gila River.

The small amount of sheep movement from the San Francisco River to Eagle Creek does not exclude the possibility that this rate is lower now than during past immigration. The movement rate of sheep from Eagle Creek to the San Francisco River was only 1.3 percent during this study.

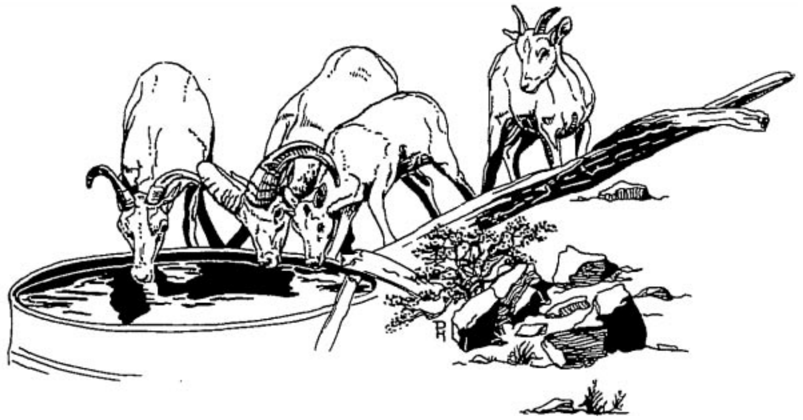
A small portion of Eagle Creek was in both Game Management Units 27 and 28, which were hunted separately. Telemetry locations from this study showed sheep in Eagle Creek freely moved across this boundary, resulting in the possibility that a hunter with a tag for sheep surveyed along the San Francisco would harvest a ram out of the Eagle Creek population by hunting that small portion that is in Game Management Unit 27. The boundary between the two hunt areas was redefined to better divide the subpopulations. The new boundary includes only 1.2 percent of the Eagle Creek telemetry locations, as opposed to 14 percent with the old boundary.

One ewe was located consistently on the Phelps-Dodge mine property. Six of 17 instrumented sheep were located at least once within the perimeter of the mine. The main mining operations are located on uplands which separate Eagle Creek and the San Francisco River. As a result, it is unclear whether the mine represents a barrier to movement among the subpopulations. Sheep from both subpopulations occasionally frequented the mine, but rarely moved through to the other drainage. These two areas of high sheep use are canyon-rimmed, riparian corridors and as such there may not be a high degree of natural interchange, even in the absence of the mine, because of a strong affinity to one drainage or the other.

Three sheep from the San Francisco River population were also located near the confluence of the Gila and Eagle Creek; some in the company of Eagle Creek sheep. Movements such as these may be inhibited by the presence of the town of Clifton, which the San Francisco River flows through (Figure 1). The small degree of interchange, along with this interaction around the mine and Gila River, should be enough to maintain the exchange of genetic material between sheep in this metapopulation.

No abnormally high mineral levels were detected in the blood samples analyzed. However, none of the animals sampled spent a considerable amount of time in the mine after they were radio-collared, indicating their normal core use area did not include the mine.

Rams appear to be observed in a lower proportion than their occurrence in the population. These observation rates of rams are consistent with information collected in populations of desert bighorn sheep (*O. c. mexicana*) (AGFD Files). The observation rate of ewes is higher than estimates obtained in other habitat types commonly used by bighorn sheep in Arizona (AGFD Files). Habitat segregation and group size doubtless accounts for much of the difference in observation rates. The concentration of ewes and lambs along the river results in a higher proportion of animals seen than in populations associated with more extensive and homogenous terrain. Rams frequently occupy the gentler uplands adjacent to these river systems, while ewes and their lambs show a higher fidelity to the cliffs directly above the stream bed. Also, rams generally occur in smaller groups or singly and ungulate group size has been shown to influence sightability (Samuel et al. 1987).



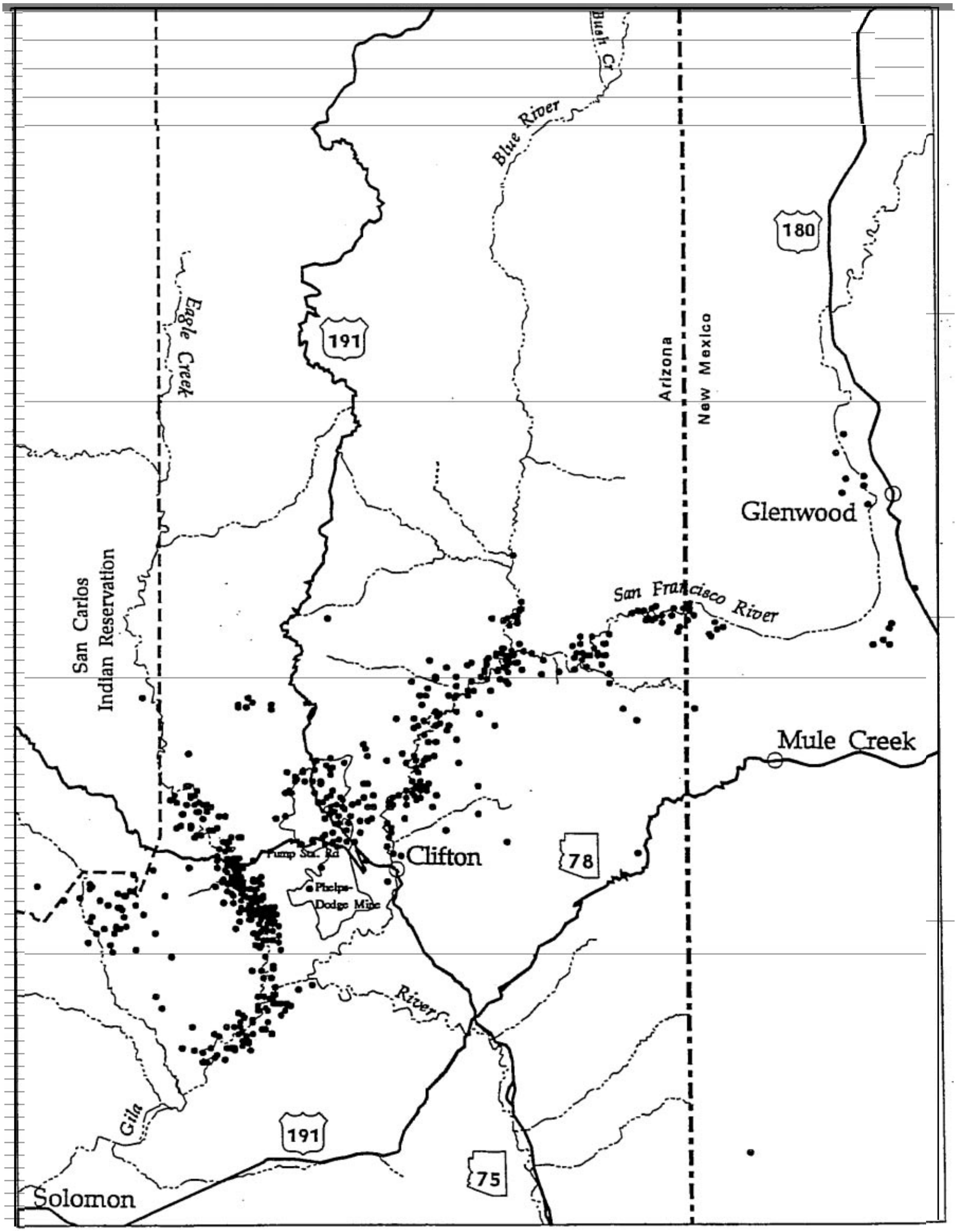


Figure 1. *Distribution of Rocky Mountain bighorn sheep along the San Francisco, Blue, and Gila Rivers and Eagle Creek, southeastern Arizona.*

Table 1. *Blood/serum mineral and vitamin values for 17 Rocky Mountain bighorn sheep captured in south eastern Arizona, 1992.*

Animal ID	Serum Vit. A (ug/ml)	Serum Vit. E (ug/ml)	Serum Cu (ppm)	Whole blood Se (ppm)
1	0.93	11.5	0.57	0.23
2	0.60	10.0	1.65	0.18
3	1.24	16.2	0.84	0.15
4	0.87	13.2	0.75	0.15
8	1.07	13.7	0.72	IS[a]
10	0.56	7.3	1.11	0.28
12	IS[a]	IS[a]	0.81	IS[a]
18	1.07	11.2	0.72	0.24

[a]Insufficient Sample

Table 2. *Occurrence of blue tongue (BT), epizootic hemorrhagic disease (EHD), and contagious ecthyma (CE) in Rocky Mountain bighorn sheep captured in southeastern Arizona, 1992.*

Animal ID	BT (AGID)	EHD (AGID)	CE (CF)
1	POS	POS	NS[a]
2	NEG	POS	POS 1:5[b]
3	NEG	NEG	NEG
4	NEG	POS	POS 1:5
8	POS	POS	NEG
10	POS	POS	AC[a]
18	POS	POS	NEG

[a]NS = Non specific, AC = anticomplementary (Exposure could not be determined).
[b]Complement Fixation (CF) titers of 1:5 are considered suspicious of previous exposure.

Table 3. *Observation rates of Rocky Mountain bighorn sheep during helicopter surveys, Eagle Creek and San Francisco River drainages, October 1993-94.*

Year	Number available to be observed			Number actually observed			Percent observed		
	F	M	ALL	F	M	ALL	F	M	ALL
1993	11	4	15	10	1	11	90	25	73
1994	11	3	14	8	1	9	73	33	64

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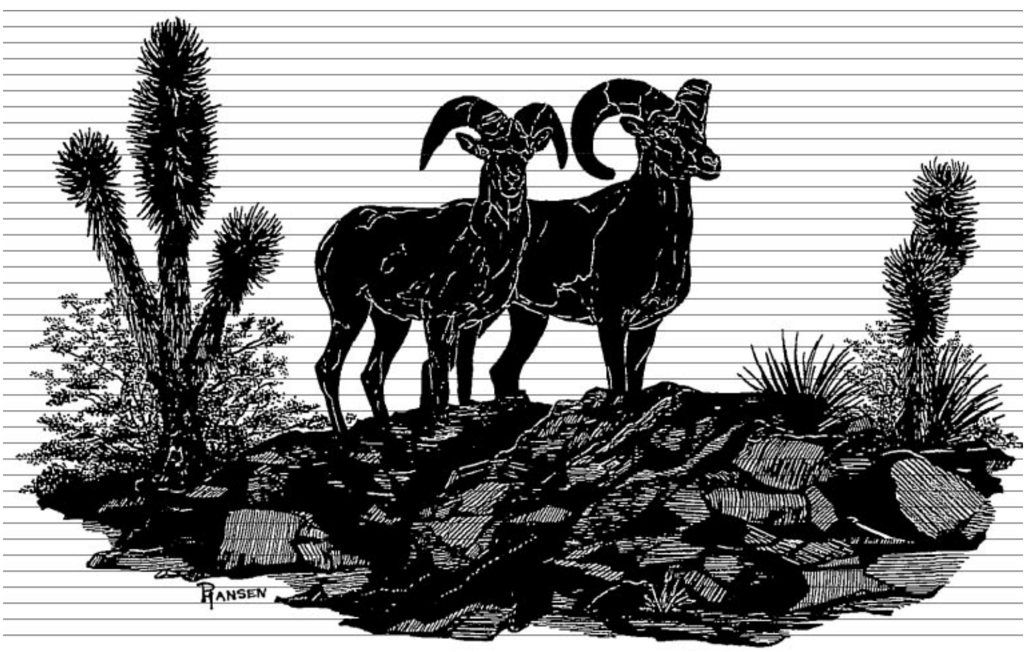

GENETIC VARIATION OF BIGHORN SHEEP AS MEASURED BY BLOOD PROTEIN ELECTROPHORESIS

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Abstract: Starch gel and agarose gel electrophoresis were used to study the patterns of genetic variation in four putative subspecies of bighorn sheep (Ovis canadensis). Of the 14 loci examined, only transferrin was polymorphic in all subspecies. Another, glyoxylase, varied only within Rocky Mountain bighorn sheep (*O.* c. canadensis) and was found in forms unique to that subspecies. Our results suggest a wide separation in evolutionary time between populations of Rocky Mountain bighorn sheep and desert-dwelling bighorn sheep (*O.* c. nelsoni and O. c. mexicana). Levels of genetic variation within populations (mean heterozygosity) were lower than those reported for white-tailed deer, but similar to those reported for other large, wild ungulates in North America.

Key Words: Bighorn sheep, subspecies, western North America, genetic variation, blood proteins, electrophoresis.

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INTRODUCTION

Mountain sheep are relative newcomers to North America. Their ancestors originated in Asia and dispersed over the Bering land bridge into North America during the late Pleistocene, approximately 650,000 years ago (Ramey 1993). Currently, two species are recognized in North America: Dall sheep (Ovis dalli) and bighorn sheep (Ovis canadensis). Dall sheep occupy Alaska and northwestern Canada, while bighorn sheep are found in southwestern Canada, the western United States, and northern Mexico. Based on morphological characteristics there are five subspecies of bighorn sheep: desert bighorn sheep (*O.* c. nelsoni), Mexican bighorn sheep (*O.* c. mexicana), Rocky Mountain bighorn sheep (*O.* c. canadensis), California bighorn sheep (*O.* c. *californiana*), and Weem's bighorn (*O.* c. weemsi) (Cowan 1940, Wehausen, and Ramey 1993, Ramey 1995). Wehausen, and Ramey (1993) recently synonymized *O.* c. *cremnobates* with *O.* c. nelsoni based on horn and skull characters, and suggested that desert-dwelling bighorn sheep be considered a single, polytypic subspecies. This conclusion has also been corroborated by analysis of mitochondrial DNA variation (Ramey 1995) and a reanalysis of Cowan's original data (Ramey 1993).

The taxonomy of bighorn sheep has importance to conservation for two primary reasons. First, subspecies boundaries are important to the choice of reintroduction stock. Second, some subspecies currently receive more protection and recovery effort because of their taxonomic status (Bureau of Land Management 1989). However, without knowing the actual patterns of genetic variation within and among bighorn sheep populations, it is impractical to develop conservation strategies aimed at preserving genetic variation. Numerous biochemical studies have revealed that previously accepted taxonomic units may not be an accurate reflection of phylogeny (Avise 1989; Dragoo et al. 1990).

Like many species indigenous to North America, the arrival of Europeans had a dramatic impact on the abundance and distribution of bighorn sheep. Market hunting, loss of habitat, and diseases of livestock are believed to be the primary causes for these declines. A more recent threat is the isolation of bighorn populations on habitat islands as a result of human development (fences, highways, reservoirs, and cities). Such isolation may reduce the genetic variability through random genetic drift within isolated populations faster than it is replaced by mutation. Migration between populations, however, may potentially offset this loss, dependent upon the rate of migration (Schwartz et al. 1986, Bleich et al. 1990).

The objectives of this study were to use protein electrophoresis as a tool to estimate the level of genetic variation found within and among populations of bighorn sheep, to compare these results with those found for mitochondrial DNA markers

(Ramey 1995), and to determine if detectable genetic differences exist between subspecies of bighorn as classified on the basis of morphology by Cowan (1940) and Wehausen and Ramey (1993).

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METHODS

Blood samples (total 984) were gathered from 54 bighorn sheep populations in the United States, Canada, and Mexico, and from five captive populations between 1983 and 1989. The location of 28 populations from which 10 or more samples were taken are presented in Table 1. Additional blood samples from *O. c. califomiana* were collected at the Warner Mountains, Modoc County, California (n=3). Additional blood samples from O. *c. canadensis* were collected at Colorado State University, Fort Collins, Colorado (n=6); the St. Louis Zoo, St. Louis, Missouri (n=6); Hells Canyon, Mountain County, Idaho (n=3); Sun River, Lewis and Clark County (n=9), and from the Yellowstone herd near Billings, Montana (n=4). Additional blood samples from *O. c. mexicana* were collected at the Plomosa Mountains (n=9), La Paz County, Arizona. Additional blood samples from *O. c. nelsoni* were collected at Tin Mountain (n=6), in Inyo County, California; at Chuckwalla Mountains (n=3), Coxcomb Mountains (n=2), Eagle Mountains (n=5), Joshua Tree National Monument (n=8), Little San Bernardino Mountains (n=2), and Orocopia Mountains (n=6), in Riverside County, California; at Picacho Peak (n=6), in Imperial County, California; at the Clipper Mountains (n=9), Granite Mountains (n=4), Hackberry Mountains (n=6), Kingston Mountains (n=2), Cady Mountains (n=8), Piute Range (n=2), south Providence Range (n=2), Turtle Mountains (n=7), and Wood Hills (n=2), in San Bernardino County, California. Additional blood samples from the Peninsular Range populations of *O. c. nelsoni* (formerly *O. c. cremnobates* (Wehausen and Ramey 1993)) were collected at the Jacumba Mountains (n=8), San Diego County, and at the San Jacinto Mountains (n=7), Riverside County, California.

The sterile blood samples were taken in acid citrate dextrose media (ACD) and fresh blood on a specially prepared stain card (Wraxall and Rawlinson 1986). All samples were taken from live, captured animals via sterile jugular venipuncture. All ACD blood samples were kept refrigerated at (4°C), and all stain cards were allowed to dry and then were refrigerated until submitted for analysis. Whole blood samples in acid citrate dextrose tubes were separated into plasma and washed red cell lysates. Lysates were treated with dithiothreotol (Hams and Hopkins 1976) and were analyzed in four agarose or starch-gel buffer-current systems (Group I-IV) (Table 2). Methods were adjusted if necessary for better separation of bighorn proteins. A limited number of samples were analyzed for Mannose Phosphate Isomerase (MPI) in an agarose gel (EO 0.07) at pH 6.25 using a 0.014M phosphate buffer. MPI screening was eventually discontinued in blood due to faint development. Phosphoglucomutase (PGAM) was separated in a tris/citrate, pH 7.1 agarose (EO .07) system. Phosphoglucose isomerase (PGI) was examined using a 10 percent starch gel and pH 8.0 tris/citrate buffer. Neuraminidase was used to remove sialic acid residues from transfemns on all samples to produce more stable, reproducible electrophoretic separation patterns (Davin et al. 1984).

Population mean heterozygosities were calculated only for populations having a sample size ≤10 (Table 1). For contingency table analyses, we pooled samples by geographic subregion or taxonomic designation, making use of all individuals sampled within each region. Our calculations of heterozygosities and F statistics assume that desert-dwelling bighorn sheep were monomorphic for all loci but transferrin, and Rocky Mountain sheep were monomorphic for all loci but transferrin and glyoxylase I. Although not all individuals were screened for all loci (Table 2), we justify this assumption on the substantial number of individuals screened that yielded no polymorphism for these loci. We did not calculate F_{ST} for Rocky Mountain bighorn sheep because all but one population we examined originated from translocations.

RESULTS

Of the 14 loci examined, all *O.* c. nelsoni, O. c. mexicana, and 0. c. *californiana* populations were either fixed at all loci or were polymorphic only at the transfemn locus. The mean heterozygosities for populations of these subspecies ranged from 0.000 to 0.042. In contrast, O. c. canadensis populations were found to have two loci (transferrin and glyoxylase I) that were polymorphic, and mean heterozygosities that ranged from 0.039 to 0.067 (Table 1).

Figures 1 and 2 graphically present the distribution of transferrin and glyoxylase I in the 27 bighorn sheep populations for which more than 10 samples were collected. These same general patterns were also present in the adjacent bighorn sheep populations from which less than 10 samples were collected. Each of the four putative subspecies of bighorn sheep that were sampled exhibited transferrin polymorphism, although some populations showed only one type.

Glyoxylase allele 2 was the only form in three of four bighorn subspecies. However, three alleles were found in populations of *O.* c. canadensis. Samples from *O.* c. canadensis from the Tarryall Mountains of Colorado had a glyoxylase variant (3-2) that was not found in any other bighorn populations (Figure 2). Only one bighorn of 661 tested, an *O.* c. canadensis from Sun River, Montana, had a variant form of carbonic anhydrase (CA).

Significant heterozygote deficiencies ($p<0.05$) were found at the transfemn locus in both the Marble Mountains and Hall Mountain populations. Otherwise, there appeared to be a trend towards heterozygote excess in other populations. Values of F_{ST} ranged from 0.14 for the Mojave Desert and Penninsular Ranges combined to 0.21 for 0. c. mexicana populations east of the Colorado River.

Within the range of desert-dwelling bighorn sheep, allele frequencies for transferrin showed a marked difference between the eastern and western parts of their range, with allele 1 being found at higher frequency in California/Arizona/Nevada, and allele 2 being found at higher frequency in New Mexico/ Utah. Contingency table analysis showed that significant differences in allele frequencies existed among desert subregions for transferrin. Allele frequencies for transfemn differed significantly ($p<0.001$) between populations in California/Arizona/Nevada and those in Utah/New Mexico. Similarly, significant differences were also found between the Santa Rosa/ Jacumba/San Jacinto Mountains in the Penninsular Ranges and San Gabriel Mountains to the North, and Mojave Desert to the east ($p<0.001$). Within the Rocky Mountains, there also appeared to be major differences in allele frequencies among populations both within Colorado and between Colorado and the northern Rockies for transferrin and glyoxylase, although only the Tarryall samples came from a native herd. Translocated herds showed a high degree of similarity to parent herds for allele frequencies despite having been separated for up to several decades.

DISCUSSION

Our results suggest that many bighorn sheep populations, particularly those in the deserts west of the Rocky Mountains and the Colorado River, have relatively low levels of genetic variation, with mean subspecies heterozygosity of 50.022 (Table 1). In contrast, 0. c. canadensis had the highest average heterozygosity at 0.049. White-tailed deer (Odocoileus virginianus) in Maryland have a mean heterozygosity of 0.32 (Sheffield et al. 1985), far greater than that found in *O.* c. canadensis. However, other wild ungulates, including pronghorn antelope (Antilocapra americana) (0.01), Dall sheep (Ovis *dalli*) (0.015-0.02), moose (Alces alces) (0.02), bison (Bison bison) (0.02), and wapiti (*Cervus* elaphus) (0.02), all show similar mean heterozygosities to those of bighorn sheep (Baccus et al. 1983, Sage and Wolf, 1986).

The extent of population subdivision for desert bighorn sheep, as measured by F_{ST} at the transfemn locus, was one-third that found by Ramey (1995) for mitochondrial DNA markers in the Mojave Desert and Peninsular Ranges. This finding is consistent with the Ramey's (1995) hypothesis that the tendency of females to disperse less frequently and over shorter distances than males would lead to a higher level of population subdivision for maternally inherited mitochondrial DNA than for nuclear genes.

The presence of unique forms of glyoxylase found in the Rocky Mountains suggests that there is a wide separation in evolutionary time between *O.* c. canadensis and the desert-dwelling subspecies, 0. c. nelsoni and O. c. mexicana, to the west and south. This result is similar to Ramey's (1993) finding of major differences in mitochondrial DNA between Rocky Mountain and desert-dwelling bighorn sheep. Significant differences in transferrin allele frequencies among sheep occupying eastern and western deserts, and among subregions suggest some local differentiation similar to that found for mitochondrial (Ramey 1995) and morphological markers (Wehausen and Ramey 1993).

With the exception of Rocky Mountain bighorn sheep, variation within the other subspecies did not appear to be concordant with subspecies boundaries.

For example, California bighorn, O. *c. califomiana*, from Mount Baxter in the Sierra Nevada were homozygous for transferrin allele 1, where *O. c. califomiana* from Williams Lake, British Columbia, and their descendants translocated to Hart Mountain in Oregon and Little Jacks Creek in Owyhee County, Idaho, had allele frequencies ranging between 0.47 and 0.7 for transfemn allele 1 (Figure 1).

Many populations of *O. c. nelsoni* in California to the south and east of Mount Baxter, and in adjacent Arizona and Nevada were homozygous for transfemn allele 1, or were nearly so. Thus, the transferrin patterns of the largest remnant herd of *O. c. californiana* surviving in the Sierra Nevada more closely resemble those of *O. c. nelsoni* in adjacent mountain ranges than more northern populations of *O. c. califomiana.* A high degree of similarity has also been reported between the Mount Baxter population and nearby *O. c. nelsoni* populations for mitochondrial DNA markers (Ramey 1993) and morphological characters (Wehausen and Ramey 1993).

Both transfenin and glyoxylase frequencies in the Hall Mountain, Washington, and the Lostine, Oregon populations of *O. c. canadensis* appear to be similar (Figures 1 and 2). These herds were started from parent stock from herds in Banff and Jasper National Parks in Alberta, Canada, respectively. The translocated Saguache herd at Trickle Mountain, Colorado, reflects the dominance of type 2 glyoxylase seen in the Tarryall Mountains parent herd, but with no apparent participation from individuals with the glyoxylase allele **3** (Figure 2). Furthermore, transferrin allele 1 is found at high frequency at Trickle Mountain, while the Tarryall parent herd shows predominance of transfemn allele 2. It is unclear to what extent this pattern may be due to founder effects (from small reintroduction population size), selection, or sampling error.

Sage and Wolf (1986) hypothesized that a series of population bottlenecks during the late Pleistocene were responsible for the low amount of genetic variability present in a number of North American mammals. They speculated that low genetic variability was mainly due to repeated founder events as populations colonized new habitat during the ebb and flow of Pleistocene glaciers. Ramey (1995) proposed that, in addition to founder events during the original colonization of North America, there may have been frequent extinction and recolonization of subpopulations, further reducing genetic variation. We agree that a bottleneck, or a series of them, was probably responsible for reducing genetic variation within ancestral populations of mountain sheep and that this reduction in variation is reflected in present day populations of bighorn sheep. Reduction of genetic variation appears to have been somewhat more severe for populations of desert-dwelling bighorn sheep than those of the Rocky Mountains. However, the near uniform distribution of low amounts of variation within regions, and similar heterozygosities observed in other large North American mammals, support the hypothesis that reductions in genetic variation largely predate the arrival of European man.

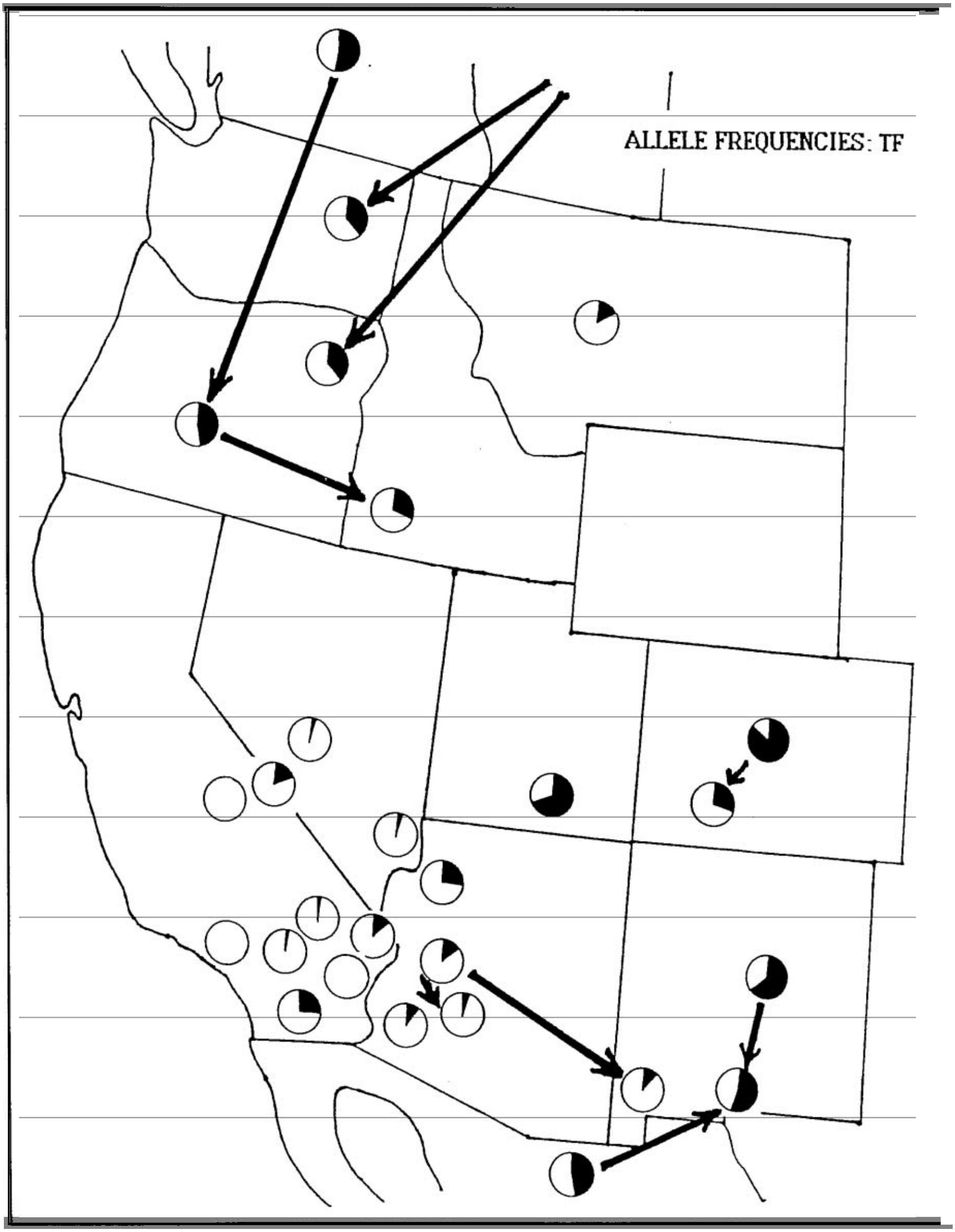

Figure 1. *Diagram showing allele frequencies of transferrin within populations of **O.** canadensis. Arrows indicate the direction of translocations from source herds to transplant sites. The proportion of alleles 1 and 2 in each population are represented by the white and black sections of each circle, respectively.*

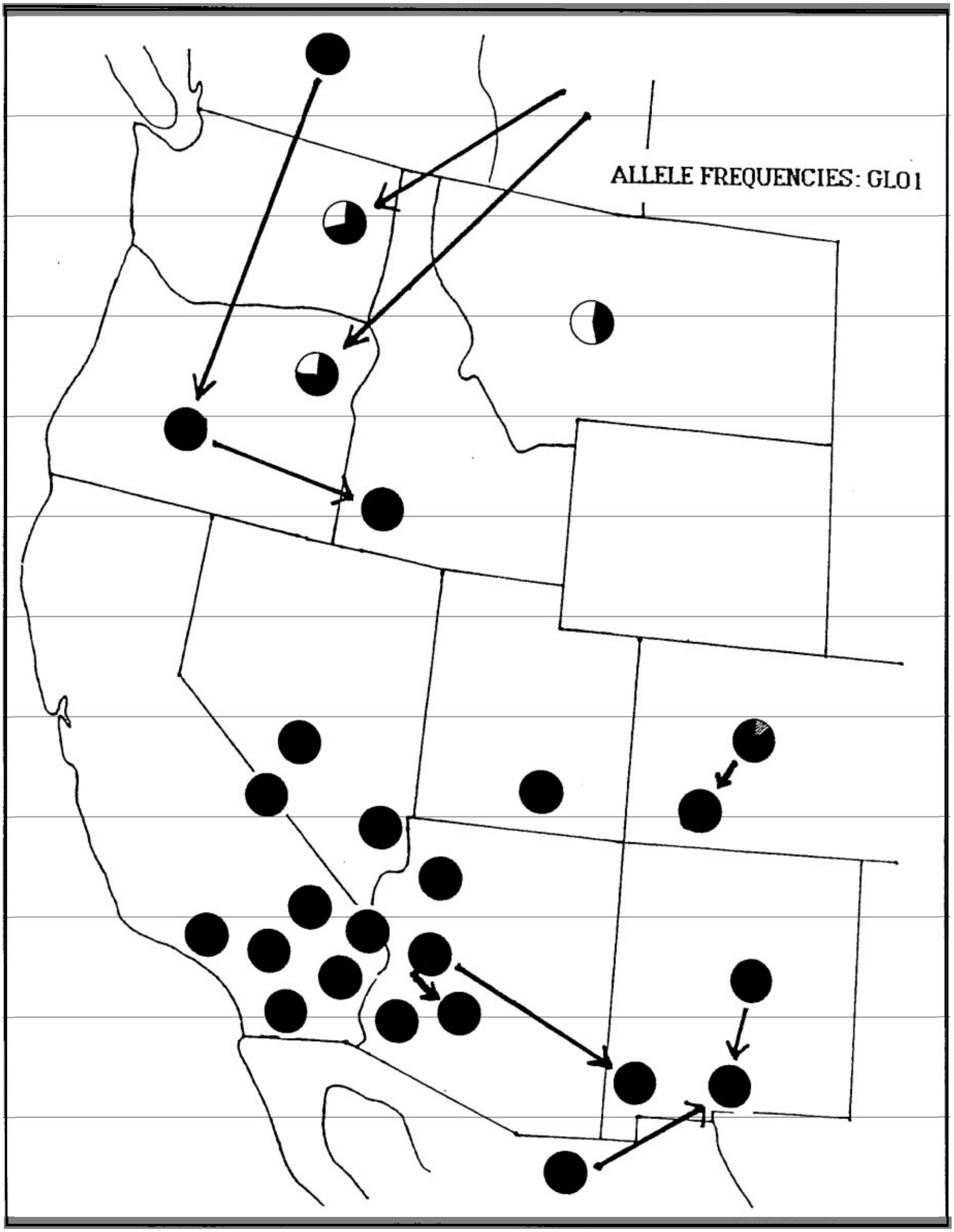

Figure 2. Diagram showing allele frequencies of glyoxylase I within populations of O. canadensis. Arrows indicate the direction of translocations from source herds to transplant sites. The proportion of alleles 1, 2, and 3 in each population are represented by the white, black, and hatched sectiorzs of each circle, respectively.

Table 1. *Subspecies, population, sample size, and heterozygosity for populations from which 210 samples were obtained.*

SUBSPECIES	POPULATION	SAMPLE SIZE	HETEROZYGOSITY AVERAGED OVER ALL LOCI	SUBSPECIES MEAN HETEROZYGOSITY
O.c. califomiana	Williams Lake, B.C.	15	0.038	
O.c. californiana	Little Jacks Creek, ID*	10	0.029	
O.c. californiana	Hart Mt., OR*	25	0.037	
O.c. califomiana	Mt. Baxter, Sierra Nevada, CA	43	0.0	0.019
O.c. canadensis	Tarryall Mts., CO	20	0.039	
O.c. canadensis	Trickle Mtn., CO*	12	0.041	
O.c. canadensis	Rock Creek, MT*	16	0.067	
O.c. canadensis	Lostine, OR*	19	0.05	
O.c. canadensis	Hall Mt., WA*	10	0.05	0.049**
O.c. mexicana	San Andres Mts., Dona Ana Co., NM	33	0.041	
O.c. mexicana	Peloncillo Mts., Hidalgo Co., NM*	14	0.015	
O.c. mexicana	Red Rock Paddock, NM*	26	0.028	
O.c. mexicana	Kofa Mts., Yuma Co., AZ	41	0.019	
O.c. mexicana	West Kofa Mts., La Paz Co., AZ	22	0.0	
O.c. mexicana	Castle Dome, Yuma Co., AZ	20	0.013	
O.c. mexicana	Pico Johnson, Sonora, Mexico	18	0.036	0.022
O.c. nelsoni	Lone Mt., NV	29	0.005	
O.c. nelsoni	Canyonlands N.P., UT	38	0.03	
O.c. nelsoni	River Mts., NV	29	0.005	
O.c.nelsoni	Lake Meade, AZ	58	0.025	
O.c. nelsoni	White Mts., CA	14	0.015	
O.c. nelsoni	Old Woman Mts., CA	16	0.0	
O.c. nelsoni	Marble Mts., CA	58	0.008	
O.c. nelsoni	Old Dad Peak, CA	124	0.003	
O.c. nelsoni	Cattle Canyon, San Gabriel Mts., CA	22	0.003	
O.c. nelsoni	Lytle Creek, San Gabriel Mts., CA	24	0.0	
O.c. nelsoni	Santa Rosa Mts., CA	55	0.03	
O.c. nelsoni	Living Desert Reserve and Bighorn Institute, CA*	16	0.018	0.010

* Captive or translocated herd

** Both native and translocated herds were used in the heterozygosity estimate for *O.c. canadensis* because only one native herd sample was available.

Table 2. *Electrophoretic separation of bighorn sheep proteins done at SERI.*

PROTEIN	ABBREVIATION	ELECTROPHORETIC SEPARATION METHOD	POLYMORPHISM (Y/N)	TOTAL SAMPLES ANALYZED
Glyoxalase	GLO I	SERI Group I Method on Starch Gel	Y	943
Esterase D	ESD	SERI Group I Method on Starch Gel	N	682
Phosphoglucomutase	PGM (CONV)	SERI Group I Method on Starch Gel	N	671
Phosphoglucomutase	PGM (ST)	SERI Group I Method on Starch Gel	N	260
Adenylate Kinase	AK	SERI Group 11 Method on Starch Gel	N	353
6-Phosphogluconate Dehydrogenase	6-PGD	SERI Group II Method on Starch Gel	N	220
Erythrocyte Acid Phosphatase	EAP	SERI Group 11 Method on Starch Gel	N	345
Transfemn	Tf	S E N Group III Method on Starch Gel	Y	985
Hemoglobin	Hb	Agarose Gel	N	741
Carbonic Anhydrase		CA II on Starch Gel	Y	661
Peptidase A	PEP A	S E N Group IV Method on Starch Gel	N	641
Mannose Phosphate Isomerase	MPI	Wolfe Method on Agarose Gel as Modified at SERI	N	71
Phosphoglucose Isomerase	PGI	Harris Method on Agarose Gel as Modified at S E N	N	216
Phosphoglyceromutase	PGAM	Starch Gel	N	332

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HOME RANGES OF DESERT BIGHORN SHEEP INHABITING THE BLACK MOUNTAINS, DEATH VALLEY NATIONAL PARK, CALIFORNIA

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Abstract: We present total and seasonal home ranges of desert bighorn sheep inhabiting the Black Mountains, Death Valley. During May and September 1992, 8 ewes and 10 rams were fitted with radio collars to determine movements and home range size. Mean total home range size for rams was 188.0 ± 22.5 km^2 (SE). For ewes, mean total home range averaged 96.8 ± 7.5 km^2 (SE). Seasonal home ranges for rams and ewes were smallest during summer months and largest during autumn. Total and seasonal home ranges of rams and ewes are considerably larger than those reported for other desert bighorn sheep populations. These larger home ranges may be related to resource availability or population density.

Key Words: desert bighorn sheep, seasonal home range, total home range, Death Valley National Park

Desert Bighorn Council Transactions 39:26-35

INTRODUCTION

An animal's home range is the area it uses while engaged in the normal activities of food gathering, mating, and caring for young (Burt 1943). The size of this area is related to population density, habitat quality (including habitat continuity), and the energy requirements of animals (Jewell 1966). A number of studies have reported total home range size for desert bighorn sheep (Ovis canadensis nelsoni) populations but information on seasonal home ranges is less common (reviewed by McCarty and Bailey 1994). Generally, mean total home range size of ewes is between 17 and 29 km^2, while ram home ranges are at least twice as large and are much more variable, ranging from 14-275 km^2 (McCarty and Bailey 1994). We present seasonal and total home ranges of desert bighorn sheep inhabiting the Black Mountains in Death Valley, California.

This project was funded by the National Park Service. We thank the pilots at Lake Mead Air and T. L. Hurst for help in data collection. We also appreciate the assistance of D. Ebert and L. Robinson.

STUDY AREA

The Black Mountains form the southern half of the Arnargosa Range in the southeastern part of Death Valley National Park, Inyo County, California (Figure 1). The mountain range encompasses approximately 1000 km^2, is 60 km long, and ranges in width from 32 km at the southern end to 8 km at the northern end. The mountains trend northwest-southeast, forming a wedge-shaped fault resulting in a steep escarpment on the western side with slopes averaging 89 percent. On the eastern side, the range slopes more gently into the alluvial-filled Greenwater Valley. Elevations range from -81 m at Badwater to 1946 m at the top of Funeral Peak. Temperatures range from below freezing to above 40° C and average rainfall is less than 8 cm per year.

Six major plant communities occur in the Black Mountains (Schramm 1982). The Alkali Sink Association is found at the foot of the western escarpment and occurs on alkali flats and where drainage is poor. The Saltbush Community occurs on well-drained alluvial fans on the western side and on xeric, west-facing slopes of up to 600 m elevation on the northwest. The steep, rocky, and arid slopes along the western side of the mountain range are dominated by the Desert Cliff Community, ranging in elevation from 600-1200 m. The Creosote Bush Community occurs from 60 m below sea level to nearly 1500 m above sea level. Within this community are found four vegetative associations: the 1) Larrea, 2) ***Larrea-Ambrosia-Atriplex,*** 3) Larrea-Ambrosia-Lycium, and 4) Larrea-Coleogyne. Cover values range from <1 percent to 10 percent. The Blackbrush Community, occurring on alluvial soils, occurs from 1400 m to the crest of the range. The Shadscale Community occupies steep, rocky slopes and mountain crests throughout the range at elevations of 600 m to nearly 1800 m.

METHODS

To study movements and habitat use, collars equipped with radio transmitters and mortality sensors (Telonics Inc., Mesa, Arizona) were placed on 18 bighorn sheep (10 rams, 8 ewes) in the Black Mountains during two capture operations in 1992. Capture operations were assisted by the California Department of Fish and Game. Bighorn sheep were captured with a hand-held net gun fired from a Bell Jet Ranger helicopter. The first capture occurred from May 19-21, 1992; nine rams were caught and fitted with radio collars. The second capture operation occurred during August 31-September 1, 1992; eight ewes and one ram were fitted with radio collars.

Relocation flights began on August 26, 1992. Flights were conducted from a Cessna 206 airplane equipped with a removable, belly-mounted, modified-H antenna (description in Lecount and Carrel 1980). From September 1992 through May 1993, relocation flights were scheduled approximately every 10 days unless prevented due to weather conditions, aircraft availability, or equipment failure. From June 1993 through August 1994, flights were scheduled every 14 days. A programmable scanner and TR2 receiver (Telonics, Inc.) were used for monitoring bighorn sheep locations. When an animal's signal was heard through the receiver, the area was circled until the signal strength along the circle's circumference was equal. The sheep's location was plotted on USGS 1:62500 scale 15 minute series maps as the center of the circle (Kenward 1987). These data were later recorded as Universal Transverse Mercator (UTM) grid coordinates. Point location data obtained during the flights were also entered into a geographic information system (GIS) computer software package for analysis of habitat use. Based on estimates of accuracy by previous researchers, we assumed an aerial location error of 4 ha (Krausman et al. 1984). This level of error has been used by other researchers for studies on Mojave Desert sheep populations (Bleich 1993).

Home ranges were calculated from relocation data using the minimum convex polygon method (Mohr 1947). Calculations were done with the CALHOME computer program developed by the California Department of Fish and Game. Location data for both years were combined to increase sample size for analysis of the effects of season on home range size. Before data were combined, a paired sample t-test (Zar 1984) was used to test for differences in home range size between years. The difference was not statistically significant ($t=1.32$, $df=14$, $p=0.21$).

To analyze the effects of gender and season on home range size, a two-factor, repeated measures ANOVA (Zar 1984) was performed on the home range data. If a null hypothesis was rejected, the Newman-Keuls multiple range test was used to determine which means were significantly different.

RESULTS

A total of 48 fixed-wing flights were conducted between August 26, 1992, and August 30, 1994, to relocate radio-collared animals. Because of the roughness of the terrain, visual sightings were not attempted, although bighorn sheep were occasionally sighted on ridge tops and on the eastern side of the mountain range. Relocation data from the first flight was not used for home range analysis because at that time only 8 rams had been fitted with radio collars. During the study, one mortality of a radio-collared animal occurred. Ewe number 2350, who had inhabited the northern part of the mountain range near Lemonade Spring, died in the hills above Natural Bridge between June 28, 1994, and July 12, 1994. Cause of death was unknown.

Radio-collared ewes formed three distinct groups centered around four perennial springs: 1) Lemonade Spring, 2) Willow and Sheep Springs, and 3) Scottys Spring. Figure 2 shows total home ranges of representative ewes occupying these areas. Unlike ewe populations inhabiting mountain ranges in southern Nevada (Leslie and Douglas 1979, and Ebert and Douglas 1993) and southwestern Arizona (Cunningham and Hanna 1992), little overlap of home ranges occurred between ewe groups in the Black Mountains, particularly during summer months. When overlap did occur, only rarely were radio-collared ewes from two different groups located in the same area. Ewes were never located at other water sources.

Total home ranges for ewes are based on 364 telemeter locations. Mean total home range was 96.8 ± 7.5 km^2 (SE) with a range of 72.9 km^2 to 124.0 km^2 (Table 1). Only one other study quantitatively examined home ranges of bighorn sheep in Death Valley. Dunn (1984) examined the ecological relationship between burros and bighorn sheep in the Cottonwood Mountains, but unfortunately was only able to collect home range data from 3 ewes and one 2-year-old ram. Total home ranges were smaller than those of radio-collared Black Mountain bighorn; average home range for the ewes was 9.3 ± 0.98 km^2 (SE).

Mean total home range of ewes from other desert bighorn sheep populations are larger than those of ewes in the Black Mountains. In the Lake Mead National Recreation Area, Nevada, Leslie and Douglas (1979) found mean total home range for ewes ($n=5$) in the River Mountains to be 16.9 ± 1.51 km^2, and in the Eldorado Mountains, Ebert and Douglas (1993) found a mean total home range of 19.0 km (range 8.2

to 30.3; 10 ewes). Average total home ranges for three ewe groups in the Black Mountains, Arizona, were similar to those in the nearby Eldorado Mountains; 13.8+3.4 km^2 (SD), 18.4 ± 5.4 km^2, and 45.5 ± 6.7 km^2 (SD) Cunningham and Hanna (1992). In the Cabeza Prieta National Wildlife Refuge, southwestern Arizona, mean total home range size was 22.0 ± 4.1 km^2 (SE), n=10 (Scott et al. 1990), similar to that of four radio-collared ewes (22.1 km^2) inhabiting the Desert National Wildlife Range in southern Nevada (Burger et al. 1983).

Rams did not form distinct groups, but instead occurred in loose associations. They were mostly located in the eastern portion of the mountain range near Funeral Peak and in the hills surrounding Gold Valley. Total home ranges of representative rams are shown in Figure 3. During summer months, rams mostly used water sources on the eastern side of the mountain range. The radio-collared ram in the northern part of the range used Lemonade and Ward Springs. Rams in the southern part of the Black Mountains were mostly found at Hidden, Lard Bucket, and Brown Springs, although they were sometimes found at springs on the western side of the range, particularly during the rut.

Average total home range of rams was significantly larger than average total home range of ewes ($t = -3.49$, df = 16, $p = 0.003$). Total home ranges for rams were calculated from 446 telemetry relocations. Mean annual home range averaged 18.8 ± 2.3 km^2 (SE) and ranged from 7.4 km2 to 32.1 km^2 (Table 2). The radio-collared ram in the Cottonwood Mountains, Death Valley National Park (Dunn 1984), had a total home range similar to that of rams in the Black Mountains (32.7 km^2), but this ram was only 2 years old. Radio-collared rams in the Black Mountains were ≥ 4 years; after age 4, home ranges of rams increase substantially as they become more independent and exploratory (Leslie and Douglas 1979).

Although total home ranges of rams from other desert bighorn populations vary in size, none for which information is available are as small as those of rams inhabiting the Black Mountains. Mean annual home range of radio-collared rams in the River Mountains was 24.7 km^2, with a range of 11.7 to 37.3 km2 (Leslie Longshore and Douglas and Douglas 1979). In the Eldorado Mountains, annual home range averaged 49.7 km^2 and ranged from a low of 31.5 to 60.5 km^2 (Ebert and Douglas 1993). Annual home range for 9 rams in the Black Mountains, Arizona, was 70.7 ± 23.1 km2 (SD) (Cunningham and Hanna 1992) and in southwestern Arizona, Ough and deVos (1984) reported a mean annual home range of over 274 km^2.

When examining the relationship between home range, season, and gender, only bighorn sheep having data sets with nine or more relocations per season were included in the analysis. In addition to the ewe that died, two rams were also excluded from the data base. The first ram (#2302) either moved out of the mountain range or its telemeter failed because we were unable to locate him after November 1993. We occasionally flew over the Funeral Mountains and south of Jubilee Pass (southern Black Mountains) but never located his signal during the remaining flights. The second ram's (#2322) signal stopped near Epaulet Peak during a relocation flight on July 12, 1994.

Results of the repeated measures ANOVA showed a significant difference in home range size within seasons, ($F_{(3,39)} = 14.0$, $p \leq 0.05$), and gender, ($F_{(1,13)} = 11.2$, $p \leq 0.05$), but there was no interaction between gender and season; seasonal pattern of change for home range was the same for both sexes. Rams had larger mean seasonal home ranges than ewes, but within gender, home ranges were similar during winter and spring and were significantly different during autumn and summer (Newman-Keuls multiple-range test).

Mean seasonal home ranges were largest during autumn months. For rams, average home range during autumn was 112.6 km^2 and ranged from 71.7 to 244.9 km^2 (Table 2). During the rut, a few radio-collared rams traversed the entire mountain range; others moved only short distances. Ewe home ranges averaged 49.6 km^2 and ranged from 16.9 to 84.6 km2 (Table 1). The smallest seasonal home ranges occurred during summer, with an average of 16.8 km^2 (range: 7.4 to 28.2 km^2) for rams and an average of 14.6 km^2 (range: 6.0 to 34.1 km^2) for ewes. Summer home range size is partially related to availability of water (Leslie and Douglas 1979), but other factors affecting seasonal home range are unknown. Krausman et al. (1989) found no relation between seasonal home range size and climatic factors for bighorn sheep in Arizona and concluded that seasonal home range dynamics were probably related to a combination of factors such as an animal's age, position in social dominance hierarchies, habitat quality, and presence of other animal species in that habitat.

Seasonal home ranges for the ram and three ewes in the Cottonwood Mountains, Death Valley (Dunn 1984), were smaller than those of bighorn sheep in the Black Mountains. In general, mean seasonal home ranges for radio-collared sheep in the Black Mountains were larger than those reported for other desert bighorn sheep populations (Leslie and Douglas 1979, Krausman et al. 1989, Ebert and Douglas 1993).

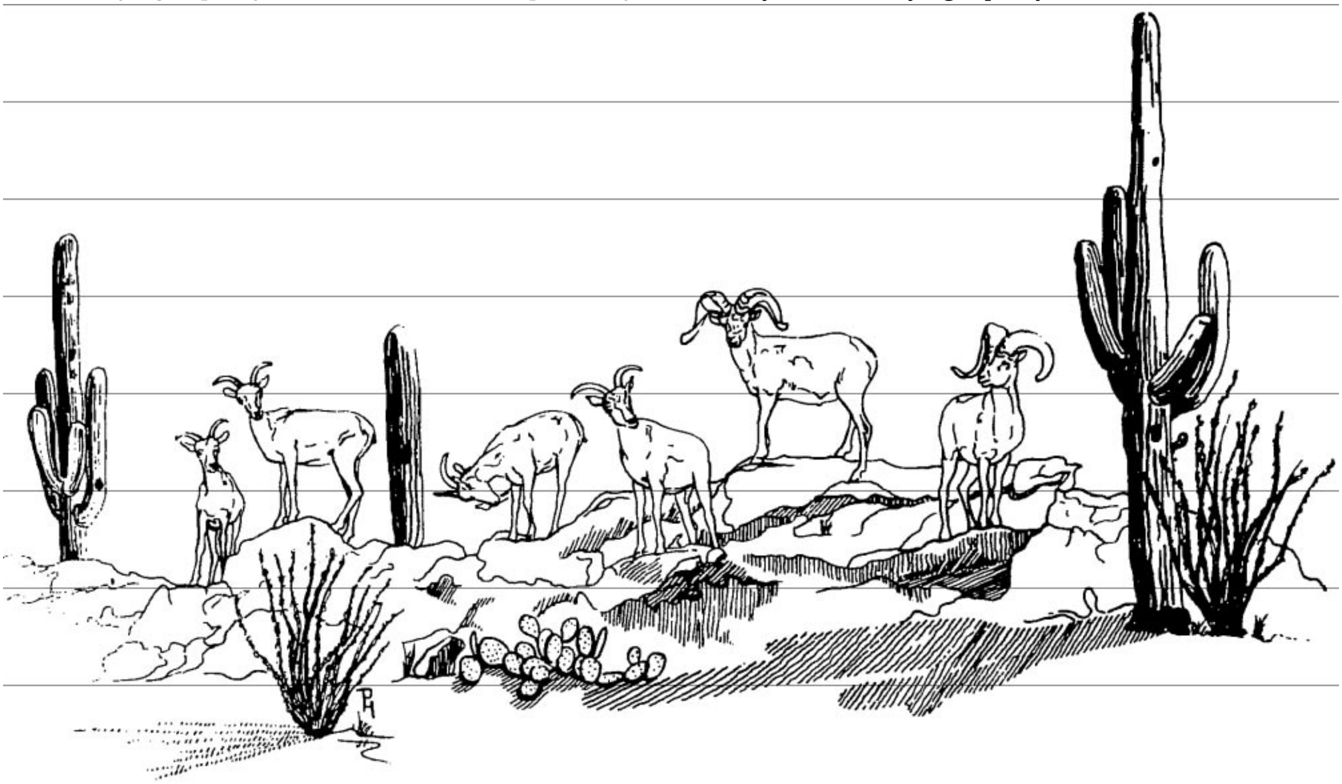
In addition to differences in overall size of home ranges between desert bighorn sheep populations, patterns of seasonal home range size can also differ. Mean seasonal home ranges of ewes in the Little Harquahala 1989), were larger than those of ewes in the Black Mountains, but both exhibited similar patterns of seasonal change and were largest during autumn and smallest during summer. Home ranges of ewes in the River Mountains was largest during autumn/winter and smallest during spring months. Except for an increase during one spring season, home ranges of ewes in the nearby Eldorado Mountains did not show seasonal changes in size (Ebert and Douglas 1993).

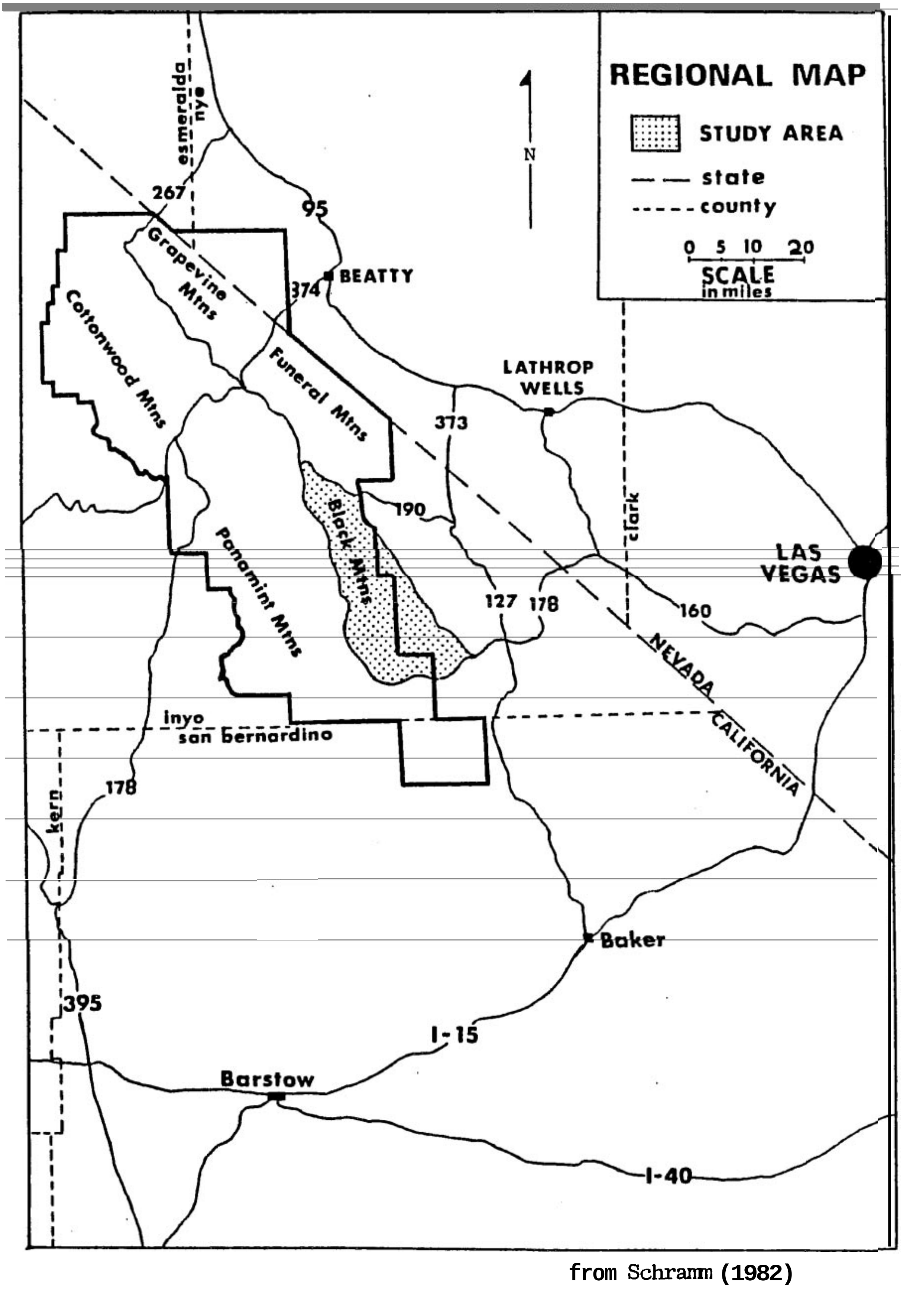
None of the ram populations with available seasonal home range data had seasonal patterns of change similar to that of rams in the Black Mountains. Home range size of some, but not all, ram populations increased in autumn during the breeding season. Mean seasonal home range of rams inhabiting the Eldorado Mountains was larger in autumn (Ebert and Douglas 1993), but home range for rams inhabiting the Harquahala and Little Harquahala Mountains did not increase during this time (Krausman et al. 1989).

There is evidence that for desert bighorn sheep, home range size and resource availability are related. In Arizona, Krausman et al. (1989) found home ranges of bighorn sheep in the Little Harquahala Mountains, which had limited and dispersed resources, to be larger than those in the Harquahala Mountains, which had greater availability of forage and water. If home range size is related to resource availability, and thus, to carrying capacity of the habitat, the comparatively large home ranges in the Black Mountains may be attributed to: 1) a relatively low level of resources, 2) a population with numbers near, or above, carrying capacity, or 3) a combination of these factors.

An examination of fecal crude protein content (a widely used index of forage quality) from the Black Mountain bighorn population (Douglas et al. 1992) showed that values from spring 1989 through spring 1990 were slightly lower than those reported for the same years by Wehausen (1992) for five bighorn sheep populations in the eastern Mojave Desert, suggesting that large home ranges are necessary in the Black Mountains in order to obtain similar, but probably not higher, protein levels as that of other Mojave Desert herds.

Estimates of bighorn sheep numbers during the late 1950s placed the population at approximately 190 animals (Welles and Welles 1960). There has been concern that since the 1930s, population numbers in the Black Mountains had decreased due to poaching, alteration of historic movement patterns (due to increased traffic on roads in, and adjacent to, the mountain range), and loss of major water sources (Welles and Welles 1960, Douglas 1986). The most recent (1994) population estimate for the Black Mountain herd was 127 animals (95 percent C.L. 9-150) (Douglas and Longshore 1995). If home range size is related to resource availability, the current population may be near carrying capacity.





from Schramm (1982)

Figure 1. *Regional map showing location of the Black Mountains, Death Valley National Park, California.*

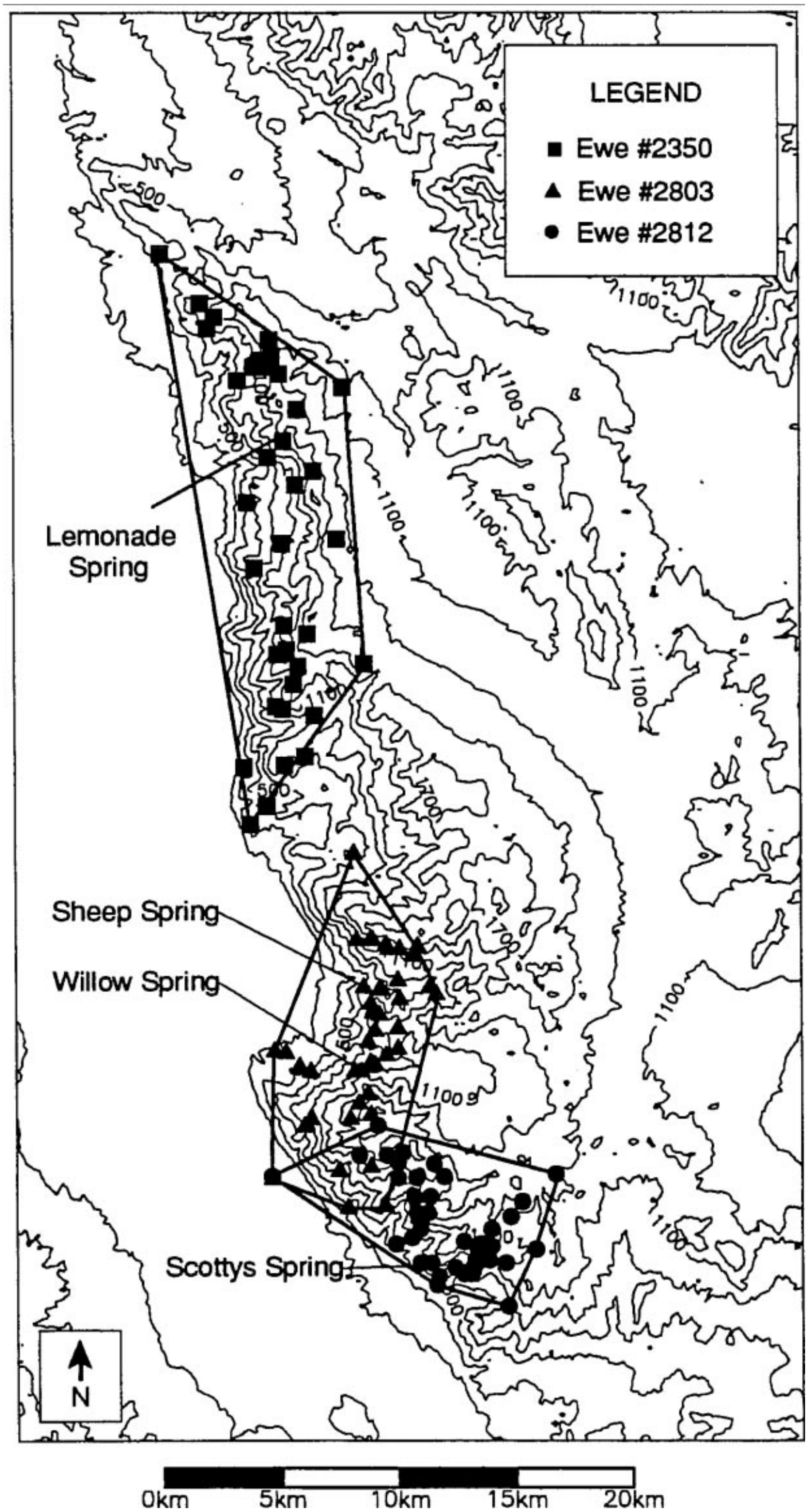


Figure 2. *Typical home range patterns for radio-collared female bighorn sheep in the Black Mountains, Death Valley National Park, California. Each location point may represent one or more sheep sightings. Contour interval = 600 m.*

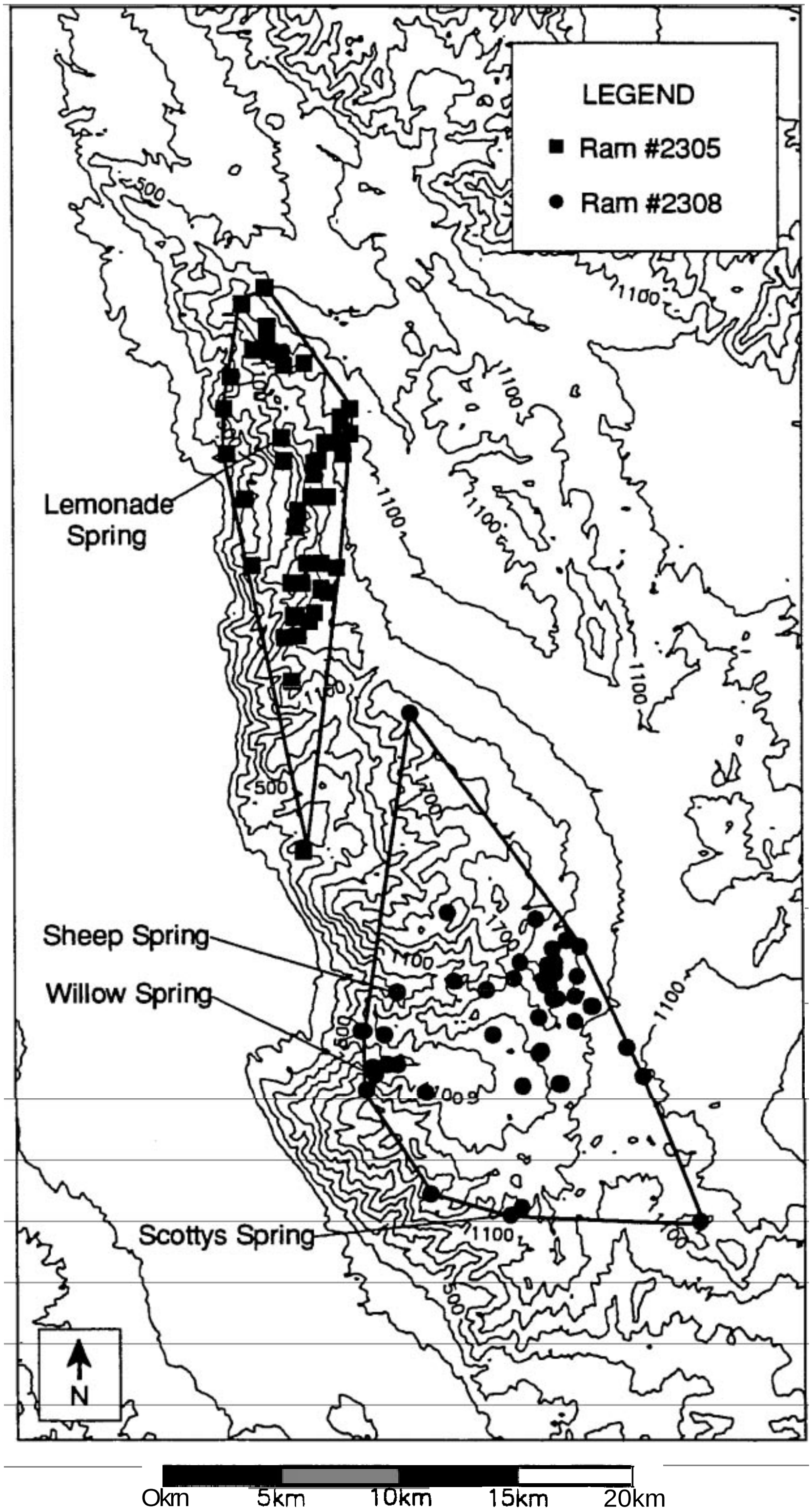


Figure 3. *Typical home range'patterns for radio-collared male bighorn sheep in the Black Mountains, Death Valley National Park, California. Each location point may represent one or more sheep sightings. Contour interval = 600 m.*

Table 1. *Seasonal and total home range size (km^2) for desert bighorn sheep ewes in the Black Mountains, Death Valley National Park, California. Ewes with <9 locations per season were not included in seasonal home range analyses. Number of locations used to determine seasonal and annual home range are in parentheses.*

SHEEP NUMBER	AUTUMN Sept-Nov	WINTER Dec-Feb	SPRING Mar-May	SUMMER Jun-Aug	TOTAL
2350	93.5 (10)	35.1 (8)	86.7 (13)	34.0 (7)	124.0 (38)
2801	64.9 (12)	12.7 (11)	34.5 (13)	34.1 (11)	101.9 (47)
2802	51.0 (12)	28.1 (11)	18.2 (13)	14.5 (11)	75.9 (47)
2803	16.9 (12)	30.4 (11)	30.1 (13)	6.0 (11)	72.9 (47)
2806	84.6 (12)	19.7 (10)	25.5 (13)	14.2 (11)	124.0 (46)
2807	35.9 (12)	22.0 (11)	11.0 (13)	14.0 (11)	107.6 (47)
2810	57.9 (11)	26.4 (10)	42.1 (13)	10.9 (11)	94.9 (45)
2812	35.9 (12)	18.5 (11)	9.0 (13)	8.5 (11)	73.3 (47)
n=	7	7	7	7	7
mean:	49.6	22.3	24.3	14.6	96.8
SE:	8.0	2.3	4.6	3.4	7.5

***Table* 2.** *Seasonal and total home range size (km²) for desert bighorn sheep rams in the Black Mountains, Death Valley National Park California. Number of locations used to calculate seasonal and total home range are in parentheses. Only rams with ≥9 locations per season were included in home range analyses. Age at capture is indicated inside brackets adjacent to sheep number.*

SHEEP NUMBER	AUTUMN Sept-Nov	WINTER Dec-Feb	SPRING Mar-May	SUMMER Jun-Aug	TOTAL
2302 [4+]	77.3 (11)	23.3 (6)	23.8 (8)	21.7 (6)	214.0 (31)
2305 [5]	72.8 (13)	27.1 (10)	33.7 (13)	16.0 (11)	74.7 (47)
2306 [7+]	85.2 (13)	32.1 (10)	83.6 (13)	17.9 (11)	174.0 (47)
2308 [6+]	71.8 (13)	51.7 (11)	95.1 (13)	9.7 (11)	178.9 (48)
2309 [4+]	86.2 (12)	66.7 (10)	15.4 (13)	25.0 (11)	161.7 (46)
2310 [5+]	71.7 (12)	65.0 (10)	52.9 (12)	7.4 (11)	136.1 (45)
2319 [4]	132.4 (12)	183.1 (11)	35.7 (12)	28.2 (11)	230.0 (46)
2321 [4+]	244.5 (12)	63.8 (11)	113.1 (13)	10.5 (11)	320.7 (47)
2322 [4+]	46.9 (13)	53.6 (10)	49.0 (13)	3.0 (6)	129.0 (42)
2805 [6]	135.5 (12)	30.4 (11)	66.8 (13)	19.7 (11)	261.4 (47)
n=	8	8	8	8	10
Mean:	112.6	65.0	62.0	16.8	188.0
SE:	21.0	17.9	11.9	2.6	22.5

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MANAGING DESERT MOUNTAIN SHEEP USING ECOREGION PLANNING AND MANAGEMENT CONCEPTS: IS IT POSSIBLE?

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Abstract: Until recently, mountain sheep management has emphasized local populations and their habitat. Current policy in some areas has established management at the metapopulation level, which requires managing whole landscapes or ecoregions rather than single mountain ranges. Information gathered on the distribution of mountain sheep for the interagency *Mountain Sheep Ecosystem Management Strategy in the 11 Western States and Alaska* (USDI 1995) was overlain on ecoregion maps and visually compared. Three ecoregion mapping strategies are currently being reviewed by an interagency task force. Our comparison was to determine which, if any, of these mapping strategies best fit mountain sheep distribution. Current ecoregion boundaries do not accurately represent desert mountain sheep habitat requirements. Ecosystem management and planning should establish, on a case-by-case basis, ecosystem boundaries that accurately reflect total desert mountain sheep habitat requirements.

Key Words: desert bighorn sheep, ecoregion, ecosystem, habitat, landscape, management, mountain sheep, metapopulation, *Ovis canadensis nelsoni.*

Desert Bighorn Council Transactions 39:36-41

INTRODUCTION

Management of desert bighorn sheep *(Ovis canadensis nelsoni)* has historically addressed local populations and single mountain ranges or small mountain range complexes. In its *Rangewide Plan for Managing Habitat of Desert Bighorn Sheep on Public Lands* (USDI 1986), the Bureau of Land Management (BLM) established priorities for desert mountain sheep habitat management based on managing local populations within geopolitical boundaries. At the same time, Schwartz et. al. (1986) emphasized the need to move from local population to metapopulation management. Bleich et. al. (1990) pointed out the problems that desert-dwelling mountain sheep face when confronted with fragmented habitat. In a report prepared for the BLM, Ramey (1991) strongly advised against local population management and urged that metapopulation management become the normal practice for desert mountain sheep. As a result of the work by Bleich et. al. (1990) and Ramey (1991), the BLM's California Desert District established a metapopulation management policy. This policy directs that the management of mountain sheep habitat on Public Lands in southern California be accomplished in accordance with the metapopulation boundaries established in 1993 (Torres et. al. 1994).

A metapopulation is defined as a set of local populations which interact via individuals moving among populations (Hanski and Gilpin 1991). California populations are patchy metapopulations. Bailey (1992) described patchy metapopulations as those having 1000 or more individuals distributed in interdependent bands of 100 or less sheep. Several of these populations should approach at least 100.

Beginning in 1993, the federal land management agencies formally committed themselves to ecosystem management (USDA 1993, USDI 1993, USDI 1994). As a part of this commitment, the BLM, the U.S. Forest Service, and the Natural Resources Conservation Service (NRCS) (formerly the Soil Conservation Service) joined in an effort to establish a national hierarchical framework of ecological units to be used in land use planning and ecosystem management.

From 1993 through 1995, the Bureau coordinated development of the interagency publication *Mountain Sheep Ecosystem Management Strategy in the 11 Western States and Alaska* (USDI 1995). Part of the preparation of this document required updated maps of mountain sheep distribution for the western United States. The authors were asked to compare these distributions to the aforementioned ecological unit map boundaries being reviewed to determine those that most accurately coincide with mountain sheep distribution. In this paper, we report the results of this comparison for desert mountain sheep.

METHODS

Desert mountain sheep distribution throughout California, Nevada, Arizona, Utah, Colorado, and New Mexico were used in this comparison.

Four different sources for ecological units or ecoregion mapping were reviewed: 1) Physiographic Regions (Brown and Kerr 1979); 2) Ecoregions of the Conterminous United States (Omernik 1993); 3) Ecoregions and Subregions of the United States (Bailey et. al. 1994); and 4) the Major Land Resource Areas (MLRA) of the United States as mapped by the NRCS. Brown and Kerr (1979) were not used past the preliminary stage. Negotiations began on merging the three latter sources into one ecoregion map acceptable for ecoregion and ecosystem planning. One additional step was to determine if the resulting ecological units would be large enough to account for management of wide-ranging wildlife species. The first comparison focused on desert mountain sheep.

A visual comparison of the distribution data plotted separately over each ecological unit map was completed using the desert mountain sheep population/metapopulation data and the ecoregion maps (Figures 1-3).

RESULTS

Desert mountain sheep distribution did not accurately match any of the ecological unit maps. Ecoregions developed by Omernik (1993) (Figure 1) provided the closest fit for mountain sheep habitat followed by MLRAs (NRCS 1993) (Figure 3). The ecoregions mapped by Bailey et. al. (1994) (Figure 2) more accurately matched mountain sheep habitat than the nested subregions.

DISCUSSION

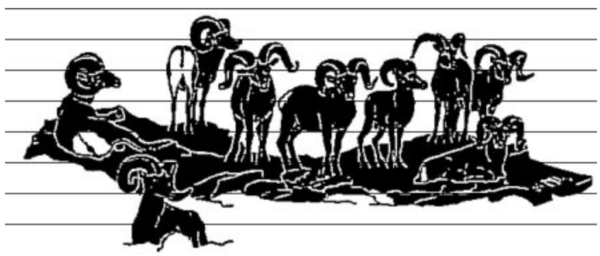
Ecoregion and subregion boundaries are delineated using climate, physiography, soils, hydrology, and potential natural communities (Bailey et. al. 1994, Omernik 1993). MLRA boundaries include geographically associated land resource units, that identify nearly homogeneous areas of land use, elevation, topography, climate, hydrology, potential natural vegetation, and soils (NRCS 1993).

Desert mountain sheep occupy those areas that provide for their habitat requirements. Topography is the principal habitat component that is fixed in the physiographic landscape. Habitat for mountain sheep can be found on both sides of the mountain, whereas many of the ecoregion, subregion, and MLRA boundaries follow watersheds and hydrologic basins. More important, however, than determining why metapopulation boundaries and ecoregion boundaries do not coincide is ensuring that ecosystem management is carried out properly when addressing mountain sheep.

A major problem in managing ecosystems containing large, wide-ranging wildlife species is that the defined boundaries frequently are not large enough to provide adequate habitat (Bailey 1992, Grumbine 1994, Noss and Coopemder 1994). Bailey (1992) and Grumbine (1994) also recommend that geopolitical houndaries not be a consideration and that all agencies involved work for themutual benefit of ecosystem and mountain sheep management.

RECOMMENDATIONS

As demonstrated, ecosystem management that includes desert bighorn sheep will require establishing boundaries other than those provided on current ecoregion maps. The authors recommend that land management agencies establish ecosystem management boundaries that accurately reflect the habitat requirements of desert mountain sheep metapopulations. Use of this approach will require a case-by-case analysis rather than attempting to predefine boundaries for every management or planning situation. To aid land management agencies in this effort, the authors further recommend that those agencies concerned with the management of desert mountain sheep complete consolidation of the bioregion maps provided for the interagency publication ***Mountain Sheep Ecosystem Management Strategy in the 11 Western States and Alaska.***



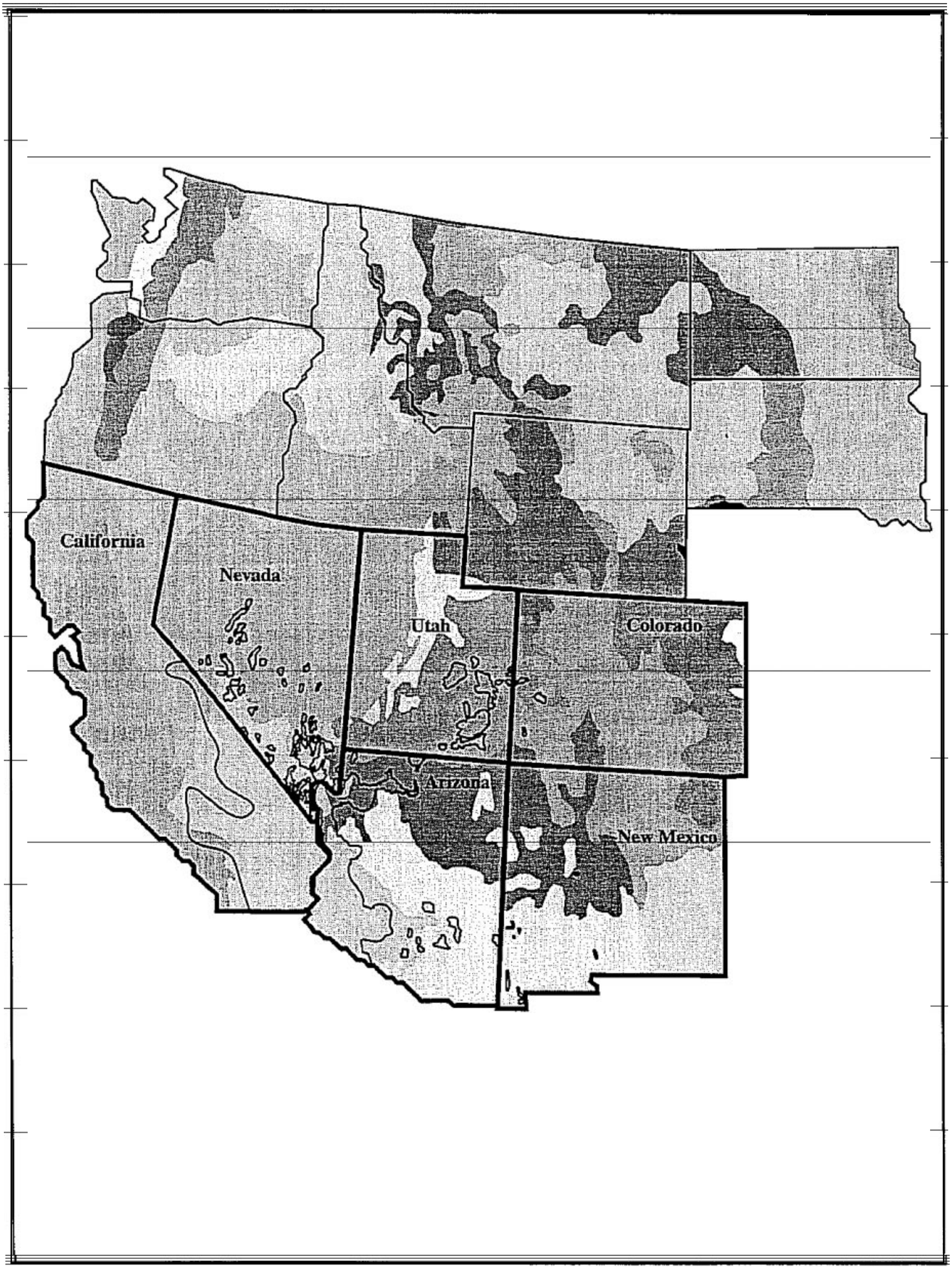


Figure 1. Desen mountain sheep distribution in relation to ecoregions of the conterminous United States (Omernik 1993).

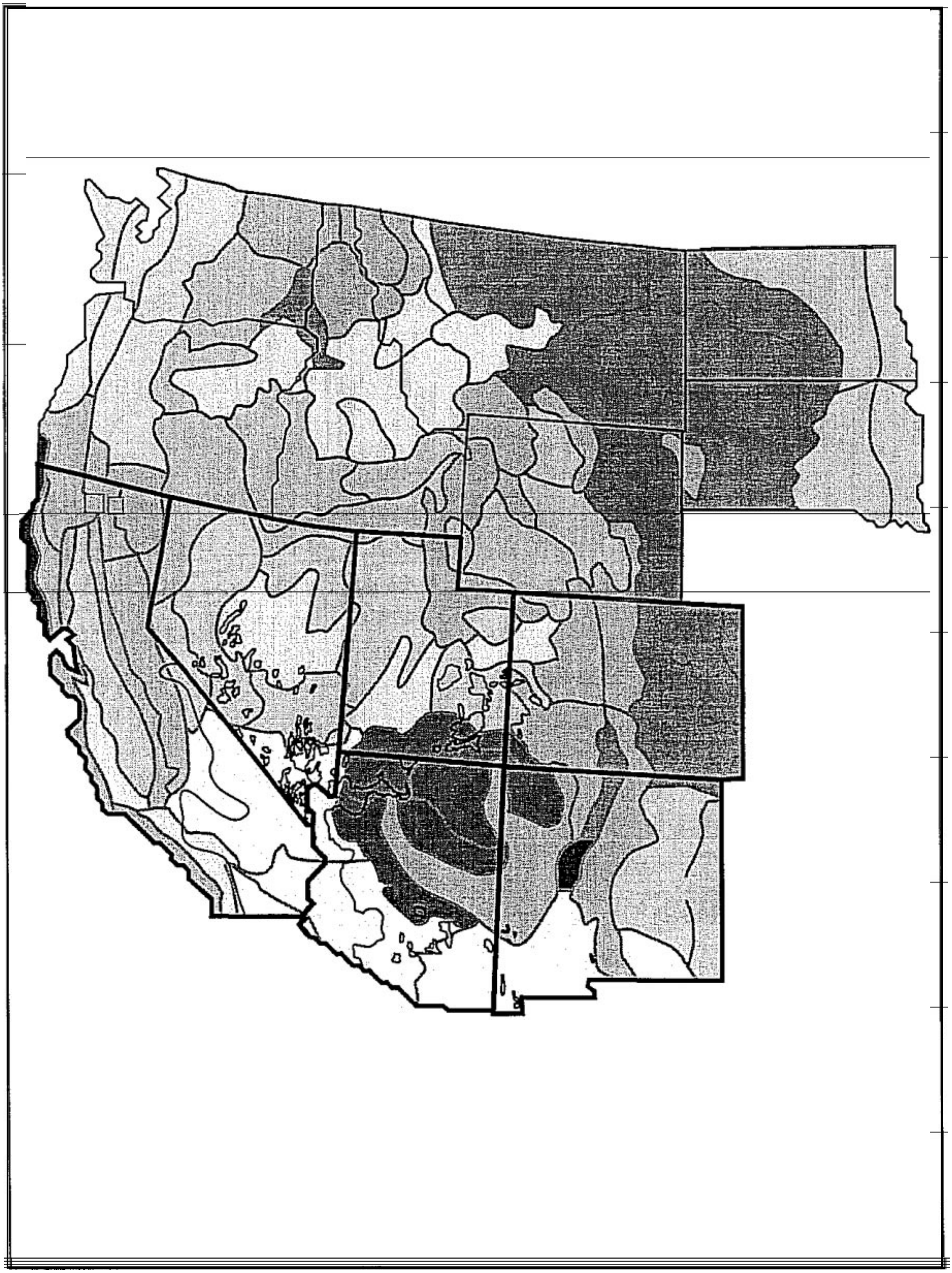


Figure 2. Desert mountain sheep distribution in relation to ecoregions and subregions of the United States (Bailey et al. 1994).

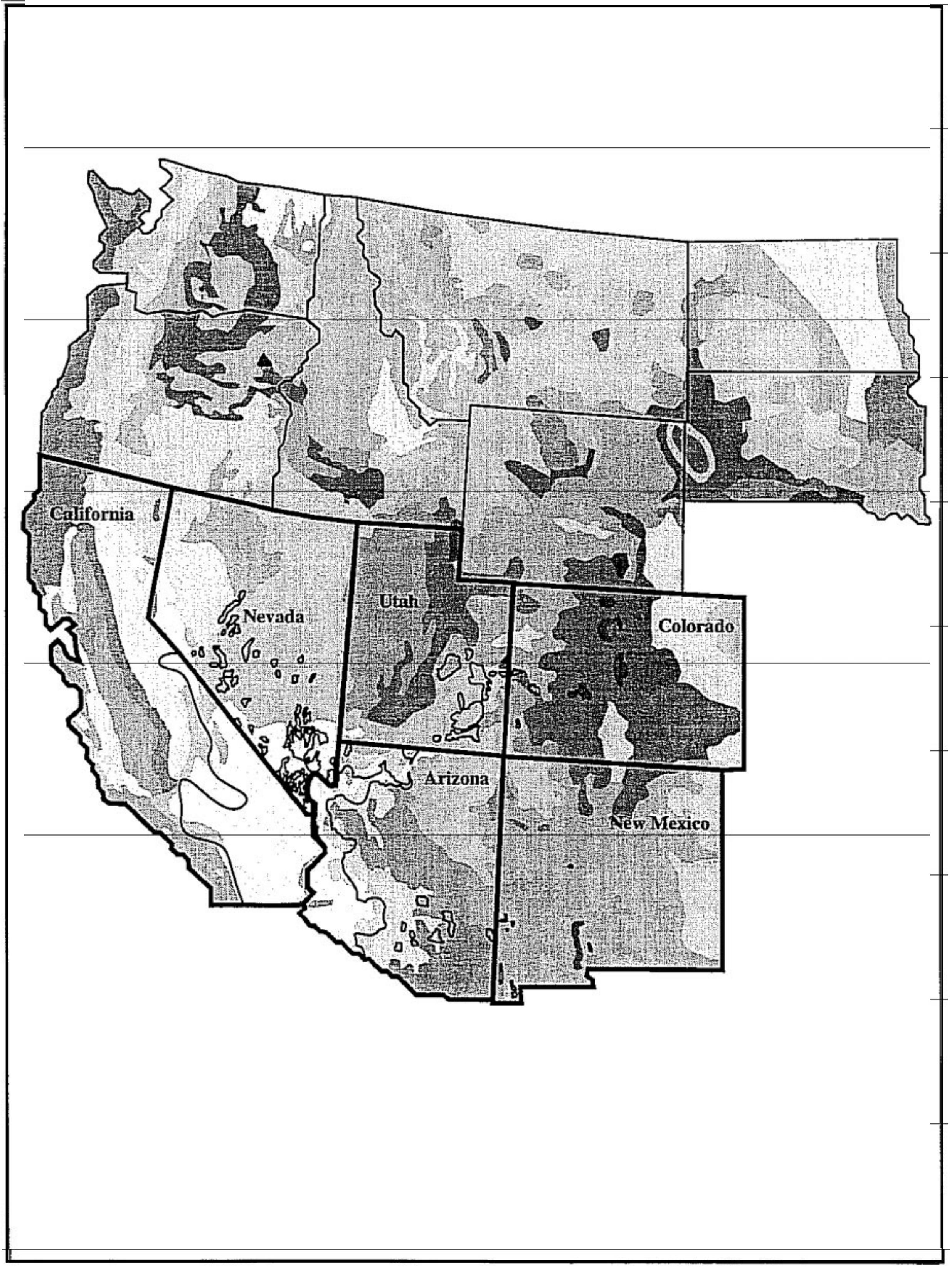


Figure 3. Desert mountain sheep distribution in relation to Major Land Resource Areas (MLRAs) of the United States (Natural Resources Conservation Service 1993).

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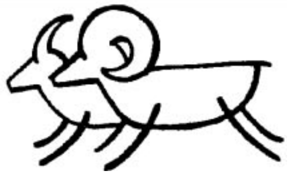

POPULATION DENSITY OF DESERT BIGHORN IN NORTHERN BAJA CALIFORNIA, MEXICO (CAÑADAS ARROYO GRANDE AND JAQUEJEL)

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Abstract: The population density and habitat characteristics of desert bighorn (Ovis canadensis cremnobates) were evaluated in 900 km' area in northeastern Baja California (Caiiadas Arroyo Grande and Jaquejel) during the summer and autumn of 1992. Line transect sampling was used to obtain population densities of 0.203 bighorn/km^2 for summer and 0.145 bighorn/km^2 for autumn. The observed population ratios (ram:ewe:lamb) were 71:100:11 for summer and 50:100:5 for autumn. Bighorn were most commonly observed in rough (>60 percent), steep (>33 percent) terrain around the watering holes. Low correlations between number of bighorns observed and the mean water close distance (MWCD) were registered in summer (r=0.287) and autumn (r=0.235) of 1992.

Key Words: Baja California, bighorn estimation, México, Ovis canadensis cremnobates, desert bighorn.

Desert Bighorn Council Transactions *39:42-49*

INTRODUCTION

Desert bighorn (Ovis canadensis cremnobates) were once abundant in the arid mountains of eastern Baja California, México (Monson 1980); however, their current population densities along the range of native distribution have been reduced due to habitat alteration and fragmentation (Graham 1980), competition for natural resources from domestic and feral livestock (e.g., goats and cattle; Jones 1980, Smith and Krausman 1988), illegal hunting, excessive harvest or poaching, recreational activities (i.e., tourism), and the occurrence of wild, free-roaming burros (Graham 1971, Ferrier 1974, Golden and Tsukamoto 1980).

The desert bighorn in México was historically protected from 1922 to 1933 (Salas 1969, Hansen 1980), and from 1944 to 1963, when hunting was prohibited (Salas 1977). This prohibition prevailed for about 4 decades. In 1964, the Mexican federal government authorized limited experimental hunting of desert bighorn in order to regulate the rate of exploitation (Jaramillo-Monroy and Castellanos-Vera 1992). Between 1975 and 1987, the management of desert bighorn was conducted by the Secretariade Desarrollo Urbano y Ecologia (SEDUE). During 1988, SEDUE, in collaboration with Universidad Autónoma de Baja California (UABC), made a survey called "Estudio de población e histopatológico del borrego cimarrón del desierto en el Estado de Baja California" during the 1986 and 1987 hunting seasons(SEDUE-UABC 1988, unpublished). But, their analyses wereexclusively based on individualsseen or killed during hunting expeditions. They saw 2101 bighorn in 10 hunting localities with an observed population ratio (ram:ewe:lamb) of 59:100:12. Based on these results, the number of permits for hunting desert bighorn in Baja California was reduced in 1988 from 73 to 33.

In that same year, the Consejo Nacional de la Fauna, A.C. (CNF) began a management program and the first telemetric studies for the desert bighorn in Baja California (DeForge et al. 1988).

In 1990, because of the strong controversy regarding the current status of desert bighorn in Baja California, Mexico's federal government declared the desert bighorn protected until the UABC evaluated the current population status (Diario Oficial, México, 24 de Diciembre. 1990. vol. II, num. 12., pages 32-33). Recently, DeForge et al. (1993) estimated that peninsular bighorn in northern Baja California, México, numbered between 780 and 1170 adults.

This study was designed to quantitatively evaluate the population density of the desert bighorn during the summer and autumn of 1992 in one of the most well-known hunting areas of northern Baja California, Mexico, where the population might unfortunately be exposed to potential anthropogenic impacts.

We wish to express our sincere thanks to SEDESOL and the field guides, A. Aguiar, M. Davis, G. Torres, T. Sánchez, and to the biologists, R. Reyes, J. Ramírez, M. Ayala, J. Morales, J.L. Cadena, F. Cota, A. Gerardo, J. Escamilla, and J. Alaniz, for their valuable assistance with the samplings. Also, to F. Clemente for advisory support and valuable comments on the project. J. DeForge and R. Valdez made comments helpful to our manuscript. This study was supported by the contract 8472 SEDESOL-UABC.

STUDY AREA

The study area (900 km^2) is located around two perennial streams (Caiiadas Arroyo Grande and Jaquejel) in northern Baja California, México, within the geographical coordinates: 31°21'03", 31°37'16" N and 115°31'39", 115°12'52" W (Figure 1). This area is bounded on the north by the sierra Las Tinajas, on the south by the sierra San Felipe and Valle Santa Clara, on the east by the sierra Las Pintas and Llano El Chinero, and on the west by the eastern slopes of the Sierra Juárez. The study site is surrounded on its south and east sides by Highways 3 and 5, respectively. A four-wheel-drive road crosses almost the entire length (west-east) of the study area (CETENAL topographic maps, 1:50,000). This area is part of the Lower Colorado River Valley subprovince (Shreve and Wiggins 1964, Turner and Brown 1982). Its climate is dry desert type or BW(h')hs(x')(e') (Garcia 1981). Mean annual precipitation and temperature is 68.3 mm and 21.9 °C, respectively (Lbpez-Saavedra 1991). The mean temperature ranges between 12°C and 48°C (Turner and Brown 1982). Rains are frequently recorded in winter and temperatures never fall below 0°C (Lbpez-Saavedra 1991).

The mountain range in the study site exhibits gradients of altitude with east-west directions and with elevations ranging between 400 m (riparian habitats) and 1600 m (Cerro de la Noche or Witiñan), as well as the east slopes of Sierra Juárez (ca. 1000 m). The mountains are mainly composed of volcanic rocks of intrusive and extrusive origin, and rocks of sedimentary type are observed at some sites of Sierras Las Tinajas and Las Pintas (Gastil et al. 1975).

The most representative plant species in the study area are Western Honey Mezquite, Ironwood, Blue Palo Verde, Desert Willow, Catclaw Acacia, Anderson Thornbush, Broom Baccharis, Creosotebush, White Bursage, Ocotillo, Brittlebush, and Foothill Palo Verde (Turner and Brown 1982, Delgadillo 1992).

METHODS

This study was conducted between July and December 1992 in an area of 900 km2 (30 x 30 km) in northern Baja California (Figure 1). We divided this area into four plots of 225 km2 each. Each plot was then systematically divided into five, 15 km-long and 3 km-wide transects, which were sampled twice (summer and autumn). The sampling design was based on Burnham's et al. (1980) line transect sampling method. The samplings were made walking approximately 5 km/day. The perpendicular distance to the line of each bighorn detected was calculated using the sighting angle and distance. All assumptions of Burnham's method were considered during the field samplings. Data obtained in the line transect samplings were analyzed with the DISTANCE program (Laake et al. 1994) to estimate the population density in the study area. Physiographic and ecological characteristics of the habitats were evaluated according to the criteria of Geist (1971), Monson and Sumner (1980), Burnham et al. (1980), and McCarty (1993).

The topographic cover (steepness, ruggedness, and aspect) and water sources (type, size, and distance) were registered along each transect surveyed (McCarty 1993). Terrain ruggedness was visually estimated within a 100 m radius at different points of the transect. The average terrain steepness, as well as distances to water sources, was obtained from CETENAL topographic maps (scale 1:50,000).

RESULTSAND DISCUSSION

During the summer, 85 desert bighorn were seen along 25 groups, averaging 3.3 bighorn per group. Based on a line-transect model (Laake et al. 1994), we estimated a population density of 0.203 bighorn/km^2 (N=183 adult bighorns, Table 1A) for summer. Bighorn sightings included 33 rams (class I=4, class II=6, class III=10, and class IV=13), 46 adult ewes (22 years), 5 lambs, and 1 yearling female, resulting in a ratio (ram:ewe:lamb) of 71:100:11 (Table 2). During the autumn, a total of 35 bighorns were observed in 10 groups, averaging 3.5 bighorns per group. The estimated density was 0.145 bighorn/km^2 (N=131 adult bighorn, Table 1B). Bighorn sightings in autumn were less than in summer, which included 11 rams (class I=0, class II=3, class III=4, and class IV= 4), 22 adult ewes (22 years), 1 lamb, and 1 yearling female, resulting in a ratio (ram:ewe:lamb) of 50:100:5 (Table 2).

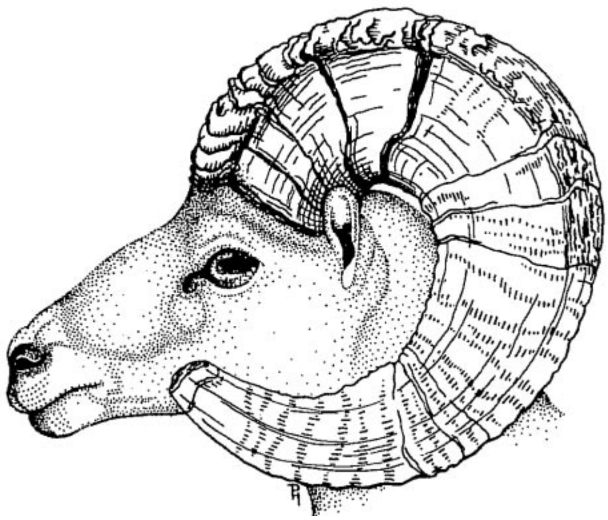
Bighorn sightings were not statistically different ($p > 0.05$) between summer and autumn (t-student's test, $t=2.04$) and among plots (one way-ANOVA test,

$F=2.06$), which suggests a homogeneous distribution of the individuals along the study area during both seasons. However, the number of individuals within plots (among transects) was significantly different ($F=2.86$, $p<0.05$), likely as a consequence of heterogeneity among transects regarding the presence and proximity of watering holes (Leslie and Douglas 1979, Douglas 1988, Wakeling and Miller 1990). A paired t-test for plots showed a significant difference only for plot III ($t=2.818$, $p=0.048$). Therefore, Pearson's correlation test showed no statistical differences between the number of bighorns observed per transect and the mean water close distance (MWCD), either in summer ($r=0.287$, $p=0.455$, Table 3A) or autumn ($r=0.235$, $p=0.611$, Table 3B). These low correlations suggest that occurrence of desert bighorn within plot III (transects 2-4 and 5) was independent from the distribution of water sources, since biannual rainfalls (summer and winter) are frequently registered in the northeast of Baja California and particularly in the Lower Colorado River Valley subprovince (Garcia 1981, Turner and Brown 1982, Lbpez-Saavedra 1991, Delgadillo 1992). In addition, Krausman and Leopold (1986) suggested that free water was not a limiting factor for desert bighorn in Harquahala Mountains, Arizona.

The estimated population density of desert bighorn for the summer of 1992 (0.203 bighorn/km^2 cf. Table 1) in northern Baja California (Cañadas Arroyo Grande and Jaquejel) was slightly lower than that observed during the spring of 1992 for this same region (0.206 bighorn/km^2 area=740 km^2, N=153; aerial survey, DeForge et al. 1993). The observed ratios and densities in the study area were similar for summer and autumn seasons, which might indicate few movements of the individuals beyond the plots surveyed.

During the field samplings, the desert bighorn were observed equally distributed along the plots; however, these were more frequently seen in altitudes between 500 m and 700 m where the terrains are very rough (>60 percent) and steep (>33 percent).

Finally, we recommend that the population density and structure of the desert bighorn, as well as their habitat requirements, be evaluated throughout range in the peninsula of Baja California in order to determine its current conservation status and their perspectives for management.



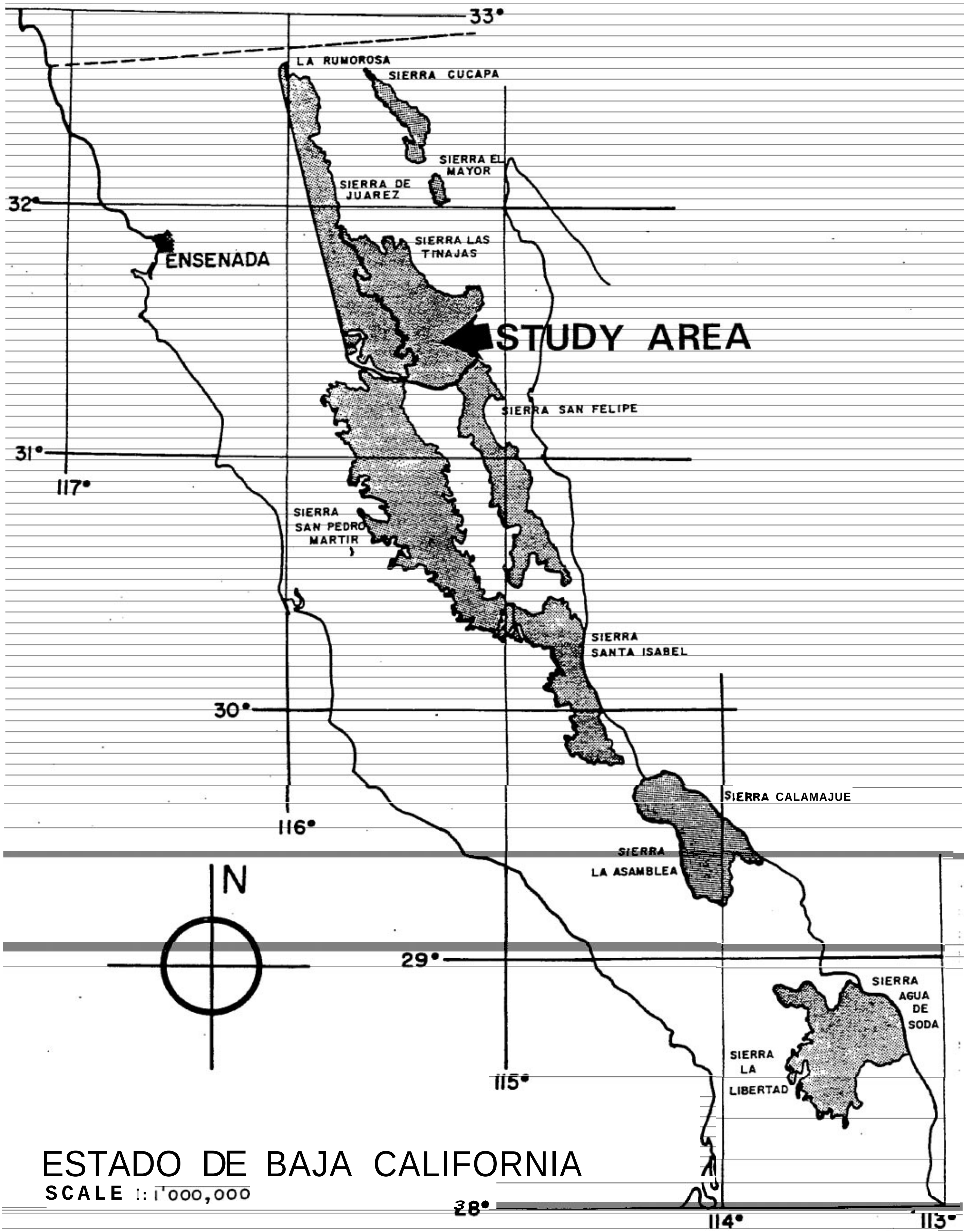


Figure 1. *Location of the study area in northeastern Baja California, México.*

Table 1A. *Summary of estimated population density of desert bighorn in summer of 1992 for 900 km^2 in northern Baja California, Mkxico.*

Parameter	Point Estimate	Standard Error	Percent Coef. of Variation	95 Percent Confidence LCL	Interval UCL
f(0)	0.3529E-02	0.9486E-04	6.2	0.1351E-02	0.1729E-02
P	0.6021	0.3736E-01	6.2	0.5322	0.6811
ESW	654.2	40.60	6.2	578.2	740.1
n/L	0.2667	0.2981E-01	11.2	0.2143	0.3318
D	0.2038	0.2606E-01	12.8	0.1588	0.2616
N	183.0	23.46	12.8	143.0	235.0

Measurement Units
Density (D): bighorns/square kilometer; p: probability of detection

Table 1B. *Summary of estimated population density of desert bighorn in autumn of 1992 for 900 km^2 in northern Baja California, Mkxico.*

Parameter	Point Estimate	Standard Error	Percent Coef. of Variation	95 Percent Confidence	Interval
f(0)	0.2365E-02	0.2271E-03	9.6	0.1947E-02	0.2872E-02
P	0.5644	0.5420E-01	9.6	0.4647	0.6854
ESW	422.8	40.61	9.6	348.2	513.5
n/L	0.1233	0.2028E-01	16.4	0.8955E-01	0.1699
D	0.1458	0.2777E-01	19.0	0.1008	0.2111
N	131.0	24.99	19.0	91.00	190.0

Measurement Units
Density (D): bighornslsquare kilometer; p: probability of detection

Table 2. *Summary of desert bighorn by age class observed during samplings on foot (line transect method) in northern Baja California, Mkxico (area surveyed=900 km^2, date: July to December 1992).*

Season	Ram Class I II III IV	Ewes/Lambs	Yrlgs. M F	Total	Rams /100 Ewes	Lambs /100 Ewes
Summer	4 6 10 13	4615	0 1	85	71	11
Autumn	0 3 4 4	2211	0 1	35	50	5

Table 3A. *Mean water close distance (MWCD) registered by transect, using bighorn sightings ($n \geq 2$) during summer of 1992.*

Pt	n	MWCD	SD	r	P
P_It_3	9	5.7	0.30	0.287	0.455
P_It_4	6	2.0	0.77		
P_It_5	5	2.4	0.84		
$P_{II}t_1$	11	0.1	0.00		
~~$P_{III}t_2$~~	~~13~~	~~5.9~~	~~0.34~~		
$P_{III}t_3$	3	5.5	4.56		
$P_{III}t_4$	23	5.2	1.83		
$P_{III}t_5$	10	2.1	1.97		
$P_{IV}t_5$	3	2.0	0.87		

P = Plot; t = Transect; r = Pearson's correlation coefficient; p = Level of significance

Table 3B. *Mean water close distance (MWCD) registered by transect, using bighorn sightings ($n \geq 2$) during autumn of 1992.*

Pt	n	MWCD	SD	r	P
P_It_2	2	5.0	0	0.235	0.611
P_It_3	2	0.5	0		
P_It_5	3	2.0	0		
~~$P_{II}t_1$~~	~~4~~	~~3.0~~	~~0~~		
$P_{III}t_2$	7	5.5	0		
$P_{III}t_4$	11	2.8	3.29		
$P_{IV}t_1$	5	4.0	0		

P = Plot; t = Transect; r = Pearson's correlation coefficient; p = Level of significance

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POPULATION DYNAMICS OF PENINSULAR BIGHORN SHEEP IN THE SANTA ROSA MOUNTAINS, CALIFORNIA, 1983-1994

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Abstract: Fall (1983-1994) helicopter surveys of Peninsular bighorn sheep (Ovis canadensis cremnobates) in the Santa Rosa Mountains (SRM) of Southern California were used to determine annual population estimates and dynamics. Age structure and sex ratio data, as well as maintenance recruitment ratios for population stability, were also examined. During these 12 years, ram:ewe:lamb:yearling ratios averaged 44.9:100:25.2:17.4. Long-term suppressed recruitment following a disease epizootic in the late 1970s caused a 69.1 percent population decline from 374.0 ± 10 adult bighorn in 1984 to 115.5 ± 24 in 1994. Spatial analysis showed that the decline occurred throughout the SRM. The bighorn population decreased at an average annual rate of 17.8 percent from 1984 to 1990, then stabilized at a density of only 0.15 bighorn/km^2.

Key Words: Chapman estimator, demography, helicopter survey, Ovis canadensis cremnobates, Peninsular bighorn, population dynamics, population estimate, recruitment, Santa Rosa Mountains.

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INTRODUCTION

The Santa Rosa Mountains (SRM) of Riverside and San Diego counties once were thought to support the largest and densest desert bighorn sheep (Ovis canadensis) population in California (Weaver and Mensch 1970). This range comprises 48 percent of the current and historic Peninsular bighorn (*O.c.* cremnobates) habitat in the United States (Peninsular Ranges Coordinated Bighorn Sheep Metapopulation Ecosystem Plan, September 22, 1995 Draft). Field studies, waterhole counts, or helicopter surveys (beginning in 1977) provided the basis for subjective bighorn population estimates of 350 in 1953 (Jones et al. 1957), and 500 bighorn in 1967 (Blong 1967), 1970 (Weaver and Mensch 1970), and 1974 (Weaver 1975) in the SRM. In 1970, the Santa Rosa bighorn population was described as stable or possibly increasing, with good recruitment (Weaver and Mensch 1970). However, since 1977, a population decline has occurred in this range, correlated with a disease epizootic causing high lamb mortality (DeForge and Scott 1982, DeForge et al. 1982, Wehausen et al. 1987, Elliott et al. 1994). A fall lamb:ewe ratio of only 11.1:100 was documented for the SRM in 1977, with subsequent years producing similarly low recruitment ratios (DeForge et al. 1982, DeForge and Scott 1982, DeForge 1984, Wehausen et al. 1987). From geographic analysis of pathogen exposure frequencies of bighorn sheep in California, Elliott et al. (1994) found that the southwestern region of the state, occupied by the Peninsular populations, had the highest prevalence values for a majority of the individual pathogens tested for, and the highest level of multiple pathogen exposure.

Peninsular bighorn sheep have been classified as Rare, and then Threatened, by the California Fish and Game Commission since 1972, and were formally proposed for listing as a federally endangered species by the U.S. Fish and Wildlife Service in 1992 (1992 Federal Register, Vol. 57, 90:19837-19843). As part of a comprehensive bighorn demography study and investigation of the population decline documented in the SRM, we conducted annual fall helicopter surveys from 1983-1994 and additional spring surveys from 1983-1986. These surveys were designed to collect demographic and distribution data. Here we examine the dynamics of population size, recruitment, age structure, and sex ratios for the SRM as a whole and spatially from 1983-1994.

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STUDY AREA

The SRM extend 56 km southeast from Palm Springs, California, into Anza-Borrego Desert State Park (Figure 1). Ranging in elevation from 75-2657 m, the SRM are the westernmost extension of the Colorado Desert division of the Sonoran Desert (Ryan 1968). Topography varies from low hills to steep, rocky escarpments and eroded canyons, creating much desirable bighorn habitat. Toro Peak (2657 m) is the highest peak in the SRM; however, bighorn are usually found below 1212 m (Weaver and Mensch 1970). Natural springs are scattered throughout the range, with perennial water most abundant in the central portion. Land ownership in the SRM is in a checkerboard pattern shared by the private sector, the Bureau of Indian Affairs, the Bureau of Land Management, the State of California, the U.S. Forest Service, and city and county governments. Bighorn habitat in the northern SRM (north of Highway 74) is fringed with urban development. Since 1985, a total of 60 (28M, 32F) adult Peninsular bighorn have been released from captivity (Bighorn Institute, Palm Desert, California) into the northern end of the SRM to augment a declining subpopulation in this portion of the range. The southern end of the range, which extends into Anza-Borrego Desert State Park, is more secluded from urbanization, but is frequented by hikers.

Dominant plant species in bighorn habitat include creosote bush (Larrea tridentata), brittle-bush (Encelia farinosa), burro-bush (Ambrosia dumosa), golden cholla (Opuntia echinocarpa), buckhorn cholla (O. acanthocarpa), barrel cactus (Ferocactus acanthodes), agave (Agave deserti), and Mojave yucca (Yucca schidigera) (DeForge and Scott 1982). Annual rainfall is highly variable, with averages for 1983-1994 of 19.8 cm/yr at Anza-Borrego Desert State Park in the southern end of the range, and 15.5 cm/yr at the University of California Boyd Deep Canyon Desert Research Center in the northern portion of the range (Western Regional Climate Center, Reno, Nevada 1994).

METHODS

Annual fall surveys of the SRM were conducted on consecutive days in mid to late October from 1983-1994 with the exception of 1987 and 1994, when due to logistical constraints, a part or all of the surveys were performed in early November. In 1983-1986, additional surveys were conducted in late April to mid-June. Surveys were initiated in the south end of the range and proceeded north, systematically flying all potential bighorn habitat. The range was divided geographically into three main sampling units: 1) southern: Anza-Borrego Desert State Park; 2) central: north of Anza-Borrego Desert State Park, including Dead Indian Canyon; and 3) northern: north of Dead Indian Canyon. This 765 km2 area was flown at 100-150 m contour intervals, up to approximately 1750 m elevation, following the same basic flight pattern each survey. We used a Bell 206B-3 helicopter during 1983-1986 and a Hughes 500-D after 1986. One pilot flew the 1983-1985 surveys, a different pilot was used in 1986, and a third pilot was used for the eight most recent fall surveys. Three observers accompanied the pilot at all times, and the doors of the helicopter were removed to facilitate optimum visibility. Observers were rotated as needed at 1.5-2.0 hour intervals to reduce fatigue. As many of the same, experienced observers as possible were used on the surveys to maximize sighting probabilities and classification accuracy. Survey length varied from 10.0 to 17.5 hours ($\bar{x}$=13.7, SD=2.1), resulting in flight intensities of 0.8 to 1.4 min/km^2.

Data collected included group size, sex and age classification, location, and elevation. When bighorn were sighted, the helicopter was maneuvered to ensure accurate counting and classification. We used a modified version of Geist's (1971) classification system (Class II-IV rams, ewes, yearling males, yearling females, and lambs). Bighorn locations were recorded on topographic maps at the time of the sighting.

Chapman Estimator

We used Chapman's (1951) modification of the Lincoln-Petersen estimator of population size because it assumes sampling without replacement (Seber 1970, 1973) and is recommended for use with two capture occasions (White et al. 1982). Annual adult bighorn population estimates ($\hat{N}$) were determined from fall surveys using Chapman's estimator as:

$$\hat{N} = \frac{(n_1 + 1)(n_2 + 1)}{(m_2 + 1)} - 1$$

with the following approximately unbiased estimate of variance:

$$\mathrm{var}(\hat{N}) = \frac{(n_1 + 1)(n_2 + 1)(n_1 - m_2)(n_2 - m_2)}{(m_2 + 1)^2 (m_2 + 2)}$$

where n_1 is the number of adult animals marked, n_2 is the total number of adult animals observed, and m_2 is the number of adult marked animals observed during the survey. We constructed 95 percent confidence intervals as $\hat{N} \pm (1.96)$ SE, where SE = var $(\hat{N})^{0.5}$. Assumptions of the mark-resighting technique are: (1) marked and unmarked animals have equal sighting probabilities; (2) marked and unmarked animals are correctly classified; (3) marked animals are randomly distributed throughout the population, or at least resighting effort is randomly distributed throughout the population; (4) each animal has an equal and independent probability of being resighted; (5) the number of marked animals in the population is known; and (6) the population is geographically and demographically closed (Bear et al. 1989).

From 1983-1992, radio-collared bighorn (Table 1) in only the northern Santa Rosa Mountains (NSRM) were available for use as marked animals (n_1) for determining population estimates. In 1993, four of the collared bighorn were in the southern end of the range, and in 1994, 42 collared bighorn were distributed throughout the SRM. The number of marked bighorn in the study area was confirmed by radiotelemetry prior to surveys.

We used the Chapman estimates for all subsequent analyses requiring population estimates, and 1984 was used as the initial year in long-term trend analysis in an effort to avoid fluctuations caused by sampling variation in the early years of this study. The 1986 estimate was dismissed as an outlier because only 32.3 percent of the collared sheep were observed, which is outside the 99.9 percent confidence interval for the proportion of collared sheep seen in all other years. Density was calculated using the total area surveyed (765 km^2) and catch per unit effort (CPUE) was calculated as the number of adult bighorn seen per hour of helicopter survey time. Population age structure was determined from ram size/age classes. Annual ewe population estimates were determined using the Chapman estimator and the number of collared ewes seen each survey.

Comparison Population Estimates

To create a bound for our Chapman estimates, annual bighorn population estimates were also calculated using three other methods (Table 2). First, to increase the sample size of marked animals in the Chapman estimator, we used the known number of adult bighorn, both marked (collared) and unmarked, in an intensively monitored subpopulation in the NSRM, as the "marked" (n_1) individuals. Second, the cumulative general correction factor (CGCF) of 1.831, determined from the total number of collared animals seen compared to the total number of collared animals present for all 12 years combined, excluding 1986 (183/335), was applied to the total number of adult bighorn seen in each of the surveys. Third, we generated population estimates using the 1994 general correction factor (GCF) of 1826 when sheep were collared throughout the range.

Spatial Analysis

The northern, central, and southern SRM were examined separately to determine the extent of the decline and differences in demography in each geographical sampling unit. These subunits were delineated to separate regions in the farthest southern and northern extensions of the range in which regular ground monitoring of bighorn subpopulations has been conducted, as well as to distinguish the NSRM as the only region where augmentation has occurred within the SRM.

Annual population estimates were calculated for the three sections using the Chapman estimator equation with the number of adult bighorn seen in the Sampling area and the proportion of collared bighorn seen during the entire SRM survey each year. We were unable to determine confidence intervals due to small sample sizes. Densities were determined using the following area estimates: northern, 148.1 km^2; central, 428.6 km^2; and southern, 188.3 km*. The Friedman test (Hollander and Wolfe 1973) was used to test for statistical differences in lamb:ewe ratios among areas.

RESULTS

A total of 1556 bighorn were recorded in 164.3 hours of flight time during the 1983-1994 fall surveys. The number of bighorn observed per survey varied from 209 in 1984 and 1986, to 73 in 1990 (Table 1). Bighorn were seen at elevations between 33-1676 m, in group sizes varying from 1 to 16 ($\bar{x}$=3.3, mode=1). Excluding 1986, an average of 54.4 percent of the collared sheep were observed each survey, (SD=12.2, range=45.8 percent to 69.9 percent). Since 1984, an average of 58.1 percent of all collared ewes and 50.0 percent of all collared rams were observed each year. Coefficients of variation for individual population estimates, excluding 1986, ranged from 10.6 percent to 19.4 percent ($\bar{x}$=14.0, SD=2.8). All four techniques used to estimate the SRM bighorn population produced similar numbers and trends (Table 2).

Population Trend

From 1984-1994, the SRM population showed two phases: the decline phase up to 1990, with an annual decline rate of 17.8 percent, and the stable phase from 1990-1994 (Figure 2). Chapman adult population estimates declined 69.1 percent from 1984 to 1994. Similarly, the total number of adult bighorn observed per survey and CPUE declined 64.2 percent and 53.3 percent (Figure 3), respectively, over the same period and the number of ewes seen per survey dropped 67.9 percent from 131 to 42 (Table 1). The number of ewes seen each survey decreased at a rate of 17.3 percent per year between 1984 and 1990, whereas this number increased at 0.6 percent per year from 1990-1994. The trend of the ewe population estimates corresponds with the trend of the entire adult bighorn population (Figure 2). Estimated bighorn sheep density declined from 0.49 bighorn/km^2 in 1984 to 0.15 bighorn/km^2 for 1990-1994.

Recruitment

Fall lamb:ewe ratios for the SRM ranged from 12.8 to 51.3 lambs:100 ewes ($\bar{x}$=25.2, SD=10.6) for 1983-1994 (Figure 4). Between 1983 and 1990, lamb:ewe ratios varied greatly but were generally low, averaging 21.3:100. Lamb:ewe ratios were considerably higher from 1991-1994, and averaged 32.8:100 (Table 1). Our 1983-1986 fall surveys produced an average lamb:ewe ratio of 25.4:100 (SD=6.9), 39.5 percent lower than the average of 42.0 lambs:100 ewes (SD=6.0) from spring helicopter surveys in those same years. The SRM averaged only 17.4 yearlings:100 ewes (range=5.2 to 33.3, SD=9.6) for 1983-1994 fall surveys, with the trend following the same pattern as fall lamb:ewe ratios (Figure 4). However, the lack of rams classified as yearling age in 1983 or 1984, and the unbalanced cumulative yearling ram:yearling ewe ratio of 150.0:100 implies that classification error may have occurred.

Age Structure

Size/age classes of rams averaged 19.3 percent (SD=14.3) yearling, 24.2 percent (SD=5.8) Class II, 25.8 percent (SD=12.4) Class 111, and 30.8 percent (SD=9.9) Class IV, over the 12 years (Figure 5). In 1985-1989, 40.0 to 47.6 percent of the rams observed during the surveys were yearling or Class II; whereas, in 1990 only 19.2 percent of the rams were in these size classes. The percentage of young rams (yearling or Class II) steadily increased from 36.8 percent in 1991 to 76.2 percent in 1994 (Figure 5).

Sex Ratios

Ram:ewe ratios ranged from 27.8:100 to 61.5:100 ($\bar{x}$=44.9, SD=10.0) for the 1983-1994 fall surveys (Table 1). During the 1983-1990 decline period, ram:ewe ratios averaged 49.7:100, while within the stabilization period they averaged 35.2:100 from 1991-1994. For 1983-1986, fall ram:ewe ratios averaged 44.4:100, while spring surveys averaged 35.8:100. In all fall surveys combined, 61.5 percent of all group sightings contained mixed sexes of adult sheep (31.3 percent of all sightings were single sheep) and 75.8 percent of all rams seen were with ewes.

Spatial Analysis

A comparison of the 1984 and 1994 fall estimates for each geographic sampling unit revealed population declines of 77.2 percent in the southern end of the SRM, and 71.1 percent in the central portion, but only 35.3 percent in the NSRM where 10 years of population augmentation has occurred (Figure 6). If the augmented bighorn existing in 1994 are excluded, the decline for the NSRM would be at least 81.3 percent, (assuming that no offspring were recruited from augmented sheep). Comparing density from 1984 to 1994, the southern section had the largest decline (76.7 percent) from 0.60 bighorn/km^2 to only 0.14 bighorn/km^2, unless augmented bighorn are excluded from the NSRM resulting in an 82.8 percent decline in density over the 11 years, from 0.29 to only 0.05 bighorn/km^2 in 1994. Bighorn density in the central SRM declined 34.1 percent, from 0.44 in 1984 to 0.15 bighorn/km^2 in 1994. During the stabilization period from 1990-1994, the Southern Santa Rosa Mountains (SSRM) had the lowest mean density of the three regions, at 0.12 bighorn/km^2 (range=0.08 to 0.16).

Density remained the most stable in the central SRM during those 5 years, ranging from 0.13 to 0.16 bighorn/km^2 ($\bar{x}$=0.15). With augmented bighorn included, the NSRM maintained the highest mean density from 1990-1994 of 0.21 bighorn/km^2 (range=0.17 to 0.30).

Lamb:ewe ratios for the central and southern SRM averaged 30.6 (SD=11.3) and 27.6 lambs:100 ewes (SD=13.3), respectively, whereas, the NSRM averaged only 12.0 lambs:100 ewes (SD=11.9) for the 1983-1994 fall surveys (Figure 7). These differences were statistically significant (X^2 = 11.79, P=.003). Yearling:ewe ratios averaged the highest in the central portion of the range at 18.4:100 (SD=13.1), followed by the south end at 15.9:100 (SD=13.2), with the NSRM being lowest at 7.2:100 (SD=8.5) when augmented yearlings are subtracted.

Average ram:ewe ratios for the different geographic subunits increased north to south with 30.5 rams:100 ewes (SD=14.9) in the NSRM, 47.8 rams:100 ewes (SD=12.7) in the central SRM, and 50.4 rams:100 ewes (SD=18.0) in the south. The largest decrease in ram:ewe ratios from 1984-1994 occurred in the SSRM from 51.5:100 down to 9.1:100, when only one adult ram was seen in 1994–the lowest number of rams seen in any one section during our surveys.

DISCUSSION

Population Estimators and Model Assumptions

Any bias caused by violation of mark-resight assumptions (Otis et al. 1978) in this study was considered negligible. Although marked animals were not randomly distributed throughout the population in all years, we attempted to distribute our resighting effort evenly by surveying all potential bighorn habitat, and following the same flight pattern each year. The similarity of habitat, bighorn distribution, and survey intensity in the NSRM compared to the rest of the range, allowed us to make the important assumption that sighting probabilities are the same throughout the SRM. Because we had the largest number of collared animals in 1994 and they were distributed throughout the range, we consider this our most accurate survey. The semblance of the 1994 GCF and the CGCF suggests that having collared animals only in the NSRM from 1983-1992 did not significantly bias our population estimates and further indicates that sighting probabilities were uniform throughout the SRM. If age and sex classes have unequal and dependent resighting probabilities due to different behavioral responses to overflight, then the lack of a random sample of marked animals will affect the bias or precision of the estimator (Bear et al. 1989). Our marked animals were predominantly ewes; however, the average percentage of marked rams and ewes observed each year from 1984-1994 differed by only 8.1 percent.

The precision of mark-resight population estimates relies primarily on three parameters: 1) the number of marked animals in the population, 2) the proportion of marked animals resighted, and 3) the number of resighting flights (Bear et al. 1989, Brower et al. 1990). White et al. (1982) stated that the most effective means of improving the precision of an estimate is to increase the sample size, which we accomplished by using the known number of bighorn in the NSRM as the number of "marked" individuals in the Chapman estimator (Table 2). The CGCF was another technique used to increase sample size, but this method assumes that the survey intensity and sighting probabilities were constant over all years. Although these assumptions were violated, the CGCF population estimates provided a useful comparison that averaged the correction factors associated with our population estimates due to sampling variation. We were able to adequately satisfy the assumptions for the mark-resight technique, and the conformity of the comparison estimates (Table 2) shows the robustness of our Chapman estimates. As White et al. (1982) suggested for reliable scientific studies, all coefficients of variation for individual population estimates, excluding 1986, were <20 percent.

Population Trend

Although oscillations are present, the overall trend of our data from 1983 to 1994 shows that the SRM Peninsular bighorn population declined significantly and then stabilized (Figure 2). Substantial fluctuations in population estimates occurring in 1983-1987 (Table I) may be attributed more to sampling variation due to the new pilots and aircraft used, than to actual changes in the population. The decline indicated by the Chapman estimates from 1989 to 1990 may have been falsely exaggerated due to potentially high estimates in 1988 and 1989. Additionally, the 95 percent confidence limits for the 1989 and 1990 population estimates almost overlap (Table 1), showing that the actual population may have not changed as much as the $\hat{N}$ values alone indicate for those 2 years.

Compared to past SRM estimates and Arizona's average 0.38-0.69 bighorn/km^2 (Remington 1993), the current stabilized bighorn density of 0.15 bighorn/km^2 in the SRM is low. In 1970, when density was approximately 0.66 bighorn/km^2 in the SRM, Weaver and Mensch (1970) referred to this range as some of the best and most important bighorn habitat in California. Potential outcomes of disease(s) causing high lamb mortality are: (1) a reduced carrying capacity; (2) periodic disappearance causing substantial population dynamics; and/or (3) population extirpation (Anderson and May 1979, May and Anderson 1979, Wehausen 1992). Further monitoring will help to determine if the SRM population is capable of increasing to its previous level of approximately 500 animals.

Recruitment

An estimate of the number of lambs surviving to yearling age can aid in predicting population dynamics and determining which segment(s) of a population is/are most susceptible to the active mortality factors (Caughley 1977, Hansen 1980, Remington 1993). The period of depressed recruitment during our study (1983-1990) appears to be a continuation of the low recruitment documented in the SRM since 1977, when an apparent disease epizootic occurred (DeForge and Scott 1982, Wehausen et al. 1987). The SRM fall lamb:ewe ratios obtained through helicopter surveys from 1977-1982 ranged from 8.5 to 28.6:100 and averaged 15.7 lambs:100 ewes (DeForge and Scott 1982). In what may have been the conclusion of a disease epizootic, and/or a density dependent response following 14 years of poor recruitment, the population stabilized and recruitment ratios improved.

Suppressed recruitment is expected following a pneumonia episode in bighorn sheep (Onderka and Wishart 1984, Foreyt 1990). Clinically healthy bighorn can shed pathogens and transmit disease to offspring, but the rate of shedding probably diminishes over time (Foreyt 1990). Additionally, there appear to be host-parasite specific threshold densities, below which the disease cannot persist (Anderson and May 1979, May and Anderson 1979). Serological evidence of viral exposure, as well as isolation of parainfluenza-3 (PI-3), bluetongue (BT), epizootic hemorrhagic disease, and contagious ecthyma viruses from wild-caught, sick lambs from throughout the SRM, has been documented (Bighorn Institute unpublished data). Seemingly healthy, free-ranging adult bighorn in the SRM have yielded serologic titers to these four viruses, as well as isolation of PI-3 virus and BT virus (DeForge et al. 1982; DeForge and Scott 1982; Turner and Payson 1982a, b; Bighorn Institute unpubl. data). The diseases that suppressed recruitment in the SRM may have shown a regulatory function through their abatement at the lower population density maintained from 1990-1994.

Subjective recruitment data (gathered through a combination of hiking, waterhole counts, and helicopter surveys) available since 1953 for the SRM (Wehausen et al. 1987), combined with data from this study, suggest a long-term cyclical pattern: at least 9 years of suppressed recruitment from 1953-1961, 15 years of stable or increasing recruitment from 1962-1976, 14 years of low recruitment from 1977-1990, and 4 years of stable or increasing recruitment from 1991-1994.

Witham (1983) suggested lamb mortality in southwestern Arizona is minimal from December-March, highest in April-June and September, and variable in October-November. Our data from spring and fall surveys in 1983-1986 indicate that significant lamb mortality occurs between April and October. High spring and summer lamb mortality make fall helicopter surveys preferable over spring surveys for obtaining accurate recruitment ratios (Russo 1956, McQuivey 1978, DeForge and Scott 1982, DeForge et al. 1993).

Maintenance Recruitment Ratios

Assuming that lamb survival is a driving force for population trends, some investigators have calculated minimum recruitment levels needed to maintain stable bighorn populations (McQuivey 1978, Wehausen et al. 1987, Remington 1993). McQuivey (1978) calculated 26.5 lambs:100 ewes as the requirement for a static population in Nevada by assuming equal sex ratios at birth and estimating annual ram mortality. However, this method depended on accurately aging rams from a helicopter, and the unsupported assumptions of a stationary age distribution with almost no bighorn mortality between fall lamb and yearling age. Maintenance recruitment ratios are dynamic and fluctuate with mortality rates; they should be used with caution, especially when extrapolating to other populations or time periods. Our 12 years of data illustrate this.

Data from the NSRM in 1977-1982 suggested that 17.5 lambs:100 ewes were needed to maintain a stable ewe population (Wehausen et al. 1987). From 1984-1994, the Santa Rosa bighorn population averaged 25.8 lambs:100 ewes, yet the ewe population declined 74.0 percent with a similar decline of 69.1 percent for the entire adult bighorn population. Clearly, a considerably higher recruitment ratio would have been necessary to maintain a stable bighorn population during this time period.

We applied a method used by Wehausen et al. (1987) for estimating the annual recruitment needed to maintain a constant ewe population based on the assumption of equal sex ratios at birth and compensating for change in the ewe population. Our 1984-1994 data indicate a 12.6 percent annual ewe decline rate (Wehausen et al. 1987 found a 3 percent annual decline rate for ewes during the 1977-1982 period). To adjust for the assumed 50 percent male lambs at birth, the 12.6 percent annual decline in the ewe population is doubled, resulting in a 25.2 lambs:100 ewes compensation factor. Adding this to the average lamb:ewe ratio from 1984-1993 of 23.2 lambs:100 ewes shows that an annual fall recruitment ratio of 48.4 lambs:100 ewes was needed to maintain a stable ewe population in the SRM during those years, assuming that all lambs survive to yearling age. Because minimum recruitment levels needed to maintain a population will change as mortality rates change, we found it more accurate to calculate minimum recruitment ratios for three separate time periods. The 18.0 percent annual decline in the ewe population from 1984-1988 resulted in a 62.1 lambs:100 ewes maintenance recruitment ratio, while the 28.0 percent per year ewe population decline in the 1988-1990 period would have required 73.5 lambs:100 ewes to retain stability. The ewe population increased an average of 2.5 percent annually from 1990-1994, producing a maintenance ratio of only 18.2 lambs:100 ewes.

Yearling survival, or more precisely the percentage of fall lambs surviving to the subsequent fall, is also an important factor to be considered for population analysis, since mortality has been shown to be higher for the period from lamb to yearling than after yearling age (Cunningham et al. 1993). Our data from the SRM suggest that yearling mortality is significant and should be considered when determining minimum recruitment levels needed to maintain a stable bighorn population. Actual fall lamb:ewe ratios necessary to balance adult mortality must be higher than those calculated above and by Wehausen et al. (1987). Due to the difficulty of accurately classifying yearlings from a helicopter, we did not determine a correction factor to compensate for yearling mortality.

Age Structure

Prior to 1991, the SRM had an abundance of old animals and a corresponding lack of young, typical of a population declining from poor recruitment. More recently, the population has shown an increasing proportion of young animals, characteristic of a growing population. Yearlings were the largest percentage of rams in 1992-1994, corresponding with increased lamb:ewe ratios for 1991-1993. However, the concurrent marked decrease in Class IV rams after 1991 may have partly caused the increased percentage of yearling rams in 1992-1994. Although the actual number of rams in all age classes continued to decline over the 12-year period, the shift in age structure after 1990 suggests that ram numbers may soon stabilize or increase, matching the recent trend of the ewe population.

Sex Ratios

Bighorn sheep sex ratios vary greatly, ranging from 36-137 rams:100 ewes for 18 studies in 7 localities within the United States (Buechner 1960). During the rut in 1977, the estimated 64 rams:100 ewes in the NSRM was considered consistent with other unhunted bighom populations (Wehausen et al. 1987). Our average ram:ewe ratio (44.9:100) appears low for an unhunted population where poaching is not known to be a substantial problem. The 1989-1990 peak in ram:ewe ratios suggests that the mortality agent(s) in that time period may have more profoundly affected the female segment of the population. The lower average ram:ewe ratio from 1991-1994 (Table I) reflects that while the actual numbers of rams seen during the surveys had continued to decline, the number of ewes seen per survey ceased to decline after 1990.

Assuming equal sex ratios for lambs, variances in sex ratios of adult bighom are a result of differential mortality between rams and ewes, and sheep behavior and movement patterns favor female survivorship (McQuivey 1978). Despite some potential classification error, our 1983-1994 cumulative fall yearling ram:yearling ewe ratio of 150.0:100 is very high compared to the adult ram:ewe ratio of 44.9 for the same time period. This suggests that considerable ram mortality is occumng during the first 2 years of life, when mortality factors typically increase due to changes in social behavior and expanded movements associated with the rut. The fact that rutting movement occurs during periods of high ambient temperatures, low water availability, and reduced forage quality, and that movement renders bighorn more susceptible to disease exposure, predation, and accidents (particularly in areas bordered by urbanization), could partly account for the low ram:ewe ratio in this mountain range. From 1991-1994 alone, four rams and three ewes are known to have been struck and killed by automobiles in the NSRM, and six out of seven of these deaths occurred during the rut (Bighorn Institute unpubl. data). Sampling error in the form of missing ram pastures during the surveys could also potentially contribute to a low ram:ewe ratio, although the high proportion of mixed sex sightings suggests that our surveys were conducted in the height of the rut, when the number of ram bachelor groups would have been minimal. Overall, sex ratios from our survey data (Table 1) suggest that ewes in the SRM have higher adult survivorship than rams.

Spatial Analysis

We recognize that the assumptions for the Chapman estimator were violated when it was used for calculating regional SRM population estimates. However, this estimator provided an annual correction factor to adjust for sampling variation and produced results that could be analyzed for changes in trend, while maintaining consistency with annual estimates for the entire SRM population.

The declining trend from 1984 through 1990 and the following stabilization are apparent in all three regions, but the changes occurred in varying degrees in each area (Figure 6). The augmented NSRM population remained substantially more stable over the years than the other regions, although it gradually declined despite the addition of 60 adult bighorn. The two major highways bordering this portion of the range, and the urbanization at its northernmost extension, create a higher potential for human-related bighorn mortalities than in the other regions. While the NSRM were maintained at a higher density, the southern and central portions of the range both stabilized at densities near 0.15 bighorn/km^2. Lamb:ewe ratios were the highest for all survey years in all three areas in 1994, perhaps indicating an increasing population trend for the entire SRM if recruitment can more than replace adult mortality.

CONCLUSION

We have shown the dynamics of a bighorn population exhibiting low recruitment for a prolonged period following a disease epizootic, which resulted in a 69.1 percent decrease in the adult population. Long-term depressed recruitment (1977-1990) led to an old age population with characteristic high adult mortality. Improved recruitment after 1990 caused the age structure to gradually shift to one dominated by younger animals, and allowed the population to stabilize at low numbers. The SRM bighorn population required approximately 13 years to stabilize following the disease outbreak in the late 1970s. Spatial analysis indicated that this trend was experienced throughout the range.

It is important to note that maintenance recruitment ratios cannot be generally applied to other populations or time periods; from 1983-1994 the SRM bighorn population averaged 25.2 lambs:100 ewes (which is higher than the maintenance recruitment ratio suggested by Wehausen et al. [1987], and near that suggested by McQuivey [1978]), yet the population declined 69.1 percent from 1984-1994. Considering the SRM 1990-1994 estimated maintenance recruitment ratio and the present recruitment rates, this bighorn population should remain stable or increase if adult survival remains fairly constant.

The compounded effects of disease and low recruitment, 4 years of drought beginning in 1987, and a high incidence of mountain lion predation in recent years (Bighorn Institute, unpubl. data; Steve Torres, CDFG, personal comm.), presumably had a cumulative influence on the SRM bighorn population. The decline response to disease or density dependent factors may have subsided with the lower population density attained in 1990, thus the resulting leveling trend. However, even after the original causes of a decline are eliminated, small, isolated populations are vulnerable to demographic, genetic, and environmental stochastic forces intrinsic to the dynamics of small populations, which may drive them to extinction (Lacy 1993, Caughley and Gunn 1996).

There is a need for further research to identify pathogen sources and pathways, the extent of infectious disease, implications of urbanization in and adjacent to bighorn habitat, and specific characteristics of this subspecies and the region they inhabit that may make bighorn in the Peninsular ranges particularly susceptible to decline. Continued surveys of the SRM bighorn population are needed to monitor the dynamics of this now precarious population and to' maintain the long-term database already established on these bighorn.

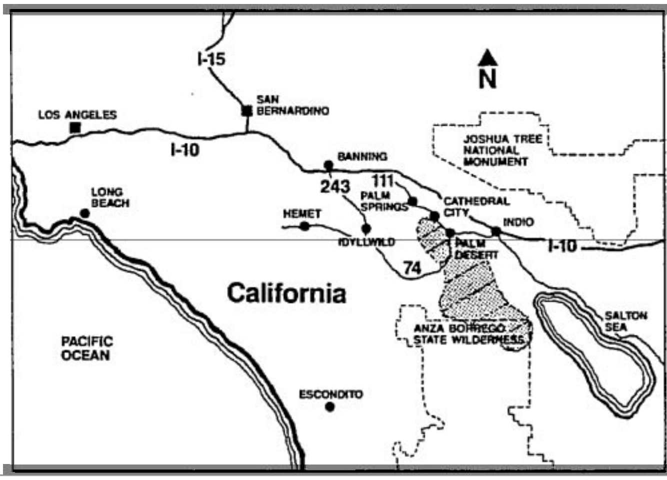

Figure 1. *Location of the Santa Rosa Mountains, California (stippled area).*

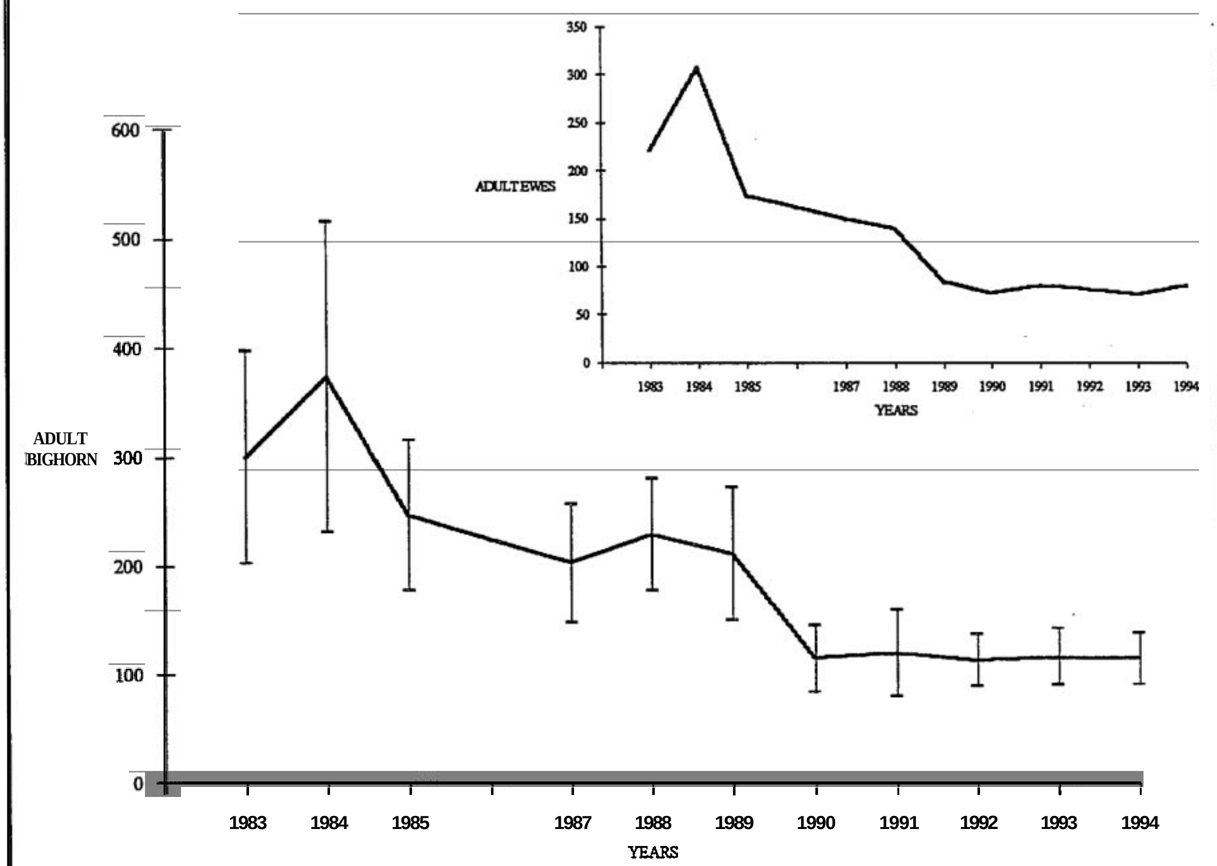

Figure 2. *Adult population estimates with 95% confidence intervals from 1983-1994 fall helicopter surveys of Peninsular bighorn sheep in the Santa Rosa Mountains, California. Inset graph shows annual adult ewe population estimates. The Chapman estimator was used to determine population estimates, excluding 1986 as an outlier*

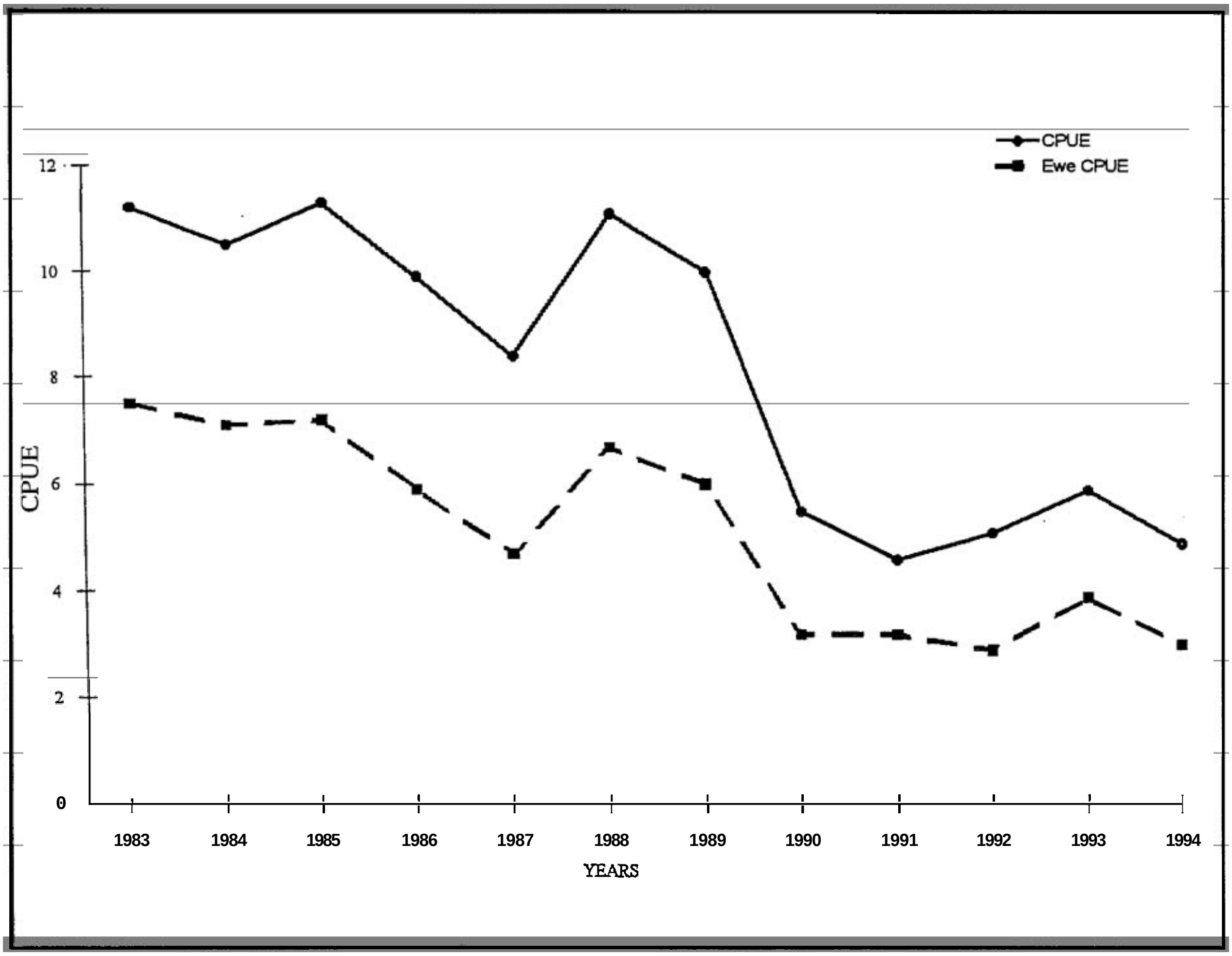

***Figure* 3.** *Adult bighorn seen per helicopter hour, or catch per unit effort (CPUE), along with ewes seen per helicopter hour during 1983-1994 helicopter surveys of Peninsular bighorn sheep in the Santa Rosa Mountains, California.*

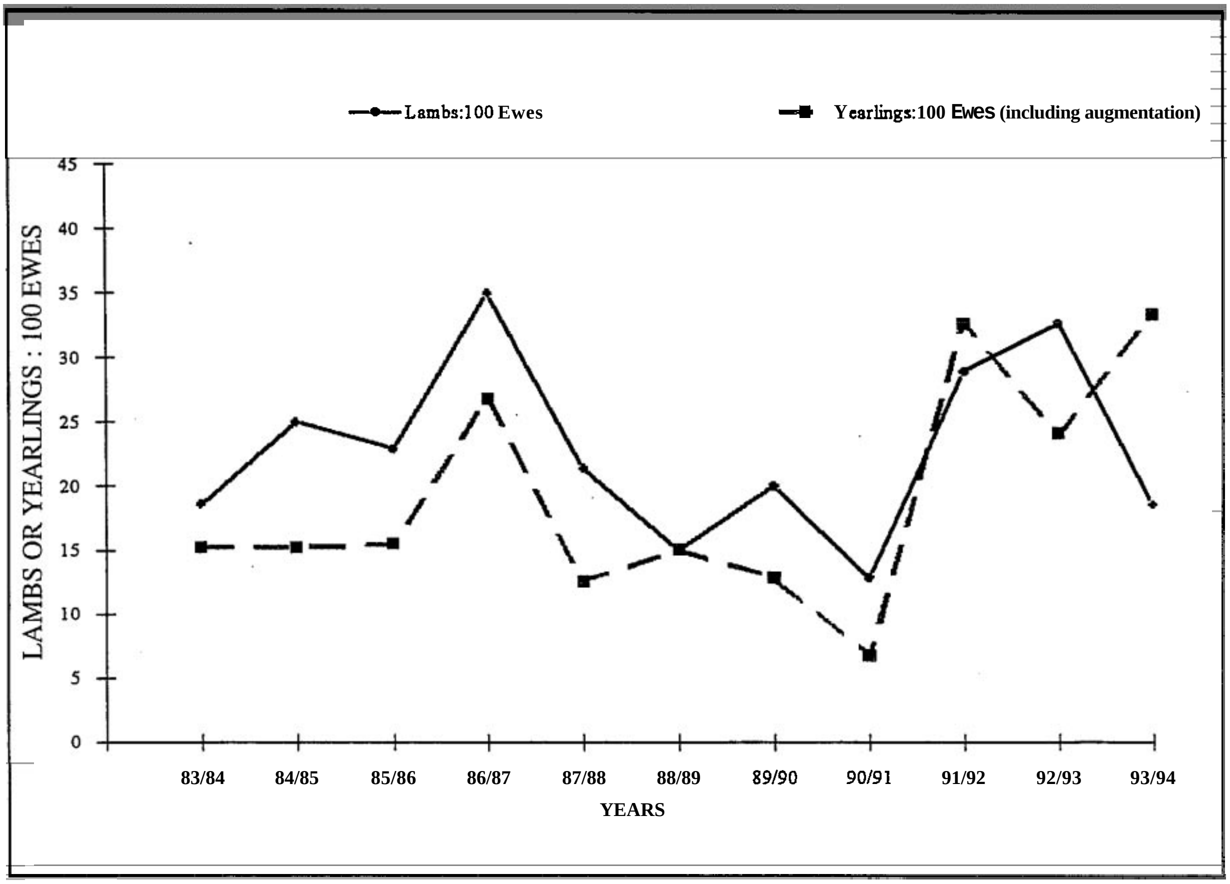

Figure 4. *Lamb:ewe ratios with the subsequent year's yearling:ewe ratios, from 1983-1994 fall helicopter surveys of Peninsular bighorn sheep in the Santa Rosa Mountains, California.*

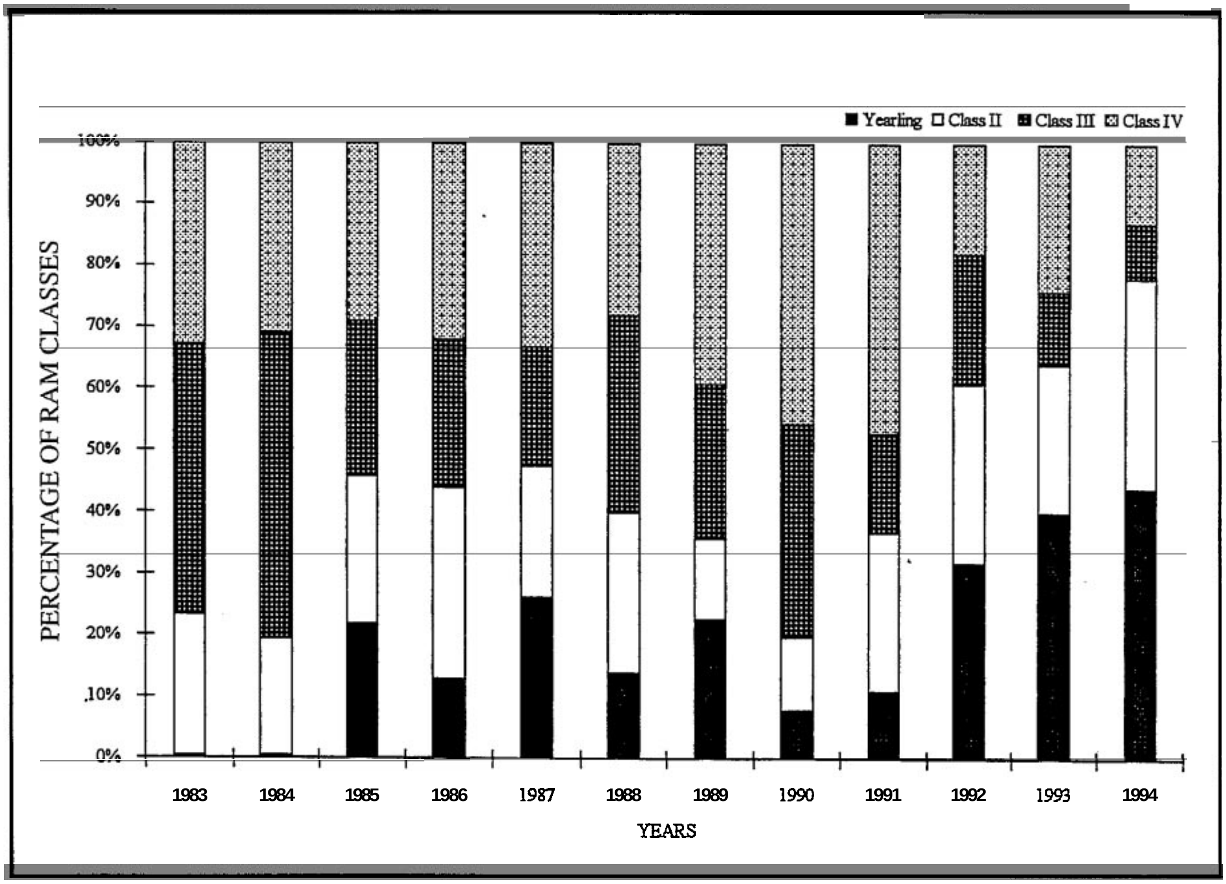

Figure 5. *Percentages of ram classes obtained from 1983-1994 fall helicopter surveys of Peninsular bighorn sheep in the Santa Rosa Mountains, California. Approximate ages were assigned to rain classes as follows: Class II, 2-4 years; Class 111, 5-7years; Class III, ≥8 years.*

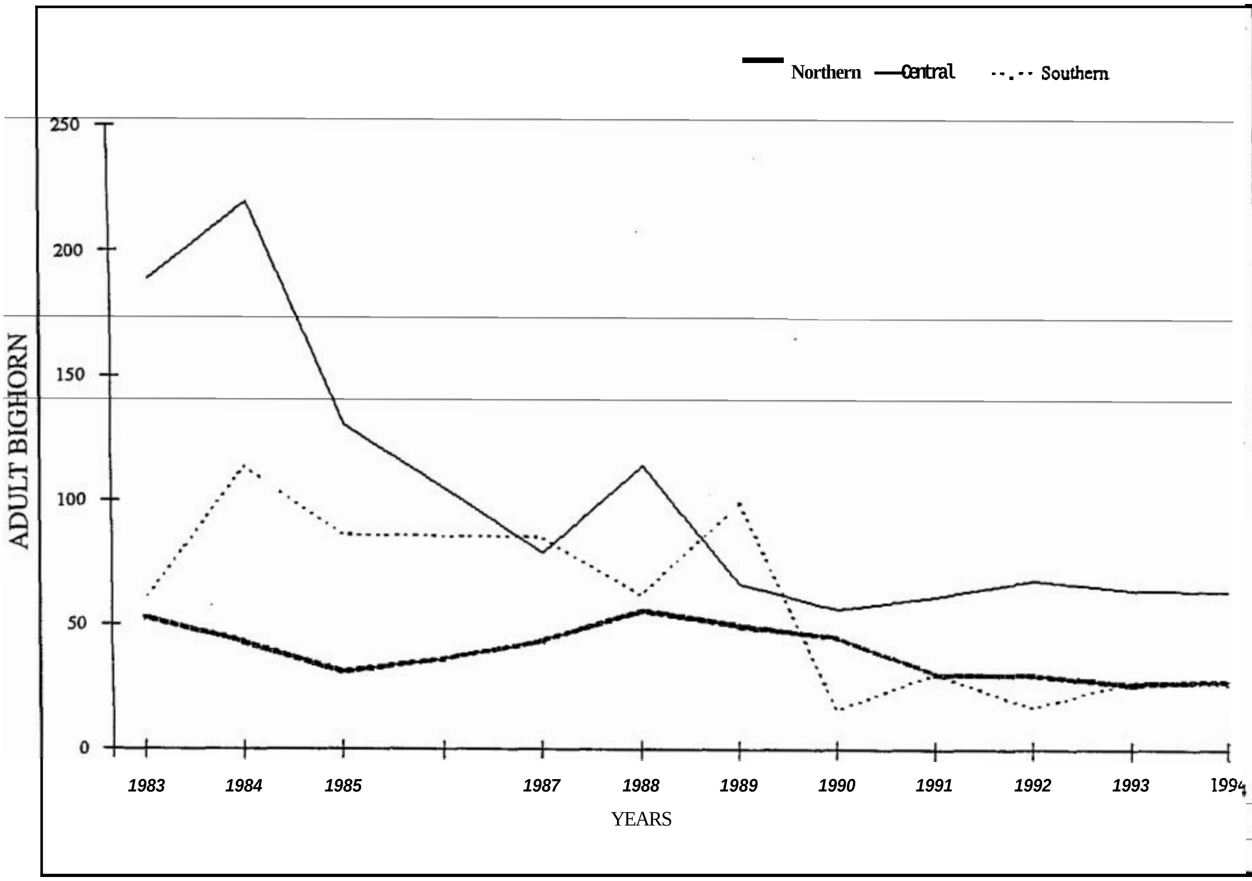

Figure 6. *Adult population estimates for Peninsular bighorn sheep in the northern, central, and southern Santa Rosa Mountains from 1983-1994 helicopter surveys, excluding 1986 as an outlier Since 1985, a total of 60 adult bighorn have been released into the northern Santa Rosa Mountains to augment a declining subpopulation.*

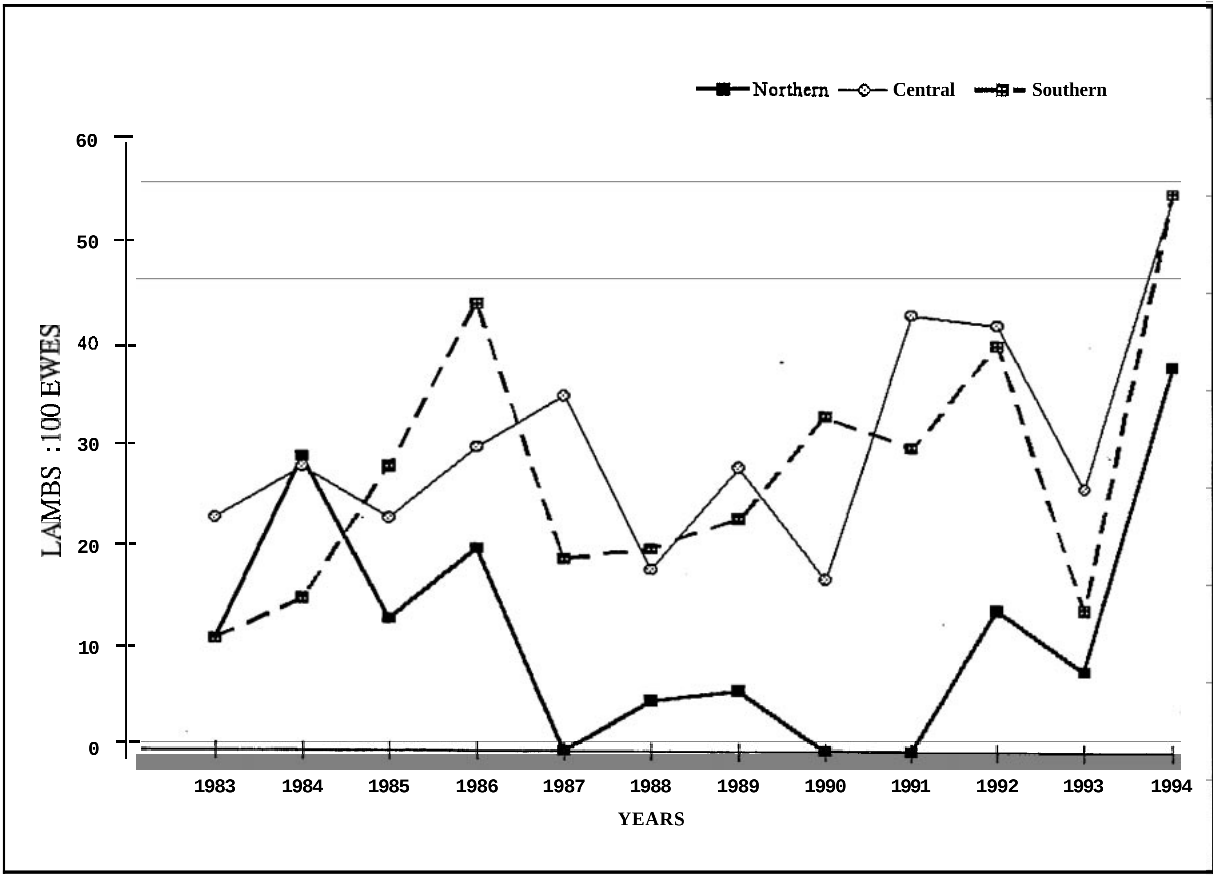

Figure 7. *Lamb:ewe ratios for Peninsular bighorn sheep in the northern, central, and southern Santa Rosa Mountains from 1983-1994 helicopter surveys.*

Table I. *Results from 1983-1994 fall helicopter surveys of Peninsular bighorn sheep in the Santa Rosa Mountains, California.*

Year	Flight time (hours)	Total adults seen during helicopter survey	Rams	Ewes	Lambs	Yearling males	Yearling females	Rams/100 Ewes	Lambs/ 100 Ewes	Yearlings/ 100 Ewes	Collared seen/Total collared	Total adults seen in NSRM/ [a]Adult bighorn in NSRM	Adult bighorn seen per helicopter hour (CPUE)
1983	13.0	145	43	97	18	0	5	44.3	18.6	5.2	15/32	25/NA	11.2
1984	17.0	179	48	120	30	0	11	40.0	25.0	9.2	11/24	20/NA	10.5
1985	14.5	164	43	105	24	12	4	41.0	22.9	15.2	13/20	20/31	11.3
1986	17.5	173	54	103	36	8	8	52.4	35.0	15.5	10/31	14/43	9.9
1987	12.0	101	30	56	12	11	4	53.6	21.4	26.8	19/39	21/52	8.4
1988	12.0	133	43	80	12	7	3	53.8	15.0	12.5	24/42	32/51	11.1
1989	10.0	100	31	60	12	8	1	51.7	20.0	15.0	18/39	23/46	10.0
1990	12.3	68	24	39	5	2	3	61.5	12.8	12.8	15/26	26/41	5.5
1991	14.0	65	17	45	13	2	1	37.8	28.9	6.7	11/21	16/30	4.6
1992	15.0	76	19	43	14	9	5	44.2	32.6	32.6	18/27	20/35	5.1
1993	14.0	82	15	54	10	10	3	27.8	18.5	24.1	16/23	18/26	5.9
1994	13.0	64	12	39	20	9	4	30.8	51.3	33.3	23/42	15/20	4.9

[a]Minimum number of adult bighorn confirmed in the NSRM through ground fieldwork prior to helicopter surveys.

NSRM = Northern Santa Rosa Mountains; CPUE = catch per unit effort; NA = not available, adequate data are not available to determine reliable population estimates for the NSRM in 1983 and 1984.

Table 2. *1983-1994 Chapman and comparison population estimates of adult Peninsular bighorn sheep in the Santa Rosa Mountains, California.*

Year,	[a]Chapman estimate ± (1.96) SE using collared bighorn	Chapman estimate ± (1.96) SE using NSRM subpopulation	Population estimate using the CGCF (1.896)
1983	300.1 ± 97	NA	274.9
1984	374.0 ± 142	NA	339.4
1985	246.5 ± 69	250.4 ± 61	310.9
1986	[b]505.2 ± 225	509.4 ± 194	328.0
1987	203.0 ± 55	244.7 ± 68	191.5
1988	229.5 ± 52	210.2 ± 37	252.2
1989	211.6 ± 61	197.8 ± 47	189.6
1990	115.4 ± 31	106.3 ± 19	128.9
1991	120.0 ± 40	119.4 ± 32	123.2
1992	113.5 ± 24	131.0 ± 30	144.1
1993	117.2 ± 26	116.9 ± 25	155.5
1994	115.5 ± 24	85.3 ± 17	121.3

[a]Population estimates used for analysis of population trends.

[b]Not applicable, coeffiecient of variation exceeded 20.0%.

NSRM = Northern Santa Rosa Mountains; CGCF = cumulative general correction factor; NA = not available, adequate data are not available to determine reliable population estimates for the NSRM in 1983 and 1984.

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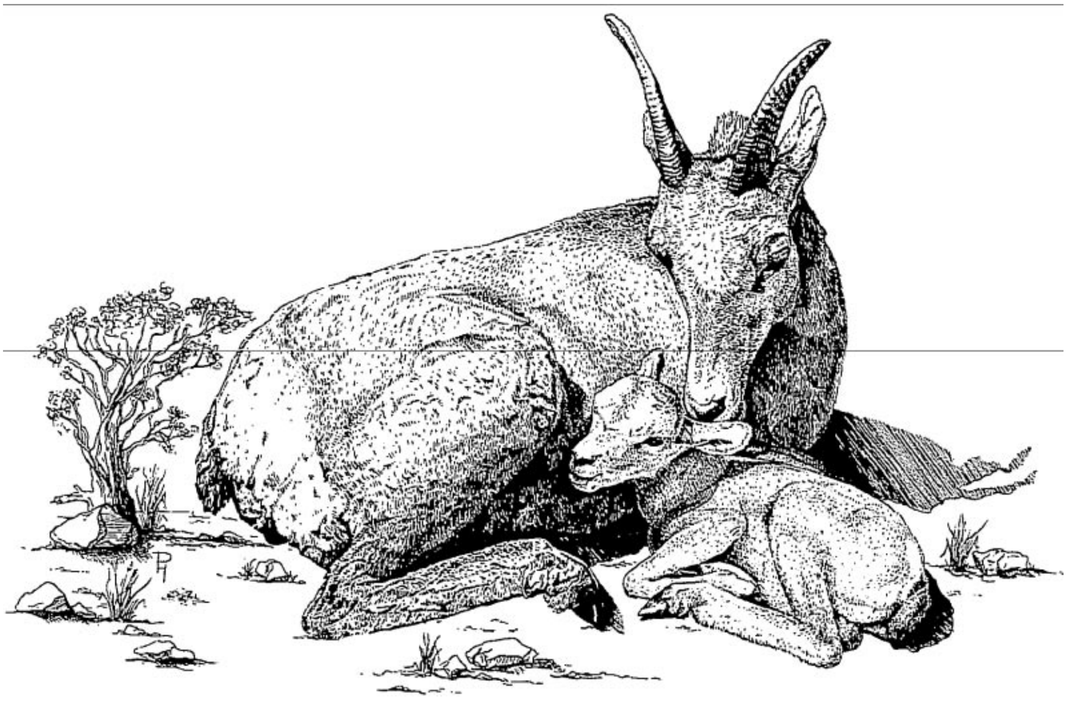

WEATHER, NUTRITIONAL STATUS, AND RECRUITMENT OF DESERT BIGHORN IN DEATH VALLEY, CALIFORNIA

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Abstract: In arid regions, the nutrients available to free-ranging ungulates may be influenced primarily by environmental variation. For desert bighorn (Ovis canadensis nelsoni) in Death Valley, California, I investigated relationships between precipitation and nutritional status, as indicated by fecal crude protein (FCP), and precipitation and recruitment, as indicated by lamb:ewe ratios. High FCP values in March of 1992 followed a period of high fall and winter precipitation, whereas high FCP values in June of 1991 and 1992 followed high precipitation during March of both years. Over a 2-year period, FCP was positively correlated with the previous 150 days' precipitation ($p=0.001$). Fecal crude protein values varied considerably, probably because of high variation in precipitation. Lamb:ewe ratio was not correlated with fall-winter precipitation, summer precipitation, or mean minimum spring temperature. Factors other than environmental variation may be influencing bighorn recruitment in Death Valley.

Key Words: desert bighorn sheep, Ovis canadensis nelsoni, precipitation, nutrient availability, diet quality, bighorn recruitment, fecal crude protein values, Death Valley

Desert Bighorn Council Transactions 39:68-**75**

INTRODUCTION

Precipitation, acting primarily on the production and timing of vegetative growth, is thought to determine nutrient availability and diet quality and ultimately recruitment in mountain sheep (Ovis canadensis spp.) inhabiting arid regions of North America (Wehausen et al. 1987, Wehausen and Hansen 1988).

Fecal crude protein values have been used to measure diet quality and nutritional status of free-ranging herbivores such as bighorn (Wehausen 1980, Hebert et al. 1984, Leslie and Starkey 1985, Seip and Bunnel 1985, Berbach 1987, Leslie and Starkey 1987, Wehausen and Hansen 1988, Wehausen 1990, Goodson et al. 1991, Irwin et al. 1993). Fecal protein reflects plant digestibility and protein content, which are highest in growing tissues of plants, and are therefore limited by precipitation and soil moisture (Wehausen and Hansen 1988, Wehausen 1990). The value of FCP in measuring nutritional status may be limited by seasonal variation in FCP and nonlinearity between dietary protein and FCP, as well as the effects of secondary plant compounds such as tannins on protein digestion (Holechek et al. 1982, Hobbs 1987, Robbins et al. 1987, Wehausen and Hansen 1988, Wehausen 1995). However, Wehausen and Hansen (1988) believe FCP is appropriate for tracking diet quality in bighorn sheep due to the importance of graminoids in their diet.

Environmental factors are thought to drive bighorn population dynamics in arid regions where environmental variation is high; density-dependence may play a secondary role (Douglas and Leslie 1986, Wehausen et al. 1987). Annual precipitation is highly variable in the Mojave Desert. It limits vegetative growth (Turner and Randall 1989), affecting nutrients available to bighorn sheep for reproduction. Recruitment, as indicated by lamb:ewe ratio, has been correlated with weather variables for some desert bighorn populations. Lamb:ewe ratio in the Santa Rosa Mountains of southern California was positively correlated with November, January, and February precipitation as independent variables (Wehausen et al. 1987). In the River Mountains of Nevada, lamb:ewe ratio was influenced by fall-winter (September-December) precipitation, but not by annual, spring, or summer precipitation, minimum spring temperature, or spring winds (Douglas and Leslie 1986).

In this study, I used weather records from Death Valley, California, to determine whether bighorn diet quality, as indicated by FCP, was correlated with recent precipitation, and whether bighorn recruitment as indicated by lamb:ewe ratio, was correlated with fall-winter or summer precipitation, or mean minimum spring temperature.

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STUDY AREA

Bighorn fecal samples were collected from the Black and Funeral Mountains of Death Valley National Park, California. The Black Mountains encompass >100,000 ha and form the south end of the Amargosa Range. Elevations range from -86 m to 1946 m. The Funeral Mountains lie north of the Blacks and encompass >80,000 ha, with elevations from 0-1965 m. The Black and Funeral Mountains lie in the rainshadow of the higher Panamint range to the west and have a less diverse flora and sparser vegetative cover than the Panamints. Schramm (1982) and Annable (1985) described vegetation in the Black and Funeral Mountains, respectively, whereas Rowlands (1993) described vegetation of the entire Death Valley region. Dominant vegetation types include creosotebush (Larrea *tridentata*)-desertholly saltbush (*Atriplex* hymenelytra) on the lower elevation alluvial fans, bursage (Ambrosia *dumosa*)-creosotebush on the upper fan surfaces, and shadscale (Atriplex *confertifolia*) and blackbrush (Coleogyne ramosissima) in the middle and upper elevations.

The climate of Death Valley and the northern Mojave Desert has been described as a rainshadow desert (Rowlands 1993, In Press). The annual range in temperature is large, with maximum July temperatures at Furnace Creek (elevation -51 m) averaging 46.7" C. The Black and Funeral Mountains lie in the triple rainshadow formed by the Sierra Nevada, Inyo, and Panamint Ranges to the west. Annual precipitation is extremely variable. Most precipitation occurs during fall and winter, but some is derived from warm convectional storms which occasionally move up the Colorado River Valley from the Gulf of Mexico in mid- to late summer.

METHODS

Daily precipitation has been recorded since 1911 at a National Weather Service station at Furnace Creek, Death Valley, California (U. S. Weather Bureau 1911-1991). A remote, solid-state weather station (Li-Cor Inc., Kansas City, Kansas) was installed in 1990 in Gold Valley in the southern Black Mountains (elevation 1160 m).

Fecal pellet samples were collected along transects at 10 springs in the Black and Funeral Mountains. Transects at each spring were checked monthly for presence of fresh pellets. Pellet groups were cleared from transects after sampling to ensure that those collected were <1 month old. Concentration of fecal nitrogen can decrease in pellet groups exposed to the elements for >24 days (Jenks et al. 1990). If pellet groups were present on the transect, a composite sample was collected from 5-10 pellet groups. Pellet groups were not present at each spring each month. Bighorn use of springs decreases when ambient temperatures decrease, or when summer storms provide alternative water sources (Blong and Pollard 1968, Hansen 1972, Turner 1973, Leslie and Douglas 1979).

A Kjeldahl procedure (Williams 1984) was performed by Washington State University Wildlife Habitat Laboratory to determine the percent of FCP (%fecal nitrogen x 6.25). On a dry matter basis, FCP values include variation due to inorganic material (ash) in the sample. Therefore, percent of total ash was determined, and FCP values are reported on an organic matter (ash-free) basis. FCP values from springs were grouped for the northern and southern portions of the Black and Funeral Mountains, respectively, according to known bighorn herd use areas (Hansen 1972).

Since time-series data (Figure 1) suggested a 3-5 month lag between precipitation events and influence on FCP, linear regression analysis (Zar 1987) was used to test for significant correlation between FCP and precipitation. Fecal crude protein values from the southern Black Mountains (all spring areas in the Black Mountains, with the exception of Lemonade and Ward Springs) were compared with previous 150 days' precipitation from Gold Valley in the southern Black Mountains.

Lamb:ewe ratio was used as an indicator of annual bighorn recruitment. A continuous long-term record of lamb:ewe ratios was not available for Death Valley bighorn. Limited data were obtained from various research and monitoring projects in which sex and age class of bighorn groups was determined from ground or helicopter counts. Lamb:ewe ratios were considered acceptable for analysis if observations were from summer-fall (July-October), and if the number of ewes sighted was >20.

Linear regression was also used to test for significant correlations between precipitation and bighorn recruitment. Weather data used were from Furnace Creek, since lamb:ewe ratios were obtained from several Death Valley mountain ranges. Lamb:ewe ratios were compared with total fall-winter precipitation (November-January), summer precipitation (June-August), and mean minimum spring temperature (January-March).

Lamb:ewe ratios and FCP values were subjected to the arcsin transformation (Zar 1987) prior to statistical analysis. Since time-series data are often autocorrelated, a Durbin-Watson test for autocorrelation was conducted for each regression (Neter et al. 1990). Significance levels were set at 0.05 for all statistical tests.

RESULTS AND DISCUSSION

Annual FCP maxima at Death Valley varied from 17 percent for the summer peak in 1991 to above 21 percent for spring and summer peaks in 1992 (Figure 1). Low FCP values occurred in fall 1990 and fall 1991, and fell as low as 7 percent. FCP was significantly correlated with the previous 150 days' precipitation ($p=0.001$, $r^2=0.625$) (Figure 2). A Durbin-Watson test indicated that the data was not autocorrelated ($D=2.25$, $D_u=1.37$).

FCP values reflect phenological green-up of vegetation (Wehausen and Hansen 1988). In this study, the influence of precipitation on FCP was evident. FCP peaks in June of both years followed precipitation in March, whereas the March 1992 FCP peak followed high fall and winter precipitation (Figure 1). However, precipitation in July 1991 had no apparent effect on summer or fall FCP values.

Only one high FCP value was recorded from several fecal samples collected in March and April 1992, suggesting that the sampling did not track nutritional status precisely. This may be partially due to decreased bighorn use of water sources during both spring seasons, when cool temperatures and adequate precipitation allowed bighorn to meet their metabolic needs without regular visits to water sources.

Death Valley FCP values vary annually, according to precipitation patterns and resultant effects on vegetation. Wehausen and Hansen (1988) compared FCP curves for several bighorn populations in California, and showed that variation in the timing of peak nutrient availability was due to delayed green-up at higher elevations, and that differences in maximum FCP values were due to the relative availability and productivity of nongraminoid forage species. In years of high fall-winter precipitation in Death Valley, such as 1991-1992, maximum FCP values in the Black and Funeral Mountains probably occur in spring. Spring FCP maxima have been observed in other Mojave Desert bighorn populations (Kirkeeng 1985, Wehausen and Hansen 1988). In contrast, the maximum FCP value for 1991 occurred in June, similar to FCP patterns displayed by higher elevation populations such as the White Mountains (Wehausen and Hansen 1988). However, high June FCP values in the Black and Funeral Mountains are probably not the result of delayed green-up at higher elevations because there is less high elevation habitat in those ranges than in the White Mountains. High summer FCP values in the Black and Funeral Mountains are more likely due to late spring precipitation events (Figure 1).

Lamb:ewe ratio (Table 1) varied between 9.1 and 54.5 percent, but was not correlated with fall-winter ($p=0.555$) or summer precipitation ($p=0.137$), or with mean minimum spring temperature ($p=0.265$).

In other areas, desert bighorn lamb:ewe ratios have been correlated with weather variables such as precipitation and temperature (Douglas and Annable 1985, Douglas and Leslie 1986, Wehausen et al. 1987, Douglas 1991). In the Mojave Desert, production of annual plants is dependent upon the amount and timing of winter precipitation (Beatley 1969, 1974), and lamb:ewe ratios have been correlated with fall-winter precipitation in the River Mountains of Nevada (Douglas and Leslie 1986) and Santa Rosa Mountains of southern California (Wehausen et al. 1987). Death Valley has the highest variability in precipitation of any long-term meteorological station in the Mojave Desert (Rowlands 1993). Lamb:ewe ratio in this study was thus expected to vary with fall-winter precipitation, but did not. Although the statistical power of this regression may be weak due to small sample size ($n=10$) and the relatively small number of ewes (22-49) in each sample, the results suggest that factors other than environmental variation influence bighorn recruitment in Death Valley. Density-dependence and disease have been identified as secondary factors influencing recruitment in other bighorn populations (Douglas and Leslie 1986, Wehausen et al. 1987), but effects of these factors in Death Valley are unknown.

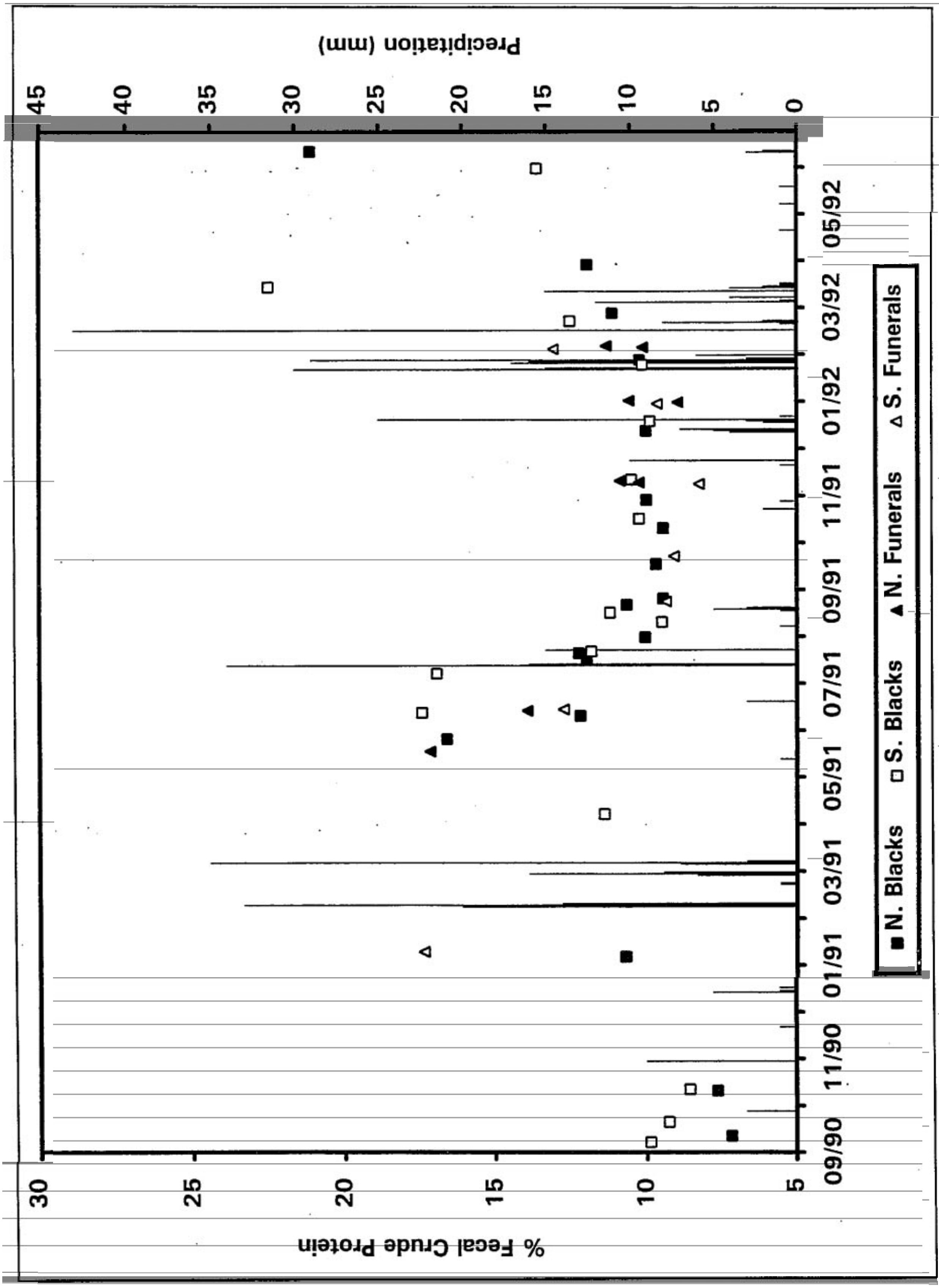

Figure 1. *Daily precipitation in Gold Valley (elev. 1160 m) in the southern Black Mountains (vertical lines), and bighorn percent fecal crude protein values for the Black and Funeral Mountains, Death Valley, California, 1990-1992.*

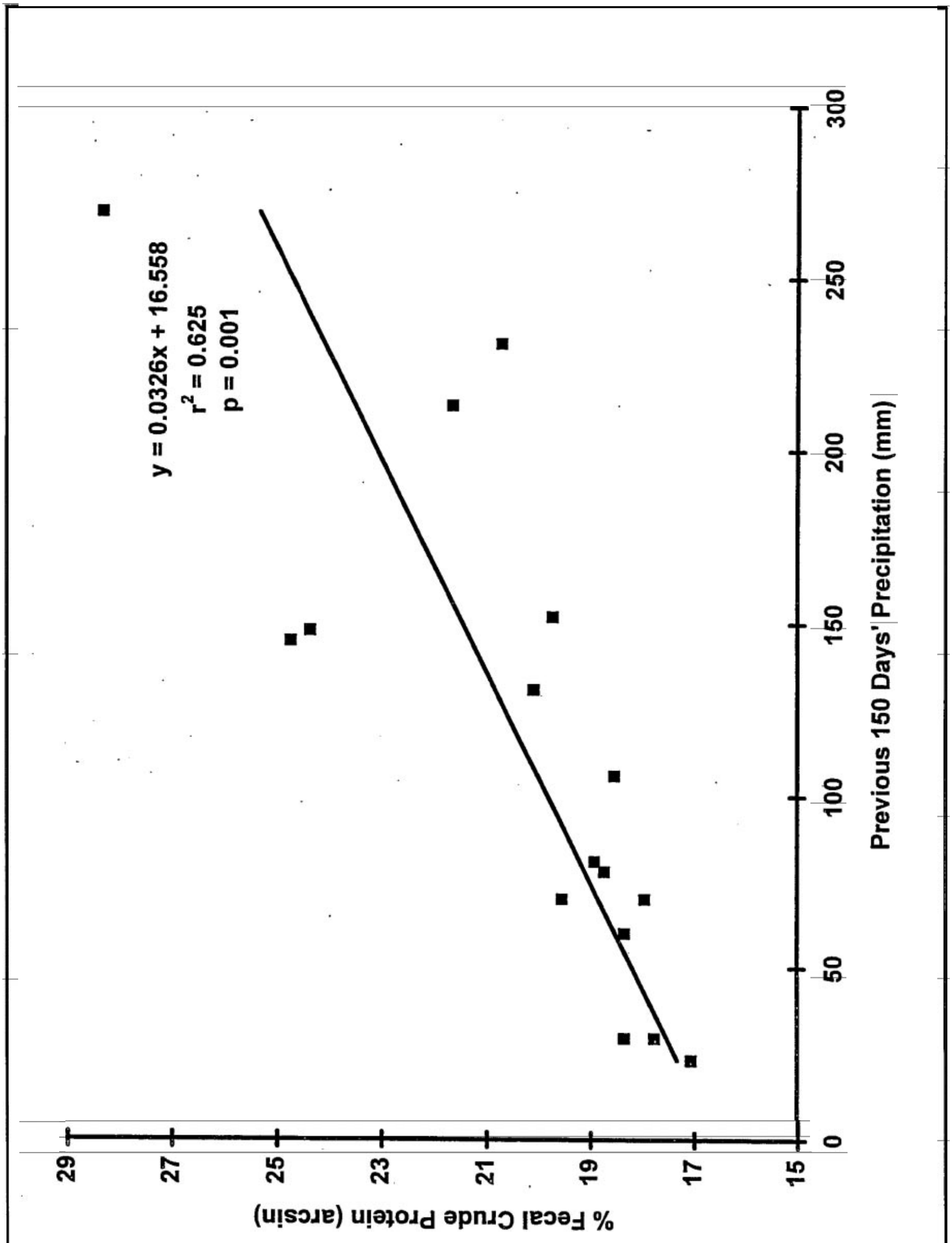

Figure 2. ***Bighorn percent fecal crude protein versus previous 150 days' precipitation, Death Valley, California, 1990-1992.***

Table 1. *Bighorn lamb:ewe ratios (lambs per 100 ewes) from Death Valley National **Park** (DVNP), California.*

Year	Mountain Range	Month	Rams	Ewes	Lambs	L:E Ratio	Source
1955	Blacks, Funerals	July	17	42	9	21.4	Welles and Welles 1961
1956	Funerals	July	9	22	12	54.5	Welles and Welles 1961
1970	Parkwide	Sept	23	33	6	18.2	DVNP unpubl. data
1980	Parkwide	Sept	16	31	11	33.3	DVNP unpubl. data
1981	Cottonwoods	Sept	25	49	12	24.4	Dunn 1984
1982	Cottonwoods	Sept	28	49	16	32.7	Dunn 1984
1985	Cottonwoods	August	7	27	5	18.5	W.C. Dunn, unpubl. data
1987	Cottonwoods	August	7	24	4	16.7	W.C. Dunn, unpubl. data
1988	Blacks	July	19	23	6	26.1	Douglas 1988
1993	Blacks	August	8	22	2	9.1	Douglas and Longshore 1995

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COMMENTS AND STATUS REPORTS

STATUS OF BIGHORN SHEEP IN ARIZONA - 1994

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Desert Bighorn Council Transactions 39:77

POPULATIONS

Estimates of Arizona's desert bighorn sheep (*Ovis canadensis mexicana* and *O. c. nelsoni*) indicate a growing population of approximately 6500 animals. The 1994 helicopter surveys produced a record 2758 observations in 292.4 hours (9.4 sheep/hour). Survey results yielded ratios of 51 rams:100 ewes:20 lambs:16 yearlings.

The Rocky Mountain bighorn sheep (*O. c. canadensis*) population, estimated at 500 animals, continues to expand both in numbers and range. This population was supplemented with 28 animals from Colorado this winter. The 26.5 hours of helicopter surveys resulted in a record observation of 383 animals (14.5 sheep/hr). These survey results produced ratios of 54 rams:100 ewes:41 lambs:10 yearlings.

Since 1981, a mean of 70 sheep have been transplanted annually, with a mean of fewer than two mortalities. In 1994, 76 bighorn sheep were successfully captured and transplanted to three release sites. This transplant effort included a trade of desert bighorns for Rocky Mountain bighorns with Colorado, and the release of 25 desert bighorns into southern Utah.

RESEARCH

The Arizona Game and Fish Department (AGFD) is currently inyolved in several sheep research and management projects, including testing of survey methodology and efficiency; studies of movement and mortality of Rocky Mountain sheep; development of a bighorn sheep management program for Sonora, Mexico; and development of an interstate bighorn sheep management complex between Arizona and Utah.

HABITAT IMPROVEMENTS

The AGFD, primarily in cooperation with the Bureau of Land Management and the Arizona Desert Bighorn Sheep Society (ADBSS), undertakes up to 10 bighorn sheep water development projects annually. These water projects may vary from simple tinaja modifications to extensive artificial water collection and storage systems. The AGFD tries to develop the most cost effective, environmentally sensitive, maintenance-free waters possible—a very difficult task.

HARVEST

Bighorn sheep permits remain the most sought-after hunting permits in Arizona. There was a record total of 5673 applicants (4190 resident and 1483 non-resident applicants) for the 110 regular season permits. This represents nearly 52 hunters applying for each permit, with individual unit odds varying from as low as 16:1 to 294:1, depending on the unit's accessibility and harvest history.

As a result of the 1994 survey, the number of permits was increased from a record 110 to 111 permits for the 1995 season. Two additional permits will again be issued to raise funds for bighorn sheep management programs. Additional areas in game management units 12B, 13A, and 39 will be opened for bighorn sheep hunting to take advantage of expanding sheep populations. There are a total of 14 units with transplanted populations being hunted in Arizona, with 30 permits being offered in these units.

During the 1994 hunting season, 110 of the 112 hunters participated, harvesting 101 rams for a 92 percent success rate. The 1994 season produced 41 animals (41.9 percent of the harvest) qualifying for the Arizona Trophy Book (minimum score of 162 Boone and Crockett points). Of these rams, 20 (20 percent) scored >170 points, with 2 (2 percent) scaring above 180 points. Over the previous 5 years, these trophy harvest percentages have averaged 38 percent and 19 percent, respectively. The average age of the harvest was 7.3 years.

Recent harvest data was analyzed to determine the differences between guided and nonguided bighorn sheep hunts. The number of days in the field and the green score were significantly higher for guided hunters. There was no difference in the hunter success rate.

For the past 10 years, the AGFD and the ADBSS have entered into an agreement whereby the ADBSS auctions one permit (at the Foundation for North American Wild Sheep convention) and raffles another to raise funds for bighorn sheep management projects. Since the program started in 1984, $1,509,860 has been raised from the 21 permits ($743,000 from 11 auction tags and $766,860 from 10 raffle tags). The success of Arizona's bighorn sheep management program is dependent upon the funds derived from these permits.

STATUS OF DESERT BIGHORN SHEEP IN NEVADA - 1994

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Desert Bighorn Council Transactions 39: 78-79

POPULATIONS

Three subspecies of bighorn sheep (Ovis canadensis) inhabit Nevada. In the northeast portion of the state, Rocky Mountain bighorn (*O.* c. canadensis) occupy five mountain ranges. In northcentral and northwestern Nevada, California bighorn (*O.* c. *californiana*) have been released at 18 sites. Desert bighorn (*O.* c. *nelsoni*) have the broadest distribution and occupy 47 mountain ranges in central and southern portions of the state. Inclusive of each subspecies, there are approximately 6500 bighorn sheep in Nevada.

Desert bighorn sheep observations totaled 2277 as a result of aerial surveys conducted on 33 mountain ranges during fall 1994. Viewed on a statewide basis, the sheep encountered through aerial surveys yielded a composition of 1143 ewes, 697 rams, and 434 lambs (61 rams:100 ewes:38 lambs). Derived primarily from these surveys, there are an estimated 5200 desert bighorn sheep in Nevada. The 1994 population estimate closely approximates the 10-year statewide average, and represents a 6 percent increase above the 5-year statewide average. Due to Nevada's varied temporal and spatial distribution of precipitation, some bighorn populations experienced recent successive years of drought, while other populations experienced more favorable moisture conditions. Regionally, measurable precipitation was below average from the latter half of 1993 and through most of 1994. Overall, water developments have served to lessen the severity of reduced water availability endured by some populations of bighorn during drought years. Water catchment construction remains an integral program element in efforts to reestablish mountain sheep into historic ranges.

During fall 1994, 83 desert bighorn sheep were captured by private contractor in the southern portion of the state. Capture operations in southern Nevada were conducted in three ranges: Mormon Mountains, Lincoln County; Muddy Mountains, Clark County; and River Mountains, Clark County. The ensuing translocation phase involved two reintroductions and three augmentations. In December 1994, a single ram was captured by a Nevada Division of Wildlife crew in the Gabbs Valley Range, Mineral County. The ram was fitted with a radio transmitter (Telonics Inc., Mesa, Arizona) and released in the Wassuk Range, Mineral County. All bighorn captures were accomplished using an aerial net-gun technique.

Fall trapping operations were initiated with the capture of 21 animals in the Mormon Mountains. A reintroduction was subsequently achieved through release of all 21 sheep in the Hot Creek Range, Nye County. In the Muddy Mountains, 36 desert bighorn were captured, of which 20 were given to the state of Texas for reintroduction on the Black Gap Wildlife Management Area. The remaining 16 sheep from the Muddy Mountains' contingent were released as an augmentation in the Highland Range, Clark County. Twenty-six desert sheep captured in the River Mountains were released to achieve three augmentations to populations in the Highland Range (*n*=3), Wassuk Range (*n*=22), and the Pine Grove Hills, Lyon County (*n*=1).

Since 1968, 971 desert bighorn sheep have been transplanted to 28 mountain ranges in Nevada. In addition, 210 desert bighorns have been furnished to Colorado (*n*=93), Texas (*n*=87), and Utah (*n*=30) to assist efforts to reestablish populations in other states. Future plans have been approved to translocate desert bighorn sheep into additional mountain ranges within Nevada. Bighorn capture and transplant operations are scheduled to occur during October 1995.

HABITAT IMPROVEMENTS

In 1994, one water catchment was constructed in both the Sheep Range, Lincoln County, and Muddy Mountains. A water collection apron was added to an existing project in the Specter Range, Nye County. Additional water storage capacity was added to two projects, the first in the Muddy Mountains and the second in the Las Vegas Range. Collectively, water project construction and unit upgrades equate to 18,400 gallons of additional water storage capacity. There are now 106 water developments in Nevada for desert bighorn sheep with a combined storage capacity of 488,700 gallons. These projects are funded all or in part by Nevada Bighorns Unlimited (Reno, Fallon, and Elko chapters), the Fraternity of the Desert Bighorn (Las Vegas), the Foundation for North American Wild Sheep, and Safari Club International (Desert Chapter). Catchment construction and maintenance is accomplished largely by volunteers from these organizations. Projects were constructed in cooperation with the Bureau of Land Management and the U.S. Fish and Wildlife Service.

HARVEST

The desire to hunt desert bighorn rams in Nevada remains great. There were 2810 applications for 112 resident tags (25:1 odds), and 1273 applications for 13 nonresident tags (98:1 odds). Two special bid tags were also allotted. In 1994, 90 rams were harvested, which equated to a hunter success rate of 73 percent (3 tag-holders did not hunt). Relative to last season and the 5-year-average, hunter success declined 10 percent and 4 percent, respectively. The average age of rams harvested was 6.2 years, slightly below the average age of 6.4 years encountered last year. Four rams exceeded the Boone and Crockett minimum score of 168 points. A ram harvested in the Arrow Canyon Range attained the highest Boone and Crockett score, 175 $^{6}/_{8}$.

Thirty-seven (30 percent) tags of the available 125 resident and nonresident tags in 1994 corresponded to hunt units with bighorn populations established through translocation efforts. Twenty-nine units were hunted in 1994, including the Last Chance Range, a newly designated unit with a resident herd established through translocation of 24 bighorn in 1988 and a follow-up release of 25 in 1989. The estimated population in this range is 141.

In May 1995, the Nevada State Board of Wildlife Commissioners will authorize desert bighorn harvest quotas for the 1995 season. Hunt areas and quotas are anticipated to remain largely unchanged relative to last year. Two harvest permits were auctioned for Nevada desert bighorns in 1995: the first at the Safari Club International (Desert Chapter) banquet in Las Vegas, Nevada; the second at the Nevada Bighorns Unlimited (Reno Chapter) banquet. Funds raised from the tags totalled $191,000.

PROBLEMS/OPPORTUNITIES

Desert bighorn populations on the East Range and Tobin Range initiated declines in August 1991; the declines coincided with detection of trespass domestic sheep in bighorn habitat. In July 1994, it was concluded the Tobin population no longer existed and that the East Range population was nearly extirpated. In each situation, nasal and pharyngeal swab samples were collected from desert sheep and domestic sheep and subsequently analyzed to determine whether transmission of *Pasteurella* contagia had occurred. Publication of results is expected in 1996 (Ward et al. 1996).

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STATUS OF DESERT BIGHORN SHEEP IN UTAH - 1994

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Desert Bighorn Council Transactions 39:80-83

POPULATIONS

Utah's desert bighorn sheep *(Ovis canadensis nelsoni)* occupy the desert canyonlands of the southeastern and southern regions of the state. Helicopter surveys conducted on 14 areas during November and December 1994 produced 1195 observations. Three areas were not surveyed. Two small populations of recently transplanted animals were not included in the survey. Table 1 shows the current status of desert bighorn sheep in Utah. Estimates of Utah's desert bighorn sheep indicate a statewide population of approximately 2233 animals.

Since 1973, when 12 desert bighorn sheep were trapped from the Lake Mead area in Arizona and released in Zion National Park, Utah has had an active transplant program. A total of 379 sheep have been translocated into, within, or out of Utah since 1973. Three sheep were shipped to Texas in 1985. Six were sent to the Hogle Zoo in Salt Lake City, Utah. Twenty-seven were brought from Nevada to Westwater Canyon along the Colorado/Utah border. The remaining 306 were trapped within Utah from native or reestablished herds and released into areas devoid of animals or to augment small populations. In addition, 25 desert bighorn sheep were trapped with a helicopter and net gun near Lake Mead in Arizona during November 1994 and released in the Beaver Dam Mountains. They consisted of 4 rams, 20 ewes, and 1 ram lamb. Since the release, one ewe has died as a result of injuries sustained in a fence. The Foundation of North American Wild Sheep, Southern Utah Sportsmens Association, and the Arizona Bighorn Sheep Society participated financially in securing a domestic sheep operation buyout, making the transplant possible. Table 2 shows the various areas receiving transplanted sheep since 1973.

Another relocation of 17 desert bighorn sheep took place on February 19, 1995. The 8 rams, 7 ewes, and 2 ewe lambs were captured by helicopter using a net gun. They were taken from the Escalante Unit and released into Rogers Canyon west of the Kaiparowits Plateau to augment a release of 13 bighorns made in December 1993. Since the 1993 release, two radio-collared rams have died, possibly killed by mountain lions. One radio-collared ewe returned to her original home range but was recaptured and translocated a second time in the February 1995 project. Mortalities of four, radio-collared adult ewes shortly after their release indicate that a February 19 capture is too late in the season to stress pregnant ewes.

RESEARCH

The Bureau of Land Management, the National Park Service, and the Utah Division of Wildlife Resources began a 3-year, multiagency disease, genetic, and sightability study in 1992. The study area includes the North and South San Juan, Potash, the Needles District of Canyonlands National Park, and the Glen Canyon National Recreation Area. Sixty-three desert bighorns have been fitted with radio collars for the study. A companion study is being conducted to evaluate survival, movements, and habitat selection of the radio-collared bighorns. Three sightability flights have been conducted during which 153 groups of bighorn were detected. The helicopter observers spotted 73 percent of groups observed by ground crews. Statistical analysis (univariate Chi-square and logistic regression) indicated that bighorn activity and topographic position were significantly related to sightability, while group size, helicopter position, cover vegetation, and solar conditions were not significantly related. Blood samples collected indicate *Pasteurella hemolytica* has been isolated from nearly all bighorns tested. A *Moraxella* sp. was also identified. Tissue samples from the various study populations are being analyzed by Dr. James R. Purdue, Illinois State Museum of Springfield, Illinois. A narrative report, discussing the significance of findings for each herd, will be completed in 1995.

During the winters of 1993 to 1995, captured deer in Zion National Park were found to be affected by an outbreak of *Chlamydia* or "pink eye." Future plans are to examine desert bighorn sheep in the Park for the incidence of Chlamydia, since deer and bighorn ranges overlap during the winter in Main Zion Canyon.

HABITAT IMPROVEMENTS

In December 1994, volunteers from the Canyonlands Wildlife Federation installed their seventh water catchment since forming an "Adopt-a-Guzzler" partnership with the Bureau of Land Management (BLM) in 1987. This catchment is the tenth to be completed within the Potash Habitat Management Plan area.

Two water catchments were constructed during September and November 1994 by BLM and Division of Wildlife Resources personnel in the Burning Hills area west of the Kaiparowits Plateau near Rogers Canyon. The two 1200- to 1500-gallon "guzzlers" were funded by BLM's Kanab Resource Area.

HARVEST

Legal desert bighorn sheep hunting began in Utah in 1967 with the issuance of 10 resident permits. Nine rams were harvested that first year. Since 1967, the number of permits issued has fluctuated from no permits in 1973 and 1974 (to protect study animals) to a high of 25 permits in 1977. Nineteen hunting permits were issued on six units for Utah's desert bighorn sheep in 1994. The permits included 16 resident, 2 nonresident, and 1 high-bid permit. Eighteen hunters were successful in harvesting bighorns for a 95 percent success rate. One hunter was unsuccessful on the Escalante Unit, an area of very rough terrain and difficult access. The permit auctioned at the San Antonio, Texas, annual Foundation for North American Wild Sheep Convention generated $51,000. The 1995 permit auctioned at the Phoenix, Arizona, Convention brought $41,000. Money from these permits is used exclusively for desert bighorn sheep programs in Utah.

PROBLEMS/OPPORTUNITIES

In the Potash Unit, chronic disturbances from mountain biking, vehicle travel, off-road recreational events, and commercial movie and filmmaking are being monitored for adverse effects on the bighorn population. There is evidence that some bighorn are becoming habituated to the presence of people. During December 1994, a large ram charged and struck a man photographing bighorn in Arches National Park. The photographer was hit a second time while attempting to flee the area.

FNAWS is negotiating with a domestic sheep permittee on BLM lands in the San Rafael Unit to purchase or offer incentives for conversion to cattle. Another plan has been proposed to keep domestic sheep from trailing through an important bighorn use area in this same unit. Livestock operators have expressed cooperation.

The pending BLM wilderness-designation proposal has caused some concern by bighorn sheep managers in areas where water development is necessary, such as the Little Rockies and areas west of the Kaiparowits. A proposed Utah Wilderness Bill will be prepared by June 1,1995. Other bighorn management activities may also be enhanced or impacted depending on the language of the bill.

Several ideas and studies are being proposed to increase interest in preserving and enhancing bighorn sheep on tribal lands. The first permit to be offered by the Navajo Tribe generated $36,000 at the Phoenix FNAWS Convention. This funding will be used for management of a small population along the San Juan River.

Restoring desert bighorn sheep to historical ranges in Utah is a primary goal of State and Federal agencies and conservation and sportsmen's groups. Several transplant proposals are presently being considered. However, protection and expansion of existing populations are of foremost importance.

Table 1. Utah Deserr Bighorn Sheep populations based on1994 November and December helicopter surveys.

Area	Trend	Rams	Ewes	Lambs	Unclass.	Total	Lambs: 100 Ewes	Rams: 100 Ewes
N. San Rafael	up	90	97	37	0	224		93
S. San Rafael	up	94	89	39	0	222	44	106
Potash	dn	32	28	15	0	75	54	114
Professor Valley	up	4	5	4	0	13	80	80
S. San Juan	up	23	41	13	0	77	32	57
N. San Juan	no survey							
Lockhart	st	5	12	6	0	23	50	42
Escalante	up	49	77	32	0	158	42	64
Kaiparowits	up	27	32	15	0	74	47	84
Little Rockies	up	11	14	4	0	29	29	79
Zion NP	st	4	14	8	4	30	57	29
Capitol Reef NP	st	9	6	3	0	18	50	150
Canyonlands NP						195	52	82
Island in the Sky	st	39	48	24	0	111		
Needles	no survey							
Maze	st	7	10	5	0	22		
Arches	up	15	35	12	0	62		
Rogers Canyon	Tr*	4	8	1	0	13	-	-
Beaver Dam Mtns	Tr**	4	20	1	0	25	-	-
Paria	no survey							
Raplee	st	6	13	3	0	22	23	46
Westwater	st	2	6	0	0	8	incomplete count	
Dirty Devil	no survey							
TOTALS		**425**	**555**	**222**	**4**	**1,401**		
Rattlesnake (BLM)***	up	32	40	32	0	104	80	80
Rattlesnake (UTE)***	up	19	45	14	0	78	31	42
TOTALS		**51**	**85**	**46**	0	**182**	**54**	**60**

dn - down
st - stable
Tr* - 12/93 Transplant
Tr** - 11/94 Transplant
*** - Rocky Mountain Bighorns

Table 2. *Desert Bighorn Sheep management areas.*

Area	Status
North San Rafael	Transplanted 1979-86 - successful
South San Rafael	Transplanted 1979-86 - successful
Potash	Established native population
Professor Valley	Transplanted 1991 - uncertain
South San Juan	Established native population
North San Juan	Native population - uncertain
Lockhart	Established native population
Escalante	Transplanted 1975-78 - successful
Kaiparowits	Transplanted 1982-86 - successful
Little Rockies	Transplanted 1985 - successful
Zion National Park	Transplanted 1973 - successful
Canyonlands National Park	Established native and transplanted population - successful
Arches National Park	Transplanted 1985-86 - successful
Capitol Reef National Park	Transplanted 1982-85 - successful
Rogers Canyon	Transplanted 1993-95 - uncertain
Beaver Dam Mountains	Transplanted 1994 - uncertain
Paria	Arizona transplanted 1984-85 - successful
Navajo Tribe	Established native population
Westwater	Transplanted 1979-90 - uncertain
Dirty Devil	Transplanted 1991-94 - successful

EAGLE MOUNTAIN BIGHORN MONITORING PROGRAM: AN UPDATE

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Desert Bighorn Council Transactions 39:84-87

INTRODUCTION

The Eagle Mountain Bighorn Monitoring Program began in the summer of 1993 with funding provided by the Mine Reclamation Corporation (MRC), in cooperation with the National Biological Service, Cooperative Research Unit, University of Nevada, Las Vegas, the California Department of Fish and Game (CDFG), the Bureau of Land Management, and the National Park Service. The impetus behind the project is transformation of the closed Eagle Mountain Mine into a regional landfill for southern California, capable of accepting up to 20,000 tons per day of inert solid waste. The mine is located in Riverside County, California, approximately 40 miles west of Blythe, on the eastern edge of Joshua Tree National Park (Figure 1).

The bighorn monitoring project was undertaken following a mandate from CDFG calling for a study of sheep movements and potential impacts of the landfill on the Eagle Mountain bighorn sheep herd. Several ephemeral water sources (small ponds formed following rainfall) located in the main mine pit and on the compacted mine roads will be lost with construction of the landfill. One goal of the study is recommendations for, and successful placement of, artificial water units to offset the loss of the ephemeral water sources. Because water development success may be tied to sheep home ranges and seasonal movements, it is hoped that movement patterns observed during the study will aid in successful placement of the artificial water units.

Ephemeral water sources may play an important role for the Eagle Mountain bighorn herd because there are only four natural water sources in the Eagle Mountains currently providing surface water: Buzzard Spring and Eagle Spring in the north, and Summit Spring, and Conejo Spring in the south (Figure 2). Of these four, only Buzzard Spring and Summit Spring appear to provide permanently available surface water.

COMPLETED WORK

In support of the project, three sheep captures have been conducted to date. The first, on June 23-24,1993, yielded 12 ewes and 1 ram. The ram was a 3 year old weighing 210 pounds, making him one of the heaviest rams ever weighed by CDFG. Unfortunately, a mortality signal was detected on this animal during the first telemetry flight following his capture, and although the cause of death was not ascertained, capture myopathy is suspected. Also during this capture, 2 ewes were injured (one with a dislocated tarsus and one with a punctured eye), but both have been spotted repeatedly and appear to have no ill-effects.

A second capture was conducted on September 27-28, 1993. During this capture, an additional 11 ewes and 7 rams were captured, bringing the total number of collars in the field to 28, the makeup consisting of 21 ewes and 7 rams. The third, and most recent, capture was conducted on September 27-28, 1994, with the sole intent of capturing additional rams. In order to document intermountain movements, a larger number of rams needed to be fitted with radio collars and monitored. Thus, an additional 7 rams and 1 ewe were captured and collared.

The most notable aspect of the captures was the size of the animals. During the third capture, 6 of 7 rams were weighed, with the lightest ram weighing 154 pounds, and the heaviest weighing 209 pounds, resulting in an average weight of 182 pounds.

During the third capture, two mortality signals were detected and located. The first mortality was a 3-year-old ewe, whose collar was located, but whose carcass was not. The second mortality was a 10-year-old ewe, whose carcass was located. These two brought the total number of mortalities to three, with two animals missing. Currently, the number of mortalities stands at four, with an additional ram having died earlier this year. Excluding the missing carcass, it appears none of the four dead animals died as a result of predation. Although it cannot be substantiated, it is felt that at least one, and maybe both, of the missing animals is due to radio transmitter malfunction rather than an undetected, long-range movement.

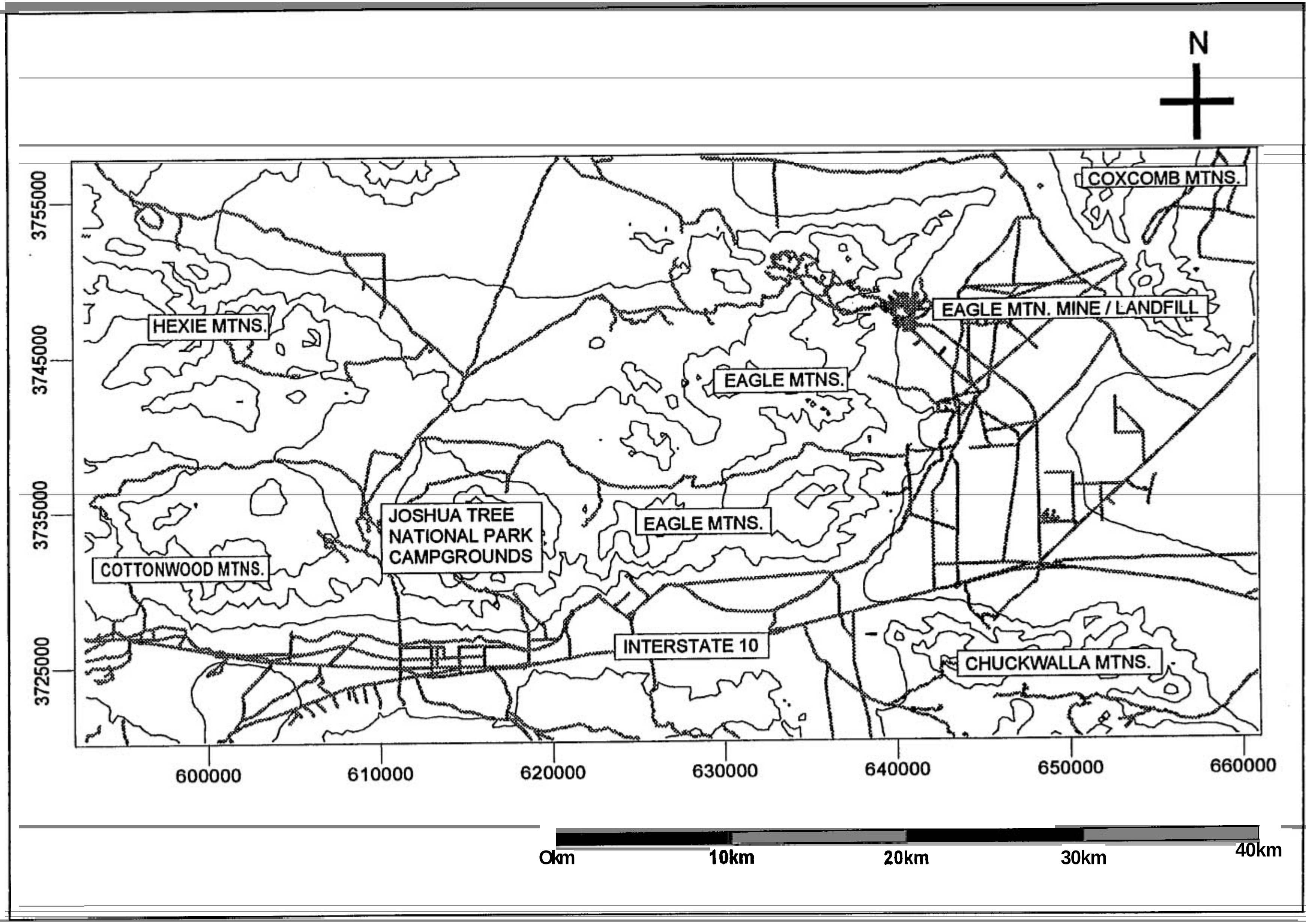

Figure 1. Eagle Mountains and surrounding vicinity.

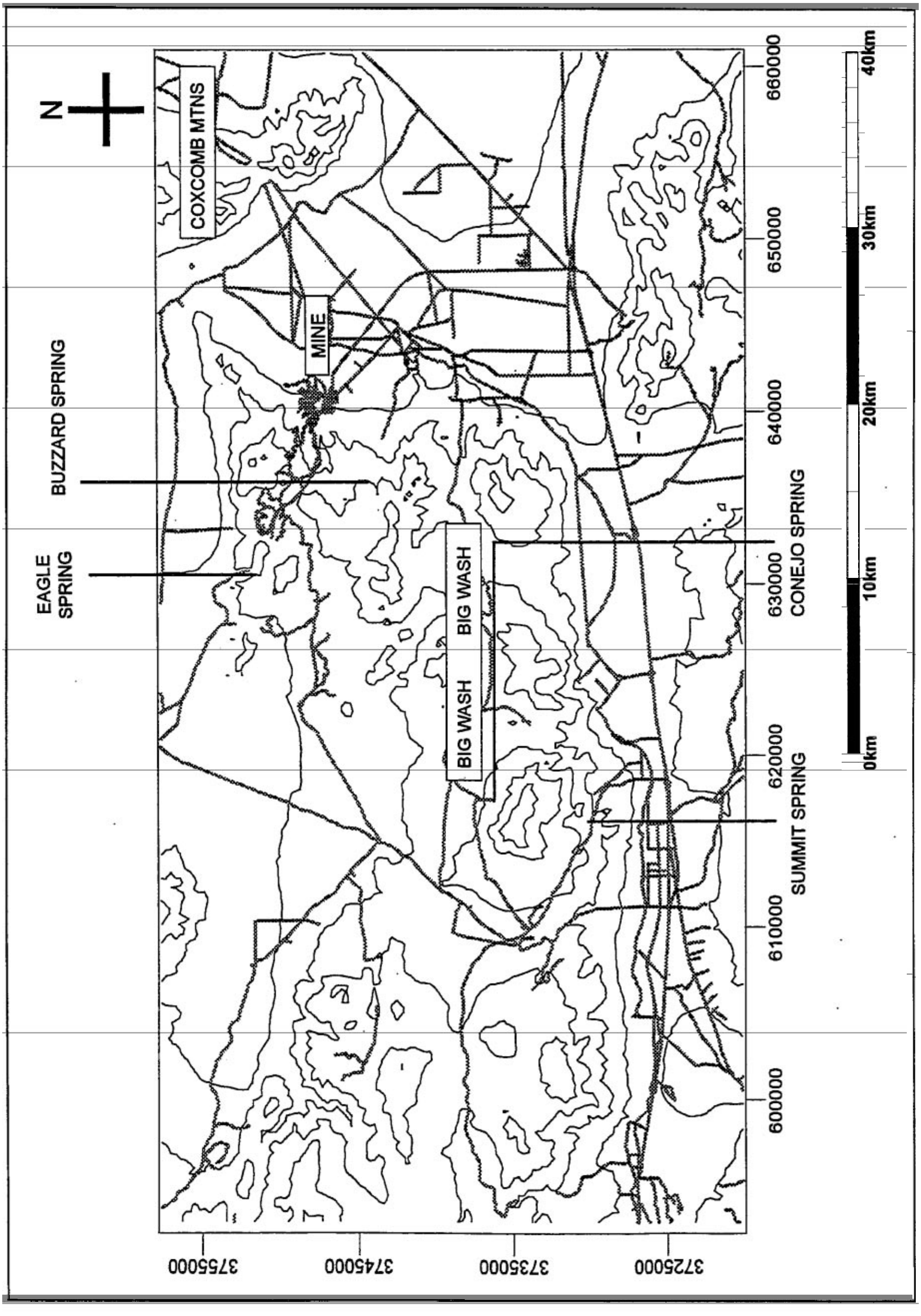

Figure 2. *Eagle Mountains and study area.*

As of April 5, 1995, 45 aerial telemetry flights have been flown, with 702 groups of sheep located. The most striking result is that although rams can be found in almost any part of the range, ewes form two, noninteractive groups, one in the north near the mine, and one in the south near Summit Spring (Figure 2). The dividing line between the two ewe groups appears to be Big Wash, a large wash running east to west bisecting the two main segments of the Eagle Mountains (Figure 2). During hot summer months, both rams and ewes tend to congregate around two major water sources, Buzzard Spring in the north and Summit Spring in the south.

One of the most anticipated results of the project was documented on January 19, 1995. Ram A361, a 3-year-old male, was captured during the third capture, but was not located until January 19, in the Coxcomb Mountains, some 15-20 kilometers from his capture and release site (Figure 2). The current hypothesis is that this ram spends most of his time in the Coxcomb Mountains and only came to the Eagles for the rut. It is hypothesized that this animal travelled to the Coxcombs from the Eagles via a peninsula that extends more than half-way across the valley separating the two ranges. This ram will be monitored very carefully during the 1995 rut season to obtain further information to support or refute these hypotheses.

A helicopter population survey was conducted on September 27, 1994. During this flight, it was estimated that prior to the third capture session, 41 percent of the population was collared, and by using the Lincoln Index Mark-Recapture Method with a 95 percent confidence interval, the overall population estimate for the Eagle Mountains is 68 $\pm$ 28 individuals. Using the natural break of the ewe groups and the same methodology, an estimate of 21 $\pm$ 9 ewes in the north, and 17 $\pm$ 9 ewes in the south is obtained.

The 1995 spring lambing estimate is 40 lambs per 100 ewes for the overall herd. But this should be viewed with extreme caution because of the disparity between groups. Because of inaccessibility of the southern range, and a study emphasis on the northern group, the southern lambing estimate is based solely on aerial data gathered in mid-February and is 15 lambs per 100 ewes. The data for the northern group was gathered during February and March, both from the ground and from the air, and the latest figures show 65 lambs per 100 ewes.

FUTURE DIRECTIONS

October 1995 will mark the end of the second year of radio telemetry flights. At that time, home ranges, animal associations, and critical habitat areas will be calculated. Based on these calculations, recommendations will be presented to CDFG and MRC concerning sites for temporary water sources. After the locations of these units has been agreed upon temporary water sources will be placed in the field, and bighorn use monitored with video cameras and radio telemetry for 1-2 years to determine the effectiveness of placement and the amount of usage.

WILD SHEEP IN TURKMENISTAN: CURRENT STATUS AND CONSERVATION PROBLEMS

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Key Words: Turkmenistan, *Ovis orientalis,* status, water needs

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Turkmenistan, a newly independent (former Russian/Soviet) republic (Figure 1) has probably the largest surviving population of wild sheep (also called mountain sheep, or arkhars) in Central Asia. Most of this population lives in mountains and foothills in the south of Turkmenistan within two natural reserves: Badghyz (established 1941, 860 km^2, 3000-3500 animals) and Kopetdagh (established 1976, 498 km^2, 2000- 2500 animals). An additional 300 to 500 wild sheep inhabit the western and northwestern parts of the republic, including the Bolshoi Balkhan mountain range, the cliffs of South Ustyurt Plateau, and the areas around the Kara-Bogaz-Gol Bay of the Caspian Sea. A number of Russian researchers (Tsalkin 1948, Geptner 1956, Ishadov 1964, Gorelov 1968, 1978) documented the human-influenced decline of this population and its range reduction. A comprehensive survey of the Turkmenistan population of wild sheep has not been conducted in many years and is highly desirable.

The diverse wild sheep of Eurasia are still presenting many problems for systematic zoology. Of three major recognizable groups of wild sheep (moufloniforms, argaliforms, and pachyceriforms), the Turkmenistan race belongs to moufloniforms (mouflons or urials). In Russian zoological tradition, there are various views toward the moufloniform and argaliform separation. Some authors traditionally included all Central Asian wild sheep into *Ovis ammon* Linnaeus (Tsalkin 1951, Geptner et al. 1961, Rustamov and Sopyev 1994), whereas others recognized a separate species for moufloniforms, *Ovis orientalis* Hutton (Nasonov 1913, Sokolov 1959). The study of karyotypes of numerous wild sheep races (Vorontsov et al. 1972a, 1972b; Nadler et al. 1973) revealed that the Turkmen population from the Badghyz Reserve has 58 chromosomes, as do several other urial forms from Central Asia, Afghanistan, and India; mouflons have 54 chromosomes (Valdez 1982). Further genetic studies are necessary to determine to what extent the discovered karyotype differences represent the geographical variation (Orlov 1974, Gorelov 1978).

The recent, and the most comprehensive review by Valdez (1982), recognizes 10 subspecies of *Ovis orientalis,* of which the valid name for the Turkmen population is the Transcaspian urial, or *O. orientalis arkal* Eversmann 1850 (Valdez et al. 1978, Valdez 1982). Another name used for Turkmen wild sheep in Russian sources, *O. orientalis cycloceros* Hutton 1842 (also quoted as *O. ammon cycloceros*, e.g., Rustarnov and Sopyev 1994), should be reserved for the Afghan urial from Afghanistan, Pakistan, and eastern Central Asia. This last subspecies is synonymous with *Ovis bochariensis* Nasonov 1914.

Ovis orientalis arkal is endemic to Turkmenistan and adjacent areas of Iran, Afghanistan, and Kazakhstan (Ustyurt Plateau). It contacts and freely interbreeds with the 54-chromosome Armenian mouflon *(O.o. gmelini)*, creating a hybrid form that inhabits the Alborz Mountains in Iran, south of the Caspian Sea (Valdez 1982). The map in Valdez (1982: p. 75) shows Badghyz as the easternmost boundary of the range of the Transcaspian urial.

Rustamov and Ishadov (1985) summarized the known data on the biology of the Turkmen wild sheep. They quote the weight of adult rams from January through March as up to 80 kg, and of ewes, up to 46 kg (in fall, 85-90 and 56 kg, respectively). Females mature earlier than males (ca. 1.5 years of age in the Badghyz Plateau); mating occurs from November to December, gestation lasts slightly longer than 5 months. Birth of the young occurs from mid-April to the end of May when one or two lambs are born (very rarely three). The population structure in the Kopetdagh Mountains has a male:female ratio of 1:2.9; part of the ewes stay barren. Yearling sheep average 22 percent of the population. Lamb survivorship to 10 months of age averages 45 percent (Rustamov and Ishadov 1985).

During the 20th century, uncontrolled hunting, use of natural pastures by domestic sheep and cattle, and disturbance by human activity has significantly decreased the population of the mountain sheep in Turkmenistan (Rustamov and Sopyev 1994). The most critical point in the wild sheep ecology is water availability, especially in the semidesert plateau of Badghyz. There is no precipitation from June to September in this area (annual average precipitation at Kushka meteorological station is 260 mm, or about 10 inches). Because of the high air temperatures (35' to 40°C in summer) and soil temperatures (32°C average in July) that lead to the drying of ephemerous grasses and sedges (primarily Carexpachystylis and Poa bulbosa), ungulates cannot get enough water from their food. In this hot period, with its water deficit, wild sheep have to use natural springs or migrate in their search. There are very few water sources in Badghyz (Gorelov 1964). These include three natural springs in the western part of the Natural Reserve (Kerlek, Kamenny, and Central), and five currently existing artificial water sources in its southern part (where water is kept in concrete tanks regularly refilled by a fire vehicle).

The size of Badghyz ungulate populations depends directly on water supply. This refers not only to wild sheep, but also to local populations of the goiter gazelle (*Gazella subgutturosa*) and the onager, or wild ass (Equus *hemionus* onager). Wild sheep are more tolerant of water salt content than onagers and all local domestic ungulates (cattle, sheep, goats, and horses). In Badghyz, wild sheep use water sources with mineralization as high as 20 to 22 g/l (Gorelov 1978). The water sources that wild sheep have to use are an excellent place for ambushes by predators such as wolves and leopards. Wolves (*Canis* lupus) can be found next to each of the water sources in Badghyz where they come to drink and hunt. The leopard (Panthera *pardus*) is also a common predator in Badghyz. On June 8, 1994, one of the authors, Kh. I. Atamuradov, observed a leopard that approached the Kerlek Spring at 9 a.m. and frightened a herd of wild sheep. At this spring, 650 wild sheep were surveyed drinking during this single day.

The severe water limitations of Badghyz are nonexistent in the Kopetdagh Reserve where sheep habitats are located in the mountains with many constant springs and streams, and there is sufficient access to water sources even in summer.

The most important measures which should be considered now in order to promote wild sheep conservation in the Badghyz area, and in all of Turkmenistan, is construction of additional artificial water sources ("guzzlers"), as well as cleanup of natural springs. The Turkmenistan Department of Natural Resources and Conservation is committed to further scientific studies directed toward the preservation and maintenance of biodiversity and welcomes joint surveys and sharing of technology by interested foreign specialists and agencies.

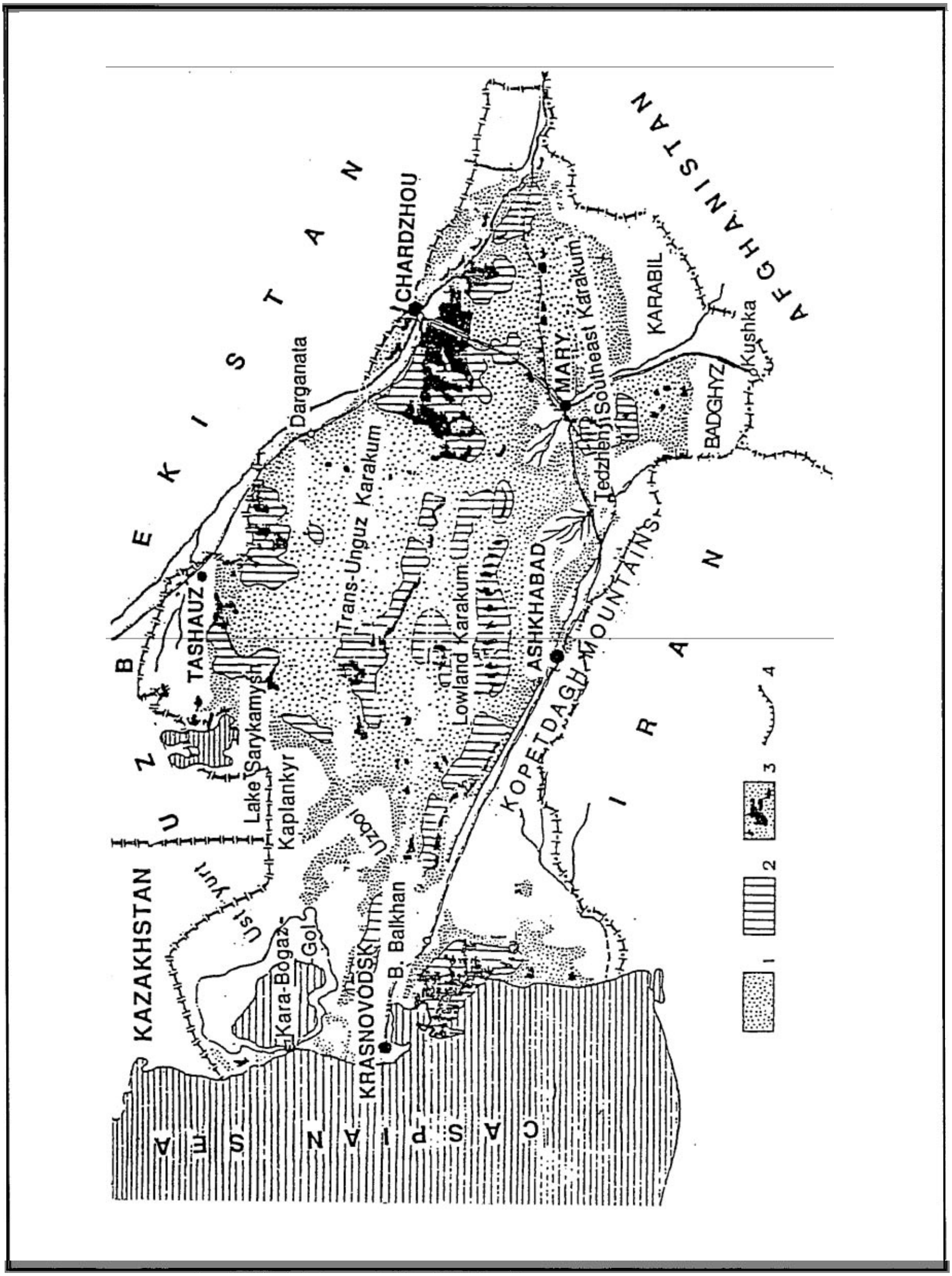

Figure 1. *A schematic map of Turkmenistan.*
Legend: *1 - stabilized sand, 2 - semistabilized sands, 3 - drift sands, 4 - the Karakum Canal.*

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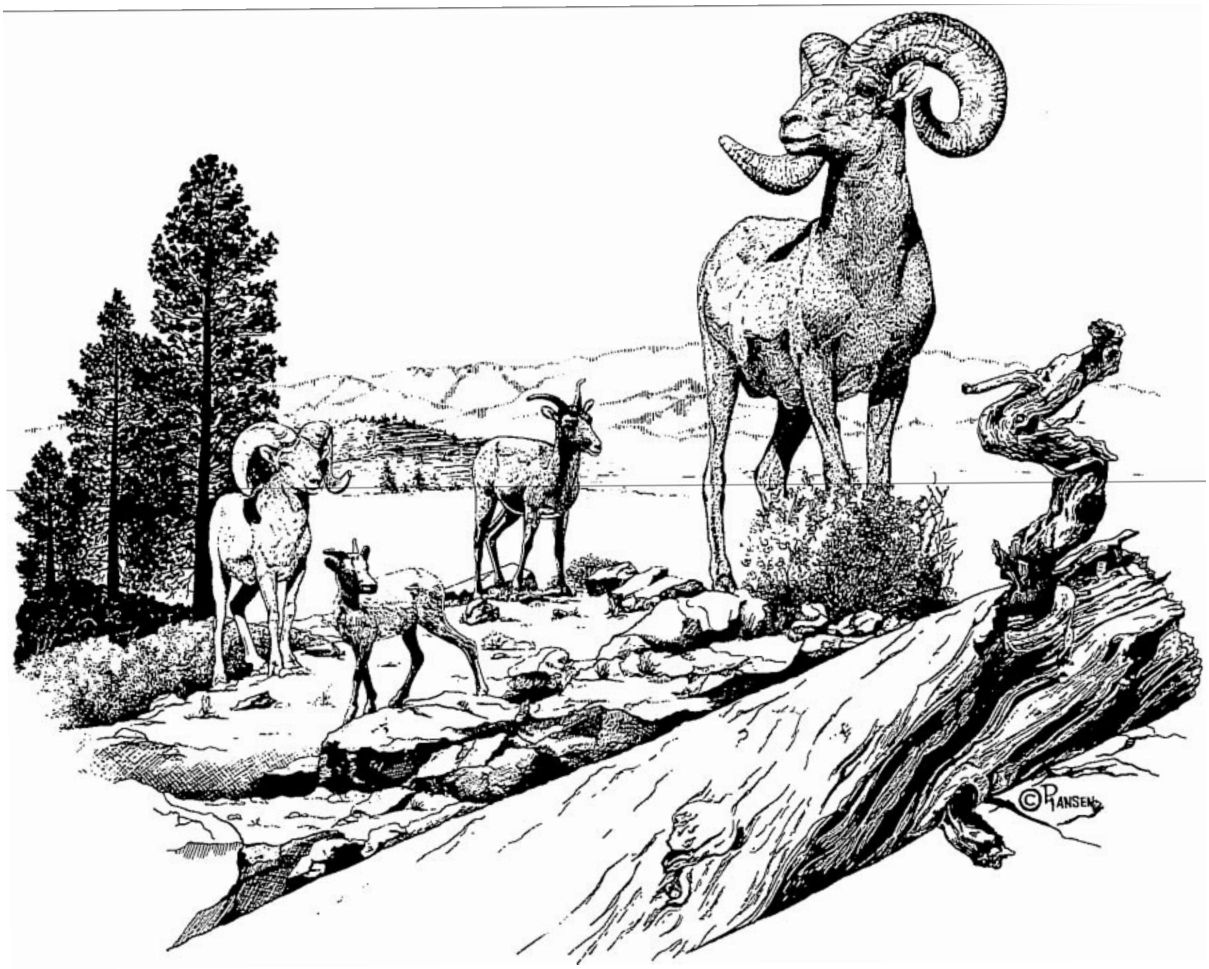
PANEL DISCUSSIONS



During the 1994 Desert Bighorn Council meeting, a panel discussion was conducted on livestock/bighorn sheep disease transmission. The discussion was recorded. Speakers had the opportunity to edit their comments that are presented in this volume.

LIVESTOCK/BIGHORN SHEEP DISEASE TRANSMISSION

Moderator: **Mike Miller,** Colorado Division of Wildlife, Ft. Collins, CO

Panel: **Walter Boyce,** University of California, Davis, CA
Marie Bulgin, University of Idaho, Caldwell, ID
Bill Foreyt, Washington State University, Pullman, WA
David Hunter, Idaho Department of Fish and Game, Caldwell, ID
Terry Spraker, Colorado State University, Ft. Collins, CO

Mike Miller - We want to spend some time this afternoon talking about disease interactions that involve bighorn sheep and livestock, particularly with reference to policies on sheep relocations and grazing policies on public lands where bighorn and livestock may commingle. We've been very fortunate to assemble such a distinguished panel who've spent a great deal of time over the last several years, if not decades for some, working with bighorn sheep disease problems. Everyone should benefit from the expertise they have to offer.

Mike stated that he would introduce each of the panel members as the panel proceeded and that everyone should try to keep their comments fairly brief as there would be an opportunity at the conclusion for open discussion among both panel members and the audience. He said he wanted to start by briefly trying to frame up the problem.

You're going to hear a lot about pasteurellosis this afternoon, I have no doubt, and you'll probably hear a lot about, hopefully, a number of other significant respiratory diseases, but one of the bigger problems we're going to be talking about and probably one of the root causes of a lot of the problems with respiratory disease in bighorn sheep, be they desert sheep or Rocky Mountain bighorns in North America, is attributable to pasteurellosis. Disease, as all of you know, plays a significant role in bighorn sheep population dynamics. Specifically, there are really two ways this occurs. Obviously this isn't the desert sheep except maybe anywhere but in Colorado. But, we see these tremendous, explosive die-offs of bighorn sheep that can create significant harm to populations. These die-offs have been reported since the last century, for over the last 100 years. Probably some of these pneumonia outbreaks have been occurring with fairly regular "irregularity," but they can be absolutely devastating. Certainly, one of the sequels to these outbreaks that's maybe a little less well understood, but in my opinion is as devastating to overall population performance of bighorn sheep is the lamb mortality that follows the outbreaks. We get to work with captive sheep and we've seen a lot of examples in Rocky Mountain sheep in Colorado, and I know that it's been seen in desert sheep, in Rocky Mountain sheep in other places, where in the follow-up, in the aftermath of one of these explosive pneumonia outbreaks, lamb survival can be abysmal for a number of years. We have one herd in Colorado and it's been 13 years now since it went through a significant pneumonia outbreak and we still see pneumonia every summer in lambs in that population and lamb survival is particularly poor. That population has taken over 10 years to double in size since that pneumonia outbreak occurred. So these things can really drag down populations in the long haul.

The results of these kinds of processes are very erratic — unstable populations that certainly don't recover very well in the face of these pneumonia outbreaks, and may in fact go extinct because of not only continuing problems with disease but also problems with predation, weather, and other kinds of things that can easily waylay small populations after they get driven down to a very low point.

The process appears, basically, to have two components. There certainly is opportunity and measurement opportunity historically in some cases for novel pathogens to be introduced into bighorn populations. We don't see these same kinds of patterns in more northern sheep species, in the Dall sheep and the stone sheep, which might suggest that some of these things are relatively new in an evolutionary sense. Certainly, in some of these, novel introductions do go on today. Once they occur, there seems to also be epizootic or endemic processes that go on. Again, with pasteurellosis, in many cases there are other bacteria and other agents that can be involved but the pasteurellosis seems most often to be the most common cause of problems. Certainly stress, viruses, chlamydia, and bloodworms can, from time to time, contribute to these problems. Once these epizootic cycles begin they seem to be very, very difficult to break.

What the panel is going to mainly talk about this afternoon is the introduction of novel pathogens. In particular, as I've said before, you'll be hearing a lot about *Pasteurella.* I hope you'll hear about some other pathogens as well and their relative importance in contributing to these cyclic pneumonia problems that seem to plaque our bighorn herds throughout North America. What we hope to do is to try to get a feel for the relative importance of these novel pathogen introductions from the epizootic cycles that are maybe sequela to those kinds of things. Certainly, some of these are going to be much more preventable than others. I think that you should get a fair bit of good information from our panel members and hopefully this will lead to some stimulating discussion as we proceed this afternoon.

I'd like to introduce our first speaker at this point, Dr. Bill Foreyt. Bill received both his masters and Ph.D. in veterinary sciences from the University of Wisconsin and is currently a professor in the veterinary microbiology and pathology department at Washington State University at Pullman. Most of you familiar with the literature on bighorn sheep and domestic sheep diseases, with respect to pasteurellosis, I am sure will be familiar with Bill's name and so I'll turn this over to Bill.

Bill Foreyt **-** Thank you Mike. Thank you everybody for corning. I got involved in the domestic livestockhighorn sheep interaction in 1979 purely by accident. So we're involved in this area of interest, not intentionally, but because it proved so interesting we pursued this area of research. In 1979, we had a herd of 14 bighorn sheep and into that herd we put some domestic sheep to try to produce a hybrid, primarily to do some additional disease studies, and 13 of 14 of those bighorn sheep dropped dead. This was purely circumstantial, but because we thought there might have been a cause/effect relationship we published the paper in the *Journal of Wildlife Disease* in 1982. Then, in 1988, the Lostine Mountain outbreak occurred in Oregon where two-thirds of those bighorn sheep died after contact with domestic sheep. At that time we had some domestic sheep in captivity at Washington State University and we decided to become actively involved, to look at this domestic livestockhighorn sheep interaction. We began by trying to duplicate what we saw from that initial situation that I described. We put 6 domestic sheep in with 6 bighorn sheep that had been in captivity for 1 year and within less than 2 months all of the bighorn sheep died from pneumonia. *Pasteurella haemolytica* was the agent that was isolated from all the dead bighorn sheep. Previous to the experiment, using only nasal swabs, we could not demonstrate *P. haemolytica.* So we published this paper which I thought was one of the best pieces of work that I have ever done and it probably resulted in the most controversy of any paper. It became a very interesting story to look at. We repeated that experiment on about three more occasions where we would put bighorn sheep and domestic sheep together and in every instance the mortality rate in the bighorn sheep was close to 100 percent. Mortality rate in the domestic sheep was zero. So it looked like there was an adverse association between bighorn sheep and domestic sheep. The question then came up, what about other adverse interactions? What about elk, deer, and the other animals that often associate with bighorn sheep in the wild? So we replicated those experiments. We put elk into our pens with captive bighorn sheep at Washington State University (WSU). The standard protocol is to keep the animals in a 1-acre pasture for 60 days, evaluate the *Pasteurella* that are there before you put the animals together, evaluate the *Pasteurella* that are there at the end of 60 days, and also from any animals that died. Well, elk seemed to be compatible because none of the bighorn sheep died in our replicated trials. We used white-tail deer on one trial, mule deer on one trial, and nothing happened there. We did one experiment with domestic goats and nothing happened. With llamas, we were not even able to isolate I? *haemolytica* from the llamas in the experiment or any of the llamas that came through WSU during this period. Llamas seemed to be compatible with bighorn sheep. We just completed a 60-day trial with mountain goats. Nothing happened with the mountain goats or the bighorn sheep. We also just completed a trial with cattle, using three cattle and four bighorn sheep in a very confined pen, and nothing happened in the bighorn sheep. Again, we always have to question these results because I? *haemolytica* is such a diverse organism. There are probably a hundred different kinds of I? *haemolytica* and when we select three cattle randomly, we don't get very many types of *P. haemolytica* in a specific kind of animal. So some of these experiments will have to be repeated using the type of I? *haemolytica* we think is more serious in bighorn sheep that is usually carried by the domestic livestock in a nonpathogenic way. The other study we did this winter was with mouflon sheep. We put five mouflon sheep into a herd of five bighorn sheep and all the bighorn sheep died from pneumonia.

The conclusion to these interaction studies were that bighorn sheep are incompatible with domestic sheep and mouflon sheep. In other words, when they have close contact, the probability of bighorn sheep dying from pneumonia is very high. We went a little further to be sure that it was the *Pasteurella* that was killing the bighorns and not stress or viruses or airplanes flying over or other stress-type factors. What we did was to take *P. haemolytica* from a normal, healthy, domestic sheep. It's a very common type of strain we call biotype A, serotype 2. A majority of domestic sheep carry it. We took it from the healthy, domestic sheep and grew it in culture, and we inoculated it into bighorn sheep and into domestic sheep. The bighorn sheep that were inoculated died from pneumonia within 24 hours and the domestic sheep never sneezed. We replicated that trial three times using different levels of *P. haemolytica* and in each trial all of the bighorn sheep except one died. So the result from that experiment is that bighorn sheep are very sensitive to some strains of *P. haemolytica* that are carried by domestic sheep and that those strains don't affect the domestic sheep.

We then began looking at the mechanism behind the pneumonia in bighorn sheep. Was there a way we could prevent it? Was there a way we could minimize the effects? That's where my colleague, Dr. Ron Silflow, has done almost all the work. His role was to look at the function of the lung and the function of these bacteria in terms of producing toxins in the lung and adversely affecting the bighorn sheep. He takes various strains of bacteria and grows them in culture. He isolates the toxin from the different strains and then evaluates that toxin against neutrophils from different kinds of animals. If the toxin kills the neutrophils, we then speculate that the bacteria will kill the kind of animals those neutrophils came from. If the *Pasteurella* toxin kills more than 50 percent of the bighorn neutrophils, we classify that *Pasteurella* strain as a pathogenic strain for bighorn sheep that is likely to cause pneumonia.

We have also tested host-resistance or host-sensitivity based on their neutrophils. What we've found is that in every healthy wild herd of bighorn sheep that we tested, none of those sheep had ever yielded a toxic-type P. haemolytica even though every bighorn sheep carries *P. haemolytica*. When we sampled domestic sheep, about 60 percent of the isolates that we tested were toxic. How do we know they're toxic? Because, if we took that same organism and inoculated it into a bighorn sheep and a domestic sheep, in every instance the bighorn sheep died. There's one exception to that and that's one toxic isolate that we found in an Oregon bighorn sheep that was found dead of pneumonia. It was a toxic isolate in our test. We inoculated it into two bighorn sheep and the bighorn sheep never got sick. We repeated it and again the bighorn sheep didn't get sick. We're hoping that this could be a vaccine strain. It's toxic enough in our test, but yet it won't kill bighorn sheep. Next week we'll challenge those same bighorn sheep with a domestic sheep isolate of our toxic strain to see what happens. If those sheep live, we may have an eventual solution to this problem.

The conclusions from these studies, then, are based on the neutrophil toxicity test. Bighorn sheep are very, very sensitive to pneumonia. They die very easily and I guess all of you know that already, but now we have the data. We've worked with Dall sheep this summer. Dall sheep are even more sensitive to pneumonia based on this test than are bighorn sheep. Domestic sheep are also relatively sensitive but five times less so than bighorn sheep. Deer, elk, and some of the other ruminants we've tested are essentially resistant to these kinds of bacteria. So, in terms of management guidelines, which you people are looking for, my suggestions are if you want to keep healthy bighorn sheep in the environment, you must avoid contact with domestic sheep and mouflon sheep or the probability of those sheep dying from pneumonia is very high. The other conclusion is that bighorn sheep are very sensitive to pneumonia, and that if they contact any of these toxic strains through nose-to-nose transmissions, they are likely to die.

Mike Miller - Our next speaker will be Dr. Marie Bulgin. Marie received her veterinary training at the University of California-Davis. She is a board-certified microbiologist and is very actively involved in the small ruminant health program at the Caine Veterinary Teaching Center in Caldwell, Idaho. Marie's going to be presenting some of the information that she brought with her and also providing some information that her colleague, Dr. Al Ward, would have presented.

Marie Bulgin - Thank you, Mike. I guess we can start out with the first overhead. I'd like to start by saying that there's actually been a lot of people involved in the research I'm going to talk to you about today. And, as you can see, I've really had very little to do with it, but I would like to comment that Dr. Ward, who isn't here, probably did the majority of it. Dr. Hunter will talk about some of the work that he's been involved in, and these other folks are really the ones that did all the culturing, did all the tough stuff, so this certainly wasn't a one-person effort by any means.

The perception of the problem of bighorn and domestic sheep has led to many groups being at dagger-point as you all know. But, in the state of Idaho, it has brought together some very diverse groups. The Idaho Wool Growers, the Department of Fish and Game, the University of Idaho, and the State Department of Agriculture have all banded together in an effort to search for knowledge, to help provide reasonable answers about how to manage our bighorns and our domestic sheep, and I think it's to their credit that this has taken place. It's my intent to try to summarize the research that's come out of that effort.

Pneumonia, specifically that caused by *Pasteurella hemolyticum,* has been one of the most recent diseases, certainly one of the most controversial ones of recent years to be looked at. As a result of several die-offs in the state, specifically two in Hell's Canyon and one in the Salmon River area, we decided to look at the *Pasteurella* that are carried by bighorn sheep. So with the cooperation of Fish and Game, the State Department of Agriculture, and the Caine Veterinary Center, we have sampled and surveyed most all of the herds in Idaho as well as samples from Arizona, California, Nevada, Montana, Wyoming, Colorado, and North Dakota. So we've looked at quite a few bighorn sheep—probably somewhere in the vicinity of 450 animals.

Let's go to the next overhead. When we began, we discovered several things. We discovered that the nasal swab is not a very good way to find *Pasteurella* in bighorn sheep. As a result, our first isolations are probably fairly low. We have here a slide that was made some time ago and we found that our isolations from both bighorn sheep and domestic sheep were about 60 to 70 percent. Since that time, since going to both the nasal and tonsilar swab, plus getting samples from the field to the laboratory faster, plus using transport media, we've improved those isolations to almost 90 percent both in bighorn and domestics. So, we did discover that bighorns do carry quite a large population of *Pasteurellas.*

I guess I ought to say a little bit about identification of these *Pasteurellas.* Next slide please. This is the part that confuses me and I'm sure it's going to confuse you too. I'll do my best here. Of course *Pasteurella* is the genus, *hemolyticum,* the species, then we go to biotyping. We have three biotypes: A, T, and 3. I've always wondered why they threw this 3 into the alphabet, but that's the way they do it. We talk about serotyping. This is where they take serum from animals that have been inoculated with various types of *Pasteurella* and then use that for identification. We have many, many serotypes. In addition to the serotyping that we don't even have on this slide, they're now doing biogrouping. The biogrouping includes quite a number of groups as well. And then, of course, you've heard about fingerprinting. That's what Dr. Ward has done a lot of work with and this breaks it down even further. So, you'll hear me talk about serotype and biogroup and biotype and if you get as lost as I do, I'm going to have you totally confused. Next slide please. This is just an example. Biotype A, as you can see, has a number of serotypes. You'll hear me talk about biotype A, serotype 1, or serotype 2. You'll hear me talk about biotype T. Serotype is not used as much or we haven't looked at it as much as we have biotype. You'll hear me talk about biogroup 2 which is not a serotype 2. And on biotype 3, although we had none identified at the time this slide was made, we now have a serotype 11, biogroup 11, that's important as you'll see in a few minutes.

The incidence of isolation of *Pasteurella* of bighorn sheep seems to run about the same as it does in domestics. About 90 percent of them will yield *Pasteurella* and that's about what we've gotten out of the bighorn sheep. Interestingly enough, one animal can carry many different serotypes. We find that in the bighorn sheep, the greatest majority of them carry T. As you can see, we do find some As. We find some that carry both As and Ts, some that carry some 3s, some that carry As and 3s, but the majority, about 60 percent of the bighorns will yield just Ts. There may be several different serotypes and several different biotypes. The domestics, on the other hand, are reversed. The majority of organisms that they carry usually biotype A, but some may have Ts, some 3s, and some combinations, but the majorities are As.

Before I go on, I should mention hemolysis. In the literature, you'll find that a lot of people relate hemolysis to pathogenicity. In other words, if they see a hemolytic organism on a blood agar plate, they assume that it is more pathogenic than one that shows no hemolysis. We feel that that's probably true. However, whether you see hemolysis or not on a blood agar plate in the laboratory has to do with a lot of factors, one being where you got the blood. In other words, if you got the blood from a sheep, and we do use sheep blood for these tests, and that sheep happens to have antibodies to the hemolysin you're testing for, you're not going to see hemolysis on the blood agar. Presently we're looking into a more reliable test for hemolysis.

One of the interesting things that we have been able to do is look at bighorn herds that have actually come into contact with domestics. Probably the most interesting work, in this regard, has come out of Nevada. I think Dr. Hunter's going to cover that so I won't go into any great detail except to tell you that we have some information that shows that we do have domestics and bighorns carrying not only the same strain and the same biogroup, but the same fingerprint, indicating that there was some transmission from somebody to somebody, but not knowing which way it went. In that particular herd, there hasn't been a die-off and it could be because the organism isn't very pathogenic. It was the biotype 3, biogroup 11, and it could be that it's just not a very pathogenic strain.

In the last **3** years, we've only had the opportunity to look at sick bighorns about 18 times. Unfortunately, it is seldom that bighorns have been found soon after death and that the finder is able to get samples to us. This is one of the weaknesses of our research. In the 18 that we've looked at, only 5 of these have been field isolates—sick bighorns out in the wild. The others have all been captive bighorns that we've had good accessibility to. The interesting thing about this is that the organism that's been isolated in five of six necropsies has been type T, the same type from 10 of 12 sick animals where we merely got a nasal or tonsilar swab. This has been type T, biogroup 2. It appears as if that particular strain, which is also carried by the majority of bighorns, can be pathogenic. For example, of 297 *Pasteurella* species that we've gotten out of healthy bighorns, approximately 42 percent of them were the same strain and the same biogroup as this organism that we've gotten out of the sick bighorns, type T, biogroup 2. It's also interesting that of the wild elk, deer, antelope, moose, mountain goats, and bison that we have cultured looking for *Pasteurella*, the elk, deer, goats, and moose all carry the same strain of *P. haemolytica*, T biogroup 2.

Marie stated that no fingerprinting had been done to determine if they are identical, but that they are the same in terms of type and biogroup. As stated by Dr. Foreyt, there has been enough research indicating that the commingling of bighorns and domestics is detrimental to the bighorn's health. Mane stated that Dr. Foreyt is not the only one who has had this experience. There have been other researchers in other states who have had this problem and in Idaho's case, it happened recently. She stated that they had nine domestics that were all positive for ovine progressive pneumonia and they were interested in observing whether or not this was a disease that could be transmitted to bighorns as well.

The domestics were placed in a pen and several days later four, 1- to 2-year-old bighorn males were placed next to them. Within 48 hours of placing the bighorns, a domestic sheep died. Interestingly, when the bighorns were placed with the domestics, we noticed that they were very curious about each other and that they all ran up to the fence on both sides and licked and sniffed noses. It was actually observed that one of the bighorns was licking the nose of one of the less healthy domestics. That was the domestic that died within 48 hours, and the bighorn died the next day. The day after the first bighorn died, the second bighorn died. The day after that, the second domestic died. By this time, we wised up, took the temperatures of the remaining bighorns, and when we found that they were exceeding 104°, we put the bighorns on antibiotics. They survived.

The organism isolated from that small die-off was *P. haemolytica* biotype A, biogroup 1. The organism had identical fingerprints in the four sheep (bighorn and domestic) that had died and the two living, remaining bighorns, as well as in two of the remaining seven domestics. This organism is of relative interest because biotype A, serotype 1, biogroup 2 is an organism that is carried by cattle, not sheep. We do not know where it came from. However, in the two domestics carrying it, it died-out after a month or so, never to be seen again in that group. The two remaining bighorns that survived, however, continued to carry the organism.

It was decided to see what would happen if all the sheep were blitz-treated with tetracycline in the feed. This was an effort to see if *Pasteurella* could be cleared from the domestic sheep in case we wanted to commingle the sheep again. Before the sheep were commingled initially, 27 different groups of *Pasteurella* were identified among all the domestic sheep mostly in biotype A. The bighorns only started out with a biotype A, biogroup 1, which they were now getting along with quite well, as well as a biotype A, biogroup 7X. After the blitz treatment with tetracycline, we wiped out a number of the groups, but there were still plenty left. However, we did wipe out that group A, serotype 1, in the two remaining bighorns, that had killed off the bighorns and the two domestics. It was eliminated after the bighorns had carried it for several months. It was thought that all the groups weren't eliminated because some were resistant to tetracycline. However, only two biogroups were found to be resistant to tetracycline. The others were residing in the sheep in spite of being sensitive to it. It was further thought that perhaps not all the animals were eating the feed with the tetracycline in it, so it was decided to inject the sheep with an antibiotic. The sheep were injected with ampicillin for 5 days, which we had determined that all the biotypes were sensitive to. In spite of ampicillin treatment, we were unable to affect the number of *Pasteurellas* we were able to isolate. One thing accomplished, although it was hard to quantitate, was we did knock numbers down. When we put swabs on plates and looked at them, there were many, many, many fewer colonies. However, the *Pasteurella* was still present. It seems safe to say that nose-to-nose contact is a good way of transmitting *Pasteurella* from one species to another in spite of prior treatment with antibiotics.

Our next consideration was to determine if *Pasteurella* could be transmitted through water or forage. We looked at water from water troughs the sheep were drinking out of, sampling the water for 14 days running. We never did isolate a *Pasteurella* out of the water. There was about a 2-gallon capacity in the trough. Next, it was decided to add *Pasteurella* to the water to see what would happen. Initially, we placed log 4 number of *Pasteurellas* per ml. in filtered sheep trough water. We just dipped it out of the water trough, filtered it, and then started culturing for *Pasteurella* one, two, four, six, and so forth hours afterwards. We discovered at 2°C or almost freezing (refrigerator temperature), that the organism was completely gone by the end of 48 hours. At higher temperatures, for example 27°C which is room temperature, we found that *Pasteurella* lasted for a full 2 hours. However, at incubator temperatures or body temperature, we couldn't isolate it after the first 20 minutes. Obviously, *Pasteurella* doesn't survive very well in filtered sheep trough water.

The next slide shows what happens in distilled water. In this experiment, we started with a larger number of *Pasteurellas*. We felt it was subjective how many *Pasteurellas* an infected sheep will put into a water trough and because we had no idea we started out by thinking a good practical number would be 104. Then, after we kicked it around for awhile, we decided to go with a worse case scenario and upped our numbers. Consequently, we discovered that the more *Pasteurellas* we put in the water, the longer they lasted. Even if you get a 90 percent die-off in the first day, the remaining 10 percent of 10^7 lasts quite a bit longer than 10 percent of 1,000 (100). When we threw in 10^7 organisms, they lasted a lot longer. At 4°C and it was more like 5 days that we could recover *Pasteurella* out of such a sample. Unfortunately, we have not inoculated 10^7 organisms into sheep trough water, but we have inoculated 104 organisms into distilled water and we find that *Pasteurellas* last longer in distilled water than they do in sheep trough water. We're conjecturing that there may be some toxic elements in the sheep trough water, perhaps from the algae or other bacteria that fall in. This is something that we need to follow up on.

Finally, we looked at forage. Although we need to do a lot more work with it, we find that alfalfa plants are fairly toxic to *Pasteurella*. At least at the 8 a.m. temperature during August, *Pasteurella* will not last longer than 1 hour on an alfalfa plant in the sunshine.

In summary, from our research, we can say that 90 percent of the bighorns do carry *Pasteurella* species. Of those that are positive, most of them come from the tonsils. This says something about the method of spreading the disease. If it isn't found in the nasal cavity, then the sheep probably aren't shedding a lot.

Of those that are positive for the *Pasteurella* species, only about 30 percent carry either the biotype A or 3. We have found that, geographically, biotypes tend to vary and that it's possible to determine the geographic area where the animal is from by the . Animals within an area tend to share the species. Elk, deer, antelope, and other wild ruminants also carry *Pasteurella* species.

We can say the most common isolated species in 18 dead sheep has been type T, biogroup 2, which seems to also be the main organism bighorns tend to carry.

Pasteurella species do not survive in the environment very well and are probably not transmitted via the environment. They probably require nose-to-nose contact to spread.

Mike Miller - *Mike stated that just from the first two talks he hopes everyone can appreciate how complicated a problem all of this is, especially as we are only talking about one species of bacteria even though there's a whole milieu of strains that appear to be out there and operating. Mike introduced the next speaker, Dr. Terry Spraker. Mike stated that Terry received both his DVM and Ph.D. from Colorado State University. Mike observed that Terry had been working on bighorn sheep respiratory problems for a number of years, at least 15 and probably closer to 20 years. Mike said that Terry is currently a pathologist with CSU's diagnostic lab and that Terry would be talking about pasteurellas as well as some of the other health problems that can arise from bighorn sheep and livestock interactions.*

Terry Spraker - *Terry gave a quick history of his background: he grew up in Wyoming and worked on sheep ranches during the summers when he attended high school. Because of this, he does have a basic understanding of sheep ranching and some of the associated issues. He stated that since veterinary school his work has involved investigating diseases in free-ranging animals, both terrestrial and marine mammals, and birds. Terry stated that he has had a particular interest in bighorn sheep and* *has invstigated diseases of bighorn sheep for the last 20 years.*

Because of long-time isolation of bighorn sheep, they seem to be more susceptible to many of the common diseases that otherfree-ranging ruminants are more resistant to. When you consider the past interactions of bighorn sheep with man, there have been numerous problems including market hunting, loss of range because of use by man and his domestic animals, and diseases. When one looks at the diseases, especially in the older literature, several diseases are mentioned, including scabies, anthrax, and pasteurellosis. Anthrax may have been misdiagnosed in these earlier days and, clinically, anthrax could look similar to acute pasteurellosisin bighorn sheep. Over the years many diseases have been diagnosed in bighorn sheep. Some of the diseases that are important in bighorn sheep that could possibly come from domestic animals include blue tongue, contagious ecthyma, and in some areas, an upper respiratory viral disease called bovine respiratory syncytial virus. Parainfluenza type 3 and chlamydia are other organisms that can be transmittedfrom domestic animals to bighorn sheep. There are other potential viral diseases that may affect bighorn sheep that can be carried by domestic sheep; however, these viral diseases have not been diagnosed in bighorn sheep to date. One of these viral diseases is bovine virus diarrhea. Scrapie is another important chronic neurological disease of domestic sheep and whether this disease can be transmitted to bighorn sheep at the present time is not known. No evidence so far has incriminated domestic sheep as being able to transmit scrapie to bighorn sheep. Ovine progressive pneumonia, which is a slow progressive viral pneumonia that occurs in range sheep is another disease of concern. Howevel; to date, at least in Colorado, this disease has not been found in bighorn sheep. Other bacterial diseases to be aware of, besides Pasteurella is Johne's disease. The etiological agent is an acid-fast organism that causes a chronic wasting and diarrhea in bighorn sheep. There are several herds in Colorado with this disease. This disease is a devastating disease to these free-ranging bighorn sheep. Recently we have found a mycoplasma in wild bighorn sheep populations with pneumonia. The significance of this organism is not known at the present time; howevel; we found this organism in the 1970s in association with a lamb mortality. Howevel; usually when mycoplasma is found, bighom sheep also have pasteurella, lungworm, and in some instances, a respiratory syncytial virus. There are also various parasites that can be transmitted from domestic sheep to bighorn sheep. One of these parasites is Oestrus ovis. This parasite manifests itself as a chronic sinusitis, especially in desert bighorn sheep. Occasionally we also see a tapeworm cyst in the abdominal cavity in bighorn sheep that are from areas in which there is an abundance of sheep, sheepdogs, and coyotes. This tapewomz is usually not pathogenic to the bighorns, but in cases of extremely high infestation could cause death to young animals.

In conclusion, we have been trying to study diseases offree-ranging animals because we think that many of the diseases of domestic animals can spill over into the free-ranging populations and can be a population-limiting factor. Any time bighorn sheep intermix with domestic animals, whether naturally or artificially, usually the bighorn sheep suffer in various ways. The problem with domestic sheep and bighorn sheep is nzore extensive than just disease transmission. There is a problem with interbreeding and probably with loss of range due to the domestic animals occupying the normal bighorn sheep habitat. Howevel; there does seem to be more of a problem with domestic sheep than other domestic animals, probably because the bighorn sheep and domestic sheep are so closely related genetically, and especially since they can interbreed. The domestic sheep appear to have an increased immunity to many of the diseases as compared to that of the bighorn sheep. Therefore, the bighorn sheep appear to be more susceptible to some of these domestic sheep diseases. It appears at the present time that we are enjoying fairly good success with bighorn sheep management for several reasons. One of the reasons is that there is a fairly extensive transplanting program in the western United States. In these instances, people are trying to transplant animals into clean habitats and they are also trying to transplant healthy bighorn sheep. Howevel; the habitat is still slowly decreasing, so even though intensive management including transplantation is showing promise at the present time, this is probably only a "temporary fix" for bighorn sheep management.

Mike Miller - *Mike stated that he would like to underscore Terry's message that this isn't a simple problem with respect just to pasteurellas. He said that's what we hear a lot about, and certainly that's a very common organism, but there are many other agents that we haven't spent the time and energy studying as we have the pasteurellas over the last 5 to 10 years. Mike said he's afraid that the more we look, the worse the news is going to be.*

Mike, in introducing Dr. Walter Boyce, stated that Walter received his veterinarian training at Auburn, has a masters degree from the University of Florida, and a Ph.D. from Purdue. He's an associate profes-

sor of parasitology at the University of California-Davis in the veterinary school. Mike said Walter had his own news as well as information from Dr. Dave Jessup, who wasn'table to attend, about disease problems as they relate to interactions with cattle.

Walter Boyce - Walter stated that rather than talk about data, he wanted to discuss conclusions. He said in his mind it's been brought home very clearly that domestic sheep and bighorn sheep don't mix. Howevel; it's much less clear with domestic sheep and bighorn sheep. He said that to the best of his knowledge there is no sound data that suggests that domestic cattle and bighorn sheep share diseases that are of importance to bighorn sheep. Walter said he needed to talk about sharing diseases versus detecting diseases. Oftentimes, the way to determine whether or not an animal has been exposed to a disease is to go out and collect a blood sample. Sera is submitted to a laboratory and examinedfor antibodies to these infectious disease agents. The presence of antibodies does not mean that the animal ever had clinical disease or will ever have clinical disease. The fact that bighorn sheep and domestic sheep or bighorn sheep and cattle have antibodies to the same infectious disease agents does not mean that those animals have been infected with the same infectious disease agent or that clinical disease occurred in either or both of those species. Walter said it's a fairly complex situation and that one can't generalize. Howevel; he said he was going to generalize: Put domestic sheep and bighorn sheep together and there are problems. The problems clearly occur due to pasteurella pneunzonias. With domestic cattle and bighorn sheep, these problems haven't been evident. He said that in California for tlze past 4 years, they have been looking at one bighorn sheep/cattle interaction in particular and that his focus has been scabies as the primary infectious disease agent although they have also been looking at other viruses and bacteria. What they found is that bighonz sheep that have scabie mites in their ears (and about 50 percent of the sheep do), that year after year, cattle in that area have never shown signs of having mites, they've never isolated mites from the cattle, and have never found antibodies to the mites in the cattle. Deer also occur in this area as well and they have never shown signs of infection. If one takes sera from these three different species, one can find tlzat they have antibodies to several dzfferent viruses and bacteria, but at this point it doesn't look like clinical disease results from any of those infections. Walter said in this one particular situation, it's possible to say that there are infectious disease agents that these animals have been exposed to that may or may not have been the same ones, but clinical disease has not been a problem. Even then it's not that simple because tlze cattle in this particular drainage are what's called a closed herd. No new animals are introduced from the outside on a year-to-year basis, and as discussed, the introduction of novel pathogens is very important. After awhile, if the group in this room all lived in close harmony, some would survive and some wouldn't because of exposure to all the dzfferent infectious disease agents in tlze room. When one introduces new cattle into this bighorn sheep herd that's closed because it's not being augmented, then there's a possibility that they can bring in new pathogens and the situation that's been seen during the past 4 years could change radically. Walter said he didn't want to say that just because we haven't seen disease interactions occurring between these animals that is always going to be the case. Most cattle operations (grazing on public lands in particular) are not closed operations and disease interactions are still an open question. But, at this point, when asked if he knows of any evidence tlzat indicates that cattle and bighorn sheep interactions are important from a disease point of view, he says no. He doesn't think the evidence is out there, but possibly someone here on the panel has evidence to the contrary and he would like to hear it.

Walter next brought up the issue of vaccination and treatment options. Walter said this gets a little bit into the philosophical realm but let's say, for example, in the case of pasteurella that we're able to clearly identify a potential vaccine. The use of a vaccine in free-ranging animals is a decision that has to be very carefully thought through. There are several considerations to think about. Is it going to have to be used year after year? Is this a management strategy we can commit to over tlze long-term? Is this the best option we want to pursue? Walter said Amy Fisher talked earlier today about the fact that we used ivermectin in the San Andres this year to try to treat scabies mites. She said it was used primarily for humane reasons because those animals had been suffering from an infestation for a prolonged period of time. It's extremely doubtful that the administration of ivermectin at this particular point in time, howevel; would have any effect on the population as a whole. Walter said his personal feeling was, that in terms of managing the diseases that need to be managed so that we're actually having effects on populations, probably the single best thing that has happened in recent years regarding diseases shared between bighorn sheep and domestic sheep was the recommendation that we keep those animals separate. He would much prefer to see that management strategy employed than for us to rely on a vaccine and then *feel we can mix the animals as long as we go in and intervene on a year-to-year basis and vaccinate. That's a personal decision on his part, but he thinks there are some valid reasons for doing this in that over the long-term is the commitment really going to be there to deliver vaccines year after year? Is the funding going to be there to do that? Walter said he'd like to hear opinions from the audience, many of whom are land managers and are the people that would actually be faced with implementing those sorts of decisions.*

Mike Miller - Thank you Walter. I think we'll go ahead and proceed to Dr. Dave Hunter who will wrap things up. Dave received his veterinary training from Washington State. Dave worked with the California Game and Fish Department for a number of years, 5 years I believe, and then most recently has had a joint appointment in Idaho. He's veterinarian for the Idaho Department of Fish and Game and also for the Idaho Department of Agriculture, serving two masters with sometimes slightly different perspectives and agendas. I think Dave's going to try to bring some of this into a personal perspective and also from an agency/management context.

Dave Hunter - Well, first of all you heard that my job as wildlife veterinarian for the state of Idaho is a doubly-funded position to work on wildlife. My job is wildlife, my funding is from two agencies. The reason for that is my job was legislated as a double-funded position. My job was basically created because of the bighorn sheep/domestic sheep interaction. Again, it kind of threw me in a new spotlight. Along with Dave Jessup in California, there were two of us wildlife veterinarians for the state at that time, so you always kind of have someone covering your backside. Well, it's like the difference between bacon and eggs at breakfast. You guys know that difference. You know the hen was involved in that breakfast, but the pig was committed to the breakfast. Well, my pork was now really on the line because I had two masters telling me there was no pressure on me, but go forth and prosper. Well, it was actually a little hard and you've heard about some of the research that's been done in regard to *Pasteurella.* Again, this is the organism that appears to be the final nail in the coffin. I think after 5 years in Idaho, we can reach a consensus. Walter mentioned it and Bill mentioned it, that what we can't do is put the two species together. You put bighorn and domestic together, in nose-to-nose contact, and there's a good possibility that you're going to end up with the demise of the bighorn sheep. After 10 years I'm a little smarter than that. We knew going in, at least I did, that what we had to do was to look at all those factors that were involved. So we came in and we said, well, we're looking at this literature here that was done under confinement and does this really happen in the wild.

There was an episode that came up about **3** years ago in Nevada. I got a call from Greg Tanner, who said all of a sudden they found domestic sheep in with their bighorn sheep populations and these were not in areas that had any kind of allotments, either a trailing allotment or a general allotment. So, they called and asked if I would be interested in looking at these animals and I said yes. Our whole objective was to see what happened in a range situation. This was like a controlled experiment and, no, I didn't do it, and I don't know who did. We went down there and were able to capture the domestic sheep out of three areas: the east range, the Desatoyas, and the Granites. Then we went into the bighorn population, net gunned those animals, and took samples. We've been able to get samples for 3 years from those populations.

First of all, we were wondering if there'd be a die-off and if we could substantiate the die-off, what caused it to occur, and was it the domestic sheep put in there or not. We brought the domestic sheep back alive and keep them alive and serially sampled them for 6 months. Again, it sounds like we really knew what we were doing when we were talking about *Pasteurella,* but when you streak out a tonsilar swab you may have a hundred different colonies that may look like four to five different types. We picked the predominant colonies. We did not get all the *Pasteurella* out of every throat swab that we tell you we do. So, we serially followed these domestic sheep and went in and followed the bighorn sheep. What we found surprised me in many ways. We didn't find a lot of similarities in organisms. In the east range we found there was a big die-off of bighorn sheep and until we saw five animals—that's what's in the east range now, anyway, three rams and two ewes. From 87 animals from the first year we went in there, we now have five left. So, basically, as far as I'm concerned, that's almost an extirpated population. And did we find that domestic sheep were the cause? Boy, it'd sure be nice if I could say we did, but we didn't. We did find a lot of *Pasteurella* haemolytica which is a different species of *Pasteurella* in those animals and we know it's a factor. We know it's in domestic sheep and we know it's in bighorn sheep and it seems to be the one that was probably instrumental in that die-off. So, we lost our east range contingent. We move onto the Desatoyas. In that population, we talked a little bit before about looking at the organisms according to the species they're normally found in and in the Desatoya Range, we found an A2. Now remember, we had domestic sheep in there, now we find an A2. An **A2** is the one we use as our standard for virulence on bighorn sheep. What we found was that was only (we did four animals that year) in one animal I believe at that time. There's two strata to the Desatoya Range—an upper and a lower. We found it down in the lower. I expected that the next year we'd go in and find a horrendous die-off. Well it didn't occur at that point in time. Again, it sure would have been nice if we could have documented that this organism, I mean if we were looking for incriminating evidence you're really pushing pretty hard, so we did look very hard at those animals. But what I think is the third major piece to the puzzle was in the Granite Range. There was a trespass animal from a good operation that had broken free and gotten in with the bighorn sheep. We went in and net-gunned the trespass animal, brought it out, took it back to Caine, and eventually I think it was sold at a BLM auction. Then we went into the bighorn population and sampled the bighorn. For the first time ever, and this may not sound like much to you, we found an organism that fingerprinted identically from the domestic to the bighorn. The kicker was that it was type 3, biogroup 11, probably not a pathogenic organism but I don't think that matters. We know that domestic sheep carry very virulent organisms, deadly organisms to bighorn sheep; now we know at least for whatever method of spread, we had fingerprinted an organism in both species after an interaction. On management decisions, I think we have to look at this as saying that domestic sheep have organisms that are potentially virulent.

Do all interactions between domestic and bighorns cause the demise of the bighorn? No. We have areas in Idaho where they're together every year. But, in a lot of cases and even in our experimental work, when we put the two together, within 96 hours all four of our bighorn were dead or dying. So, we now have that major piece. We've got to keep them apart. Also, can it spread in a wild situation? I don't care which way that organism went, I say that we got something to say, that organisms can pass between sheep species. To me, that's a big piece of the puzzle because we did some work with the water, you saw the water work and the temperature and all that, because we wondered if you could contaminate a water source and spread *Pasteurella* that way. That apparently isn't the way it happens. We tried it on alfalfa, to see if on the species they're browsing on if they could lick the twigs, stems, rocks, whatever bighorn sheep are eating at that time of year, could domestic sheep spread it to bighorn that way? Apparently, that's even more toxic to *Pasteurella* than water. So what you need to complete this scenario is what Bill Foreyt has said for many years: Keep them from going nose-to-nose. Does it take 20 miles to keep them from going nose-to-nose or 6 inches or 3 inches? I think the problem arises in that what we have to look at is not letting them get nose-to-nose under range conditions or under research conditions. So, we've got some pieces to the puzzle that now allow us to manage the two species.

To throw another kicker in, I think Walter who's been looking at cattle and their interaction with bighorn sheep, well you know the one that killed our sheep, the one Marie told you about, basically that's an organism normally found in cattle, but here it was in the domestic sheep before they were put in with the bighorn sheep and it did kill some domestics, but it would have killed all the bighorn. So, I think cattle could potentially carry *Pasteurella* organisms that are deadly to bighorn sheep, but why haven't we found it? Well, if you look on the hillside, I think you'll find that bighorn sheep and domestic sheep will get together. You know they're kind of curious; they do go nose to nose. But, I don't think bighorn like cows. Those of you who work on these allotments will see that bighorn sheep and cattle rarely, if ever, have been seen nose to nose. The potential is there although they do not get together. So, I think we've got another piece of the puzzle. I don't think these other species on the range are less lethal, I just don't think the opportunity is there to pass organisms.

We've done deer, elk, and pronghorn down in Nevada, and we wondered if the pronghorn might not be a carrier between domestic sheep to the pronghorn; the pronghorn don't die but carry it to the bighorn sheep. No, in our experiments we've had deer, elk, pronghorn, just about everything in and next to our bighorn sheep without any problems. So, I don't think those species on their own are of much concern to bighorn sheep. We've got to watch what we do on our management areas and realize that we've been putting a lot of time and effort into *Pasteurella* and domestic sheep and this isn't a panacea for our bighorn sheep problems on the mountainside. In Idaho, we've got wilderness areas where we don't have domestic sheep or many domestic animals at all and we have horrendous die-offs. In researching these die-offs, I was involved in the Warner Mountains when we extirpated our population out of the Warner Mountains after a potential interaction with domestic sheep. I know it happened in the Lostines, it happened in the Lava Beds in California before I got there, and apparently it happened down in the east range here. One recommendation I think you guys are going to talk about tomorrow is when to do our transplants. It seems like most of these transplants where we have extirpation of populations, I mean total die-offs because of apneumonia outbreak whether it's questioned to be livestock-induced or whether it's one of these epizootics that come through, but I think what were doing is that all of these started out with transplants of 20 to 25 animals. In the east range, it was up to 80 to 87 animals. The domestic sheep went in there and we've just about lost them all. I think when we do transplants, we have to look at transplanting bigger numbers of animals. I think we need to be looking at a little bit more genetic diversity...

(Tape problem)

...we ought to be starting out with maybe 70 to 75 animals and where we have done that, in our Wybie Canyon Range, what happens (in fact if anyone needs California bighorns, please give us a call) is that we're taking a lot of animals from our desert out there. (Taking animals is not a problem there, that's the area where the Air Force is putting in a bombing range.) There's a lot of problems out there for bighorn sheep and *Pasteurella,* in a lot of cases, is the final nail in the coffin. It might be that we can work on our management practices and if we can't put a greater number of animals in each time, augment as heavily as we can for the first 3 or 4 years so that when that population starts it's upward growth, there will be a lot of diversity in there. In the east range, of the three, four, or five animals that make it out of that die-off, it appears that the *Pasteurella* that they carry is the same one that we found that potentially killed off the rest of the animals. So maybe they have something in their own immune system that allows them to carry on. We did also get the last animal out of the Tolkein Range that is about an 11-13 year old ram. It is the last animal out of the Tolkein Range that is carrying an isolate—a cattle isolate—and this ram is not dead. We put him in with our Rocky Mountain bighorn and he's doing fine. There's a lot of questions yet to be answered; *Pasteurella* isn't the only problem out there. It may seem like the biggest one right now, but again, we have a lot of areas in Idaho where we have populations die-off, and the summer lamb mortality carrying on for 4 to 5 years, and then they come back up to a level of 80 to 100 animals. But, they don't crash to zero.

Everyone on the panel has put a lot of time and effort into these studies and we've learned a lot of interesting and boring things, but in my estimation we need to start spreading out from *Pasteurella* and looking at some of these other factors. I personally think that the livestock industry in general, in Idaho anyway, we're working together to say we're not trying to put the wool growers under. We're trying to keep sheep on the mountain and trying to remain viable as an industry. Let's look at these areas where there's a potential problem and handle them each individually by spreading it out or whatever. Also in Idaho, the evidence is strong enough that if we have bighorn sheep coming down into a domestic sheep flock, which happens quite regularly, our orders are now either to dart them and get them out of there or to kill them. If we have feral or trespass animals in with bighorn populations, instead of notifying the BLM or Forest Service and waiting 48 hours for them to pull them out, those animals are shot and sent to me. We do think that potential problems are there. I think you ought to look at that—to sacrifice two rams that come down into a domestic flock in order to save the population on the hillside. I think the evidence is there to support that.

Mike Miller - Thank you, Dave. Part of the reason I wanted Dave to finish up is because I knew he'd raise more questions than he'd answer. I want to reemphasize some things he mentioned, especially the idea of no contact between bighorn and domestic sheep. We've certainly had a couple of cases I know of in Colorado where bighorn that have spent time with domestic sheep have been captured and returned to the nearest herd of bighorn sheep. In one case at least, the animal died fairly soon after it was moved; in the other case, we don't know what happened. But, it's a very dangerous practice and I don't know of any place, at least in our state, where we have that desperate a need for single rams that we can afford to run that risk. If we really believe that this has high potential for transmission and for loss of a population, I just don't think it's a risk we can afford. But it does go both ways. We can't expect livestock to stay off of bighorn ranges, but to cut a lot of slack for bighorn sheep that tend to wander off and go places where they shouldn't isn't acceptable either. Tom Porter and I, several years ago, wrote a letter that ended up in the American Association of Wildlife Veterinarians newsletter. One of the things that we recommended was essentially having no-sheep zones in some of these places where, no matter which species it is, if they show up in these areas where there's potential for them to go back and intermix with a wild, free-ranging herd, that those animals not be allowed to survive.

Another thing I want to mention and I'm sure it's going to be covered in more detail tomorrow is the idea of translocations. What Marie mentioned earlier in terms of the tremendous variety of diseases and strains of *Pasteurella* among wild sheep herds in Idaho, we've also been seeing in Colorado. In contrast to some of Bill's work, we have isolates that appear to be pathogenic, at least according to the neutrophil toxicity assays we've been running. In healthy bighorn sheep and also in dead bighorn sheep, one of the things I've grown real concerned about in looking at trapping and transplanting is the way we've been behaving with some of that over the last 20 years or so. How many of these problems have we actually brought on ourselves by moving bighorn sheep and intermixing bighorns in areas where we may be the ones bringing novel pathogens in by moving bighorn sheep from one place to another. Again, it cuts both ways and we need to be as careful as the other entities we're asking to be responsible in terms of preventing disease introductions. Thanks largely to Kerry Swagert's efforts, we have a great wealth of information on health and exposure to a variety of pathogens for most of the bighorn herds in Colorado that we use as donor herds. Unfortunately, we haven't always paid a lot of attention to where we move those sheep, but I think as we start talking about metapopulation management, genetic supplementation, and some of these kinds of things, the potential impacts of novel disease introduction are things that really need to be weighed in there in a cost-benefit-type approach. With that, I'd like to go ahead and open this up to questions. They want to get the questions and answers on tape, so holler your questions really loud. I'll repeat the question, then I'll hand the microphone to someone on the panel to answer. If you want a general answer that's fine. If you have a specific individual you're targeting with your question, that's fine too.

QUESTION AND COMMENT PERIOD

(Comment/question from audience)

Mike Miller - I'm going to summarize and paraphrase what was just said. Basically, the comment was that there are places in the southeastern comer of Utah where cattle and sheep, over a number of decades, probably developed sympatric uses of range where they actually separate themselves in space. Yet just across the border in Colorado, with a recent transplant, there's a situation where some transplanted desert sheep are actually interacting in an area with cattle. It sounds like it's partly due to operating with other, supplemental feed. I guess another point to make would be that traditional movement patterns and range uses of established sheep herds are going to be very, very different from transplant herds. Another reason we see so many more problems in our transplant herds could be because some of the patterns that may allow for this separation may just go completely out the door when you start moving animals into novel environments and into places where they don't know where they should and should not go. Places where they haven't been selected for going or not going.

(Comment/question from audience)

Mike Miller - The comment was that in California's experience with desert sheep transplants there are a variety of mortality factors including predation, accidents, etc., that can lead to the demise of the transplant herd, and that simply talking about genetic diversity with respect to disease resistance may be something to think a little bit longer and harder about. I guess I would tend to agree. Small populations are likely to become extinct. There's just not anything good to say about tiny populations over long periods of time and it doesn't really matter what kills them I guess. They just don't do well. It seems like, from my perspective anyway, if we're going to spend the time and energy moving sheep or any other species for the purpose of starting new populations, we certainly owe it to them to try and give them a population size that will ultimately be viable. I don't know if I completely agree with the magic number being 50 or 100 or whatever, but the point is well taken that there are a lot of things that can contribute to bighorn demise. I think the metapopulation approach with respect to mixing sub-populations of animals that may be exposed to different groups of pathogens does have some potential for leading to problems with disease.

Walter Boyce - I'd like everyone to save all their interesting questions about transplants until after tomorrow's panel, otherwise we're not going to have much to talk about then.

(Comment/question from audience)

David Hunter - Dick Weaver's question to me was concerning the areas in Idaho where we had bighorn sheep come into contact with domestic sheep populations. This occurs very frequently, at least once a year in our Salmon-Challis area. These are normally young rams that come down into a band of ewes and they seem to do it every summer with regularity and it's not always the same sheep. I questioned what happened there too. We've gone over and taken a lot of samples from that area, and we do indeed have samples that do not show any compatibility. We have no A types. We have none other than what we consider the normal flora in our bighorn sheep there. Again, we believe strongly enough now, that that's such a potential problem that we do indeed take those animals when they're seen with domestic sheep. So, I'm not saying that it's not a problem but that we've just not found a problem associated with it. Realistically, in these ram bands, some of these *Pasteurella* may be so hot that the rams won't make it back by breeding season alive to the ewes that need to be bred. Again, that's speculation.

Terry Spraker - Let me interject a statement here because there seems to be confusion in regard to goats and llamas. How many of you have experienced an increase in utilization of goats or llamas being used as pack animals? This is becoming an increasingly frequent request. We have primarily talked about *Pasteurella*, however there are numerous other pathogens that eventually may turn out to be important. I would like to hear what the other panelists would say specifically in regard to pack animals.

The answer to your question, Amy (New Mexico Game and Fish), is Johne's disease. Johne's disease has been found in llamas by several veterinarians at Colorado State University. However, goats with Johne's disease may be more of a problem. Goats may or may not show diarrhea. Goats can easily be shedders of the organism for extremely long periods of time without showing any clinical signs, so they could easily spread the disease. We do not have very much information about caprine arthritis/encephalitis of goats as far as its transmissibility to bighorn sheep. At the present time, we have no evidence that this disease of goats has been transmitted to bighorn sheep.

Marie Bulgin - I would wonder too about the contact. I think a domestic goat and a wild sheep might very well come into contact, because we do know that they breed with domestic sheep. So I think there might be the same contact you'd have between domestic sheep and wild sheep.

(Comment/question from audience)

Mike Miller - The question basically was that most of the discussion has focused on pasteurellosis which is a disease that we all agree requires fairly intensive, direct contact between domestic animals and whatever species of bighorn sheep. We're being asked to address some of the other arthropods and possible airborne pathogens that could also be equally important in terms of disease problems in bighorn herds.

Terry Spraker - The disease in question is blue tongue. The actual distance that the blue tongue virus can be spread is not known. The distance would be dependent on the distance that the *Culicoides* species of gnat could fly, since they are the primary vectors for transmission of this disease. If they are caught in the right types of winds, these organisms probably could be spread for miles. We have seen one instance where we had bighorn sheep in captivity near Fort Collins. There were domestic sheep about 3 or 4 miles away from this bighorn sheep enclosure. Two of the animals died during one summer due to blue tongue. There was a suggestion that the blue tongue may have been transmitted from these domestic sheep. To date, we have not seen blue tongue in the free-ranging bighorn sheep. However, blue tongue has been diagnosed and is considered to be an extremely important disease of desert bighorn sheep. The other part of the question, in regard to Johne's disease, is that this organism is deposited on the ground and can remain on the ground from up to 6 months to 1 year depending on the alkalinity and type of soil. Contagious ecthyma is another viral disease of domestic sheep that can be transmitted to bighorn sheep. This organism can remain on the ground in specific circumstances for up to 20 years without losing virulence.

Bill Foreyt - The one arthropod-transmitted disease that we worked with was anaplasma. We found that anaplasma can kill bighorn sheep fairly easily. So ticks from cattle or possibly from sheep, after they fall off that animal, can transmit it to bighorn sheep.

Walter Boyce - Let me follow up on the anaplasma situation in our sheep in California. In the desert regions, bighorns commonly had antibodies to anaplasma. This is true in areas where there are cattle-grazed allotments; it's also true in areas where there are no cattle-grazed allotments. When you move into some of the higher elevations, where the tick species that occur on sheep change, we don't see anaplasmosis in bighorn sheep or cattle even if they occur together. So, you have to look at it on a case-by-case basis.

Another arthropod, just to bring it up, is the scabies mite. Once again, in the situation in the San Andres, was that mite there prior to the late 1970s or was it introduced and has it now become established in the environment, perhaps on deer? Essentially it's there now and for forever. The sheep that are there are going to have to deal with it. That's an issue we would really like to resolve. Another way to think about this, and it goes back to something I said we shouldn't talk about until tomorrow, is transplants.

That is that you may only have the opportunity to make certain mistakes one time. If you introduce an infectious disease that becomes established in the environment, regardless of whether or not the sheep that were there survive initially, you may never be able to put sheep there again. With something like *Pasteurella,* if you get rid of domestic sheep and bighorn sheep, it seems like okay, we can kind of start over, we have a clean playing board. But, that's not necessarily the case when we're talking about some of these arthropods, bug-borne viruses, and other infectious disease agents that can persist out in the environment. So if we're going to err, we should err on the side of caution, because often times you introduce things you'll have problems you can't deal with down the road.

(Comment/question from audience)

Mike Miller - Two-part question. I'll try to remember both parts. The first part was relative to the applicability of the experimental work that has shown that these *Pasteurella* isolates don't survive for very long in filtered water and in distilled water, when in fact in most of the situations where domestic sheep and bighorn sheep share a water source, the water source is somewhat less pure than might otherwise be related in these experiments. The idea is that perhaps these organisms can survive in soil or in situations with high sediment content, in bottom sediment layers, or in situations where there may be high organic matter content in water, if in fact that would aid *Pasteurellas* in surviving. We'll let Marie answer that one. The second part of the question was regarding horses and burros and the fact that nobody's really mentioned any potential pathogens of horses or burros that could be problematic to bighorn sheep.

Mane Bulgin -Yes, you're right, they generally don't drink filtered water or distilled water. That was to get rid of some of the organisms that would make it difficult to find *Pasteurella* such as proteus that spreads across plates. I think *Pasteurella* is a very poor competitor in the environment and my guess would be, although I can't back it up with the data, that in the water, without being filtered, *Pasteurella* would live even less long. As far as living in sediment, it's an aerobe which means it needs oxygen. I don't think it would compete very long in depth of sediment; however, we are going to look at mud, thinking possibly that in muddy, shallow, cool areas it might survive for a longer period of time. I can't comment on whether it might or might not. I really don't know.

As far as burros and horses go, actually they don't, unless one of you can think of some organisms that they share. Generally, they don't share too many organisms. The ruminants and the monogastrics seem to have their own set.

Bill Foreyt - The horse is next on our list of animals and I think it's the last one we're going to be checking. So hopefully next month, we'll have horses in with our bighorn sheep. They do have *Pasteurella haemolytica.*

Mike Miller - I guess I would just add a note of agreement with what Marie has said. Based on some of our experimental work with *Pasteurella* isolates under different laboratory conditions, one of the things we had to do to improve our ability to recover *Pasteurella* from bighorn sheep was to cut down the competition with other bacteria. They seem not to do particularly well, in at least media-type situations, where there's any opportunity for other bacteria to overgrow them. Colder temperatures may somewhat offset that, certainly, but they don't tend to be particularly good competitors outside the host. Even inside the host, in some cases, they don't compete very well. So, they're a relatively fragile organism compared to some of the other things we've talked about.

(Comment/question from audience)

Mike Miller - ...conjunctivitis in mule deer. I believe it is mule deer in Zion National Park that actually get two agents of bacteria, moraxella and also chlamydia that are involved. To date it is not spread into the desert sheep as I understand it, but the question is, first of all, how long is that likely to persist and in terms of maybe bringing other sheep in or using these sheep as a source of animals for other places, what kind of period of watching and waiting is necessary? I know that there have been a couple of fairly recent cases where moraxella has been isolated in pneumonia outbreaks. Probably the most significant one is the Whiskey Mountain die-off several years ago in Wyoming where they lost several hundred sheep and moraxella was the primary bacteria that was isolated from the dead animals. There have been some outbreaks of chlarnydiosis in bighorn sheep. I know that Terry's had some experience with some in Colorado and there was a pinkeye outbreak in Yellowstone in Rocky Mountain bighorns about 10 years ago.

David Hunter - In Idaho, of the first 93 animals that came out of one of our hunting units, 91 had lesions that were pinkeye-type lesions. We did culture out bronomello, which used to be moraxella, but taxonomists like to break things apart. Well, again, this one hit that population very hard. We went back in the spring and sampled some animals and we did hunter surveys coming out the next year and it was cleared up. The reason we believe it was in there that year was because we had an Indian summer type condition where we had a large gnat and fly bloom right around hunting season. What happened was that some of the animals weren't taken off the grazing allotment, and it was during a drought year, so they were all concentrated in one area. We have not found it since. We have not found any wildlife reservoir for those organisms at least in the eyes of the animals that have come out in the **3** years preceding that. But, it was up in the 95 percent range that the animals had severe lesions, corneal apastacices, and the whole bit from the organism. It seems like we lost the necessary conditions. The winter came on and we took away the carrier animals. We don't believe it was in that deer population.

Terry Spraker - In regard to the question dealing with chlamydia and bighorn sheep—Yes, we have seen a variety of conditions with this organism. We have seen a mild, upper-respiratory problem in captive sheep that clinically looked like a mild bacterial or viral pneumonia, and in this instance, the animal spontaneously recovered. In this instance, chlamydia was isolated; however, viral and bacterial organisms were not isolated in this particular incidence. We have seen herds of free-ranging bighorn sheep with antibodies to chlamydia and in these herds occasionally you would see animals with ocular lesions. These animals had a form of keratoconjunctivitis. We have also seen a type of keratoconjunctivitis in deer; however, chlamydia could be part of this syndrome in deer, but we have also isolated a bacteria called *Moraxella* species. Therefore, I think that both wild and domestic animals can be carriers of chlamydia. Therefore, the importance of chlamydia in free-ranging bighorn sheep populations is not known at the present time; however, I think in some situations it can be pathogenic, whereas in other situations, it carries a relatively low pathogenicity. I think there has only been one isolated instance where chlamydia was isolated from an aborted bighorn sheep fetus. This was done, I think, in the mid-sixties by Jim England.

Mike Miller - I don't think we've really answered your question, so maybe I'll stick my neck out and take a stab at it. Since you haven't seen problems in—and I got a little bit lost on which way you were talking about moving animals, whether you were talking about bringing sheep in to supplement this population or the other way around—the fact that the disease has been present for 2 years in deer and hasn't been seen yet in your bighorn sheep may just be luck or it may be a function of what we've been talking about in terms of direct contact.

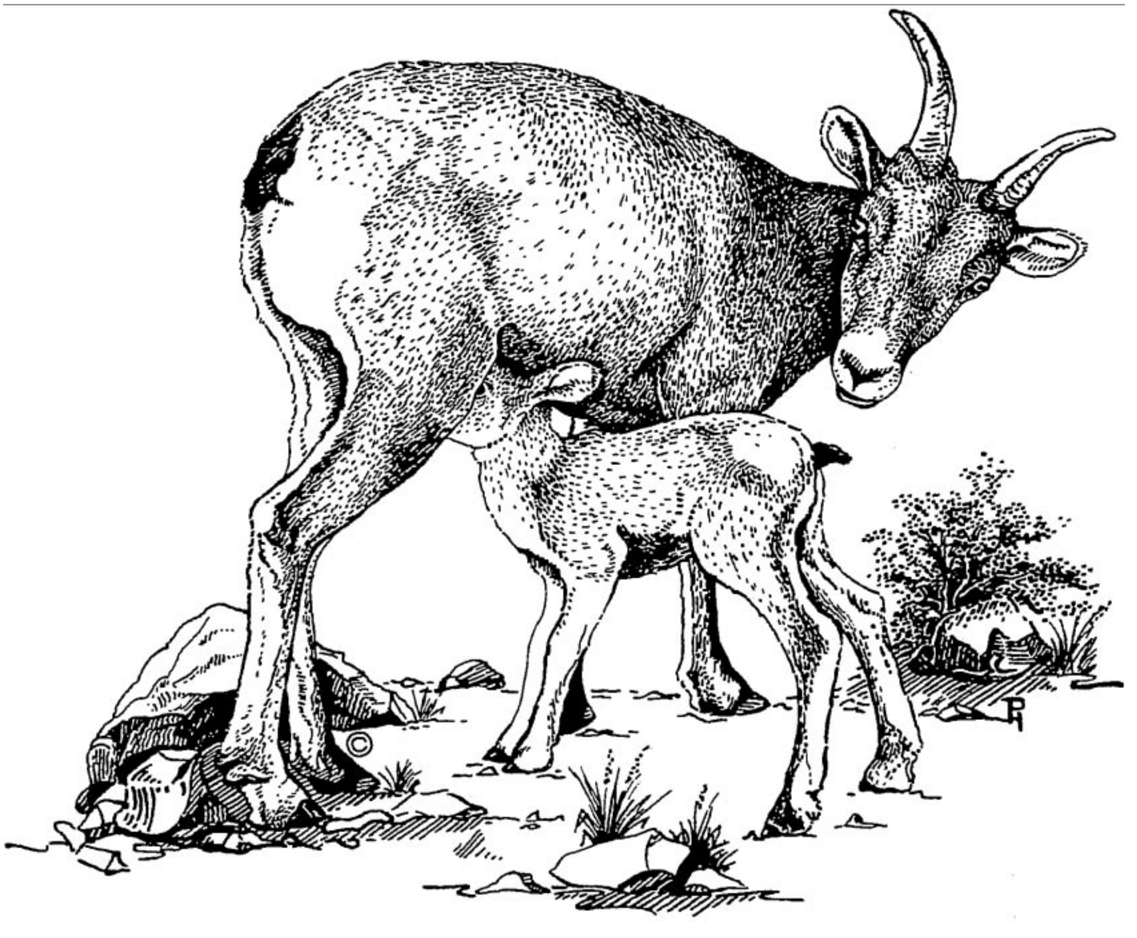
Frank, are those sheep some of the sheep that have been sampled as part of the Park Service survey work and have we seen any evidence of conjunctivitis in any of the sheep that have been sampled there? I know we've see titers to chlamydia. As Walter said, titers don't really prove much of anything except that the animal may have been exposed to something at some point along the line. But I know that we've seen titers in just about all of the herds that we've sampled for chlamydia. We have not been looking specifically for moraxella or moraxella titers. I think there is some likelihood, as we mentioned earlier, with translocated animals. We're going to hear more about this tomorrow—that as they spread and wander and go places that you may not expect them to, that they could certainly come into contact with them. It really depends on how badly you want more sheep in there and what you're willing to risk I guess. If it were me calling the shots and these were bighorn sheep from a surplus area and all other things were equal, this was the only thing you were worried about, the potential for them getting chlamydia or moraxella from these deer, I guess I wouldn't worry a whole lot about it with respect to some of the other potential problems you might run into.

If you had the luxury of waiting, you could wait until you stop seeing the large scale problems in mule deer. That would probably be the most prudent thing to do. Maybe also give it another year or two and see if it's ever going to get into your bighorn sheep if you have that kind of time to wait. I agree with Terry, there are places in Colorado where we see these kinds of things on pretty much a yearly basis if enough people are looking. It seems to be in deer and we don't really see it in much of anything else. The extent to which some of these things may be more host-specific then we might realize, we just haven't looked at all the things that are out there. It's great job security for the people who are doing disease work because there's many more things to look at than anyone has the time to do right now. So if you have the time to wait, you might watch existing herds and see what happens. I guess that's because there's some likelihood, from my perspective, that the transplanted herd, for several reasons, might end up being more susceptible to becoming infected with this problem. If that happens, going from one group of bighorn sheep to another group of bighorn sheep is probably much more likely than going from a group of deer to a group of bighorn sheep.

(Comment/question from audience)

Mike Miller - I guess the only comment I would add is if that is a private land situation, it would probably be more incumbent on the responsible agencies to keep their bighorn sheep off that private land by whatever means necessary. I think that's a situation where you really get into some difficult issues with respect to private land use and civil rights. That's a case where, yes, there'd certainly be some potential for concern, but it's going to be much more the responsibility of the agency to try to keep those things from happening.

If those are all the questions, I want to thank all our panel members, some of whom have traveled quite a long way to get here. And, I want to thank all of you for some good questions.



PROGRAM 39th ANNUAL MEETING
DESERT BIGHORN COUNCIL
ALPINE, TEXAS, APRIL 5-7, 1995

WEDNESDAY, APRIL 5, 1995

7:30	**REGISTRATION**
8:30	**WELCOME** AND **INTRODUCTIONS**
9:15	**SESSION I - STATE STATUS REPORTS** Chairperson - *Rick Brigham*, Bureau of Land Management, Carson City, NV Arizona California Colorado Nevada New Mexico Texas Utah
1:00	**SESSION II - POPULATIONS, DISTRIBUTION, AND MOVEMENT** Chairperson - *Pat Cummings*, Nevada Department of Wildlife Eagle Mountain Bighorn - An Update Migration Incentives for Desert-Dwelling Mountain Sheep Ewes Distribution, Movements, and Mortality of Rocky Mountain Bighorn Sheep in Arizona
2:30	**SESSION III - HABITAT ANALYSIS AND SURVEYS** Chairperson - *Steve Torres*, California Department of Fish and Game Modification of Cunningham's Habitat Evaluation Model for Desert Bighorn Sheep GIS Analysis of Desert Bighorn Sheep Habitat in the Trans-Pecos, Texas Evaluation of Desert Bighorn Sheep Habitat and Food Habits in the Sierra Diablo, Beach and Baylor Mountains, Texas Visibility Bias in Bighorn Aerial Surveys
4:20	**SESSION IV - TURKMENISTAN** Chairperson - *Steve Torres*, California Department of Fish and Game Biogeography and Ecology of Turkmenistan

THURSDAY; APRIL 6, 1995

8:00 **SESSION V - POPULATION MANAGEMENT AND CONSERVATION**
Chairperson - *Raul Valdez*, New Mexico State University

Rapid Extinction of Mountain Sheep Populations Revisited

Metapopulation Concepts and Their Application to Mountain Sheep Conservation

Management of Desert Sheep Within Ecoregion Planning and Management Concepts

9:45 **SESSION VI - INTERNATIONAL SHEEP CONCERNS**
Chairperson - *Ray Lee,* Arizona Game and Fish Department

Wild Sheep (Ovis orientalis arkal) in Turkmenistan: Current Status and Conservation Problems

Population Density of Desert Bighorn in Northern Baja California (Canadas Arroyo Grande and Jaquejel)

Desert Asiatic Wild Sheep Conservation

Develop Supporting Model for the Management and Administration of the Borrego Cimarron in Baja California Sur. Mexico

1:00 **BUSINESS MEETING**

FRIDAY, APRIL 7, 1995

8:30 **FIELD TRIP TO ELEPHANT MOUNTAIN WILDLIFE MANAGEMENT AREA**

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DESERT BIGHORN COUNCIL MEETINGS 1957- 1995

Year	Location	Chair	Secretary-Treasurer	Transactions Editor
1957	Las Vegas, NV	M. Clair Aldous		
1958	Yuma, AZ	G. Monson & W. Kelly		
1959	Death Valley, CA	M. Clair Aldous	Fred Jones	
1960	Las Cruces, NM	Warren Kelly	Fred Jones	
1961	Hermosillo, Mexico	Jon V. D. Akker	Ralph Welles	
1962	Grand Canyon, AZ	James Blaisdell	Charles Hansen	C. Hansen & L.Fountein
1963	Las Vegas, NV	Al Ray Jonez	Charles Hansen	Jim Yoakum
1964	Mexicali, Mexico	Rudolfo H. Corzo	Charles Hansen	C. Hansen & D. Smith
1965	Redlands, CA	John Goodman	John Russo	Jim Yoakum
1966	Silver City, NM	Cecil Kennedy	John Russo	Jim Yoakum
1967	Kingman, AZ	Claud Lard	John Russo	Jim Yoakum
1968	Las Vegas, NV	Ray Brechbill	John Russo	Jim Yoakum
1969	Monticello, UT	R. & B. Welles	W. Glen Bradley	Jim Yoakum
1970	Bishop, CA	William Graf	W. Glen Bradley	Jim Yoakum
1971	Santa Fe, NM	Richard Weaver	Tillie Barling	Jim Yoakum
1972	Tucson, AZ	George Welsh	Doris Weaver	Charles Hansen
1973	Hawthorne, NV	Warren Kelly	Doris Weaver	Juan Spillet
1974	Moab, UT	Carl Mahon	Lanny Wilson	Juan Spillet
1975	Indio, CA	Bonnar Blong	Lanny Wilson	Juan Spillet
1976	Bahia Kino, Mexico	Mario Luis Cossio	Lanny Wilson	Charles Douglas
1977	Las Cruces, NM	Jerry Gates	Peter Sanchez	Charles Douglas
1978	Kingman, AZ	Kelly Neal	Peter Sanchez	Charles Douglas
1979	Boulder City, NV	Bob McQuivey	Peter Sanchez	Charles Douglas
1980	St. George, UT	Carl Mahon	Peter Sanchez	Charles Douglas
1981	Kerrville, TX	Jack Kilpatric	Peter Sanchez	Charles Douglas
1982	Borrego Spgs., CA	Mark Jorgensen	Rick Brigham	Charles Douglas
1983	Silver City, NM	Andrew Sandoval	Rick Brigham	Charles Douglas
1984	Bullhead City, AZ	Jim de Vos, Jr.	Rick Brigham	Charles Douglas
1985	Las Vegas, NV	David Pulliam, Jr.	Rick Brigham	Charles Douglas
1986	Page, AZ	Jim Guymon	Bill Dunn	Paul Krausman
1987	Van Horn, TX	Jack Kilpatric	Bill Dunn	Paul Krausman
1988	Needles, CA	Vernon Bleich	Donald Armentrout	Paul Krausman
1989	Grand Junction, CO	Jerry Wolfe	Donald Armentrout	Paul Krausman
1990	Hermosillo, Mexico	Raul Valdez	Donald Armentrout	Paul Krausman
1991	Las Cruces, NM	Bill Montoya	Donald Armentrout	Paul Krausman
1992	Bullhead City, AZ	Jim de Vos, Jr.	Stanley Cunningham	Paul Krausman
1993	Mesquite, NV	Kathy Longshore	Charles Douglas	Walter Boyce
1994	Moab, UT	Jim Guymon	Charles Douglas	Walter Boyce
1995	Alpine, TX	Doug Humphries	Charles Douglas	Ray Boyd