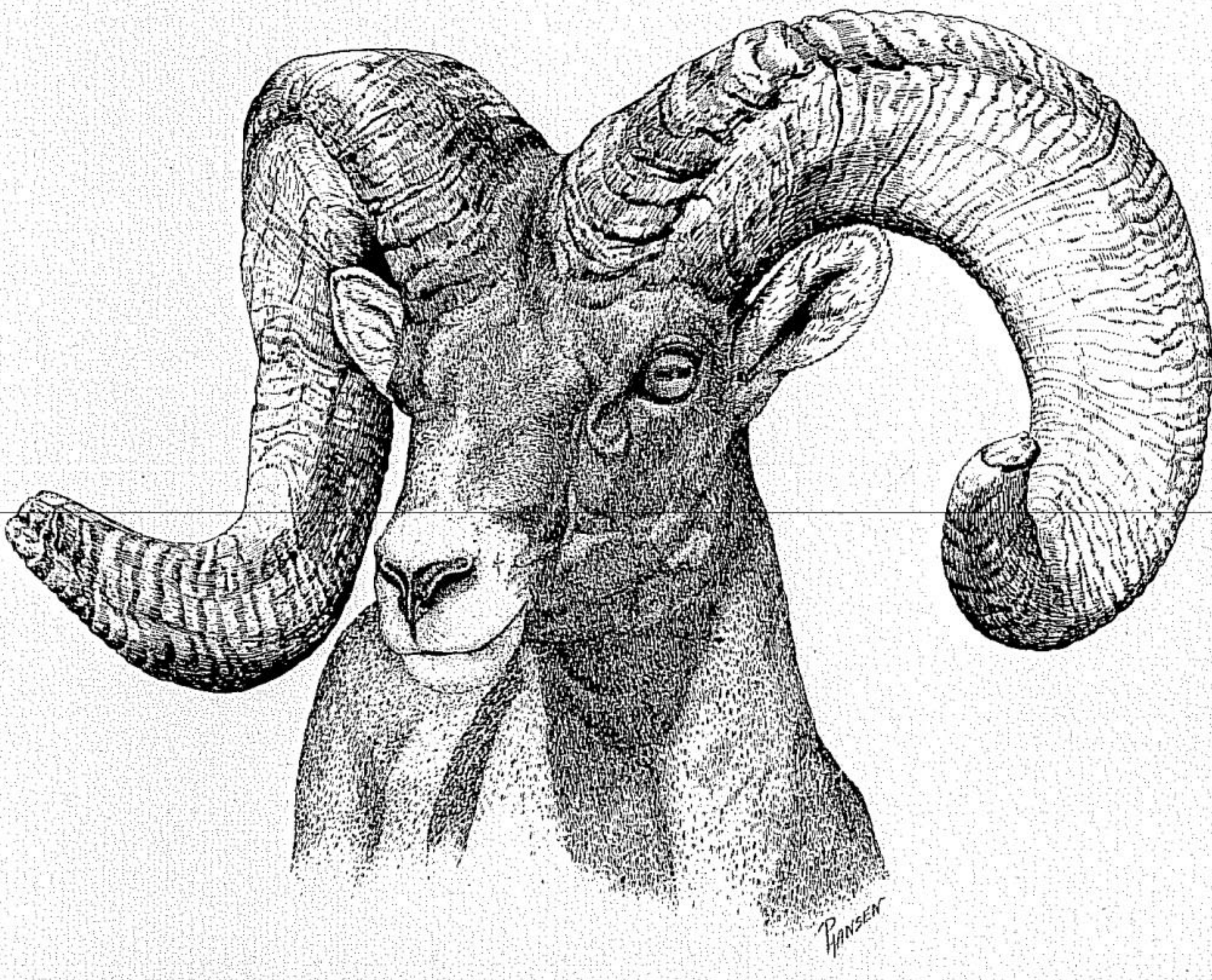
DESERT BIGHORN COUNCIL TRANSACTIONS



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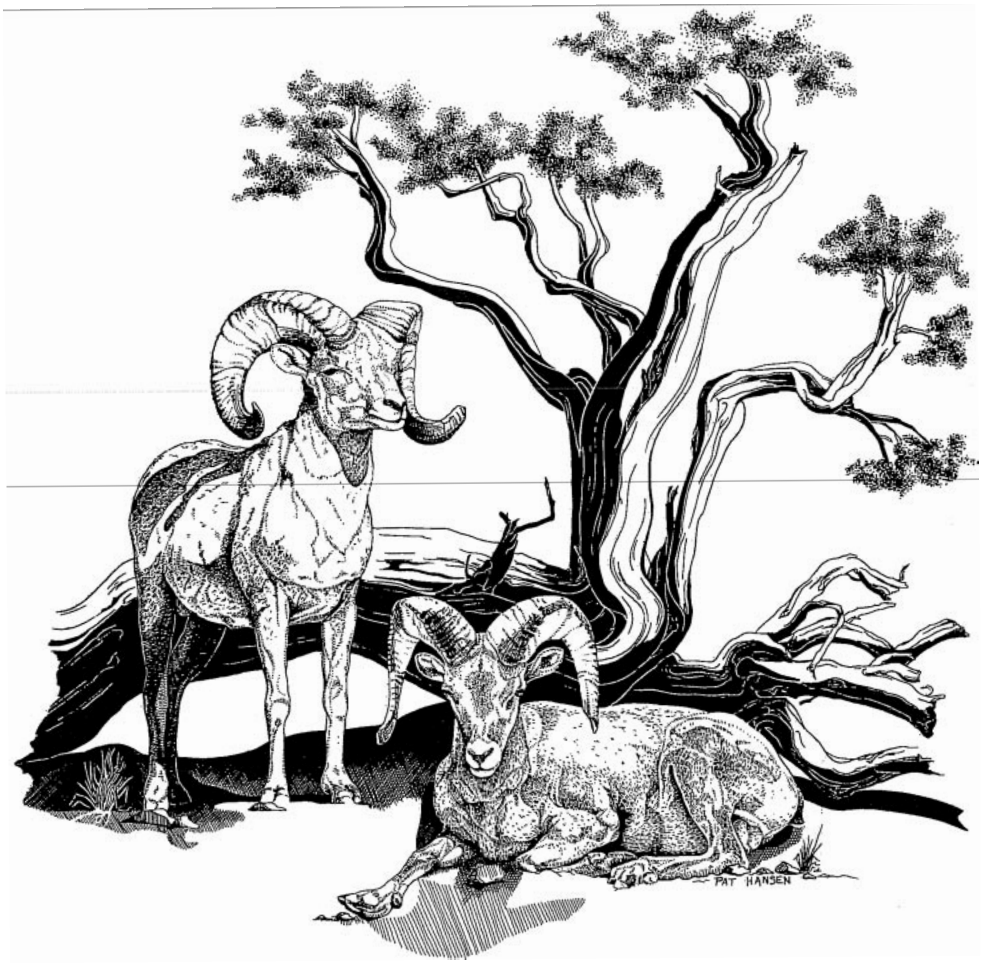

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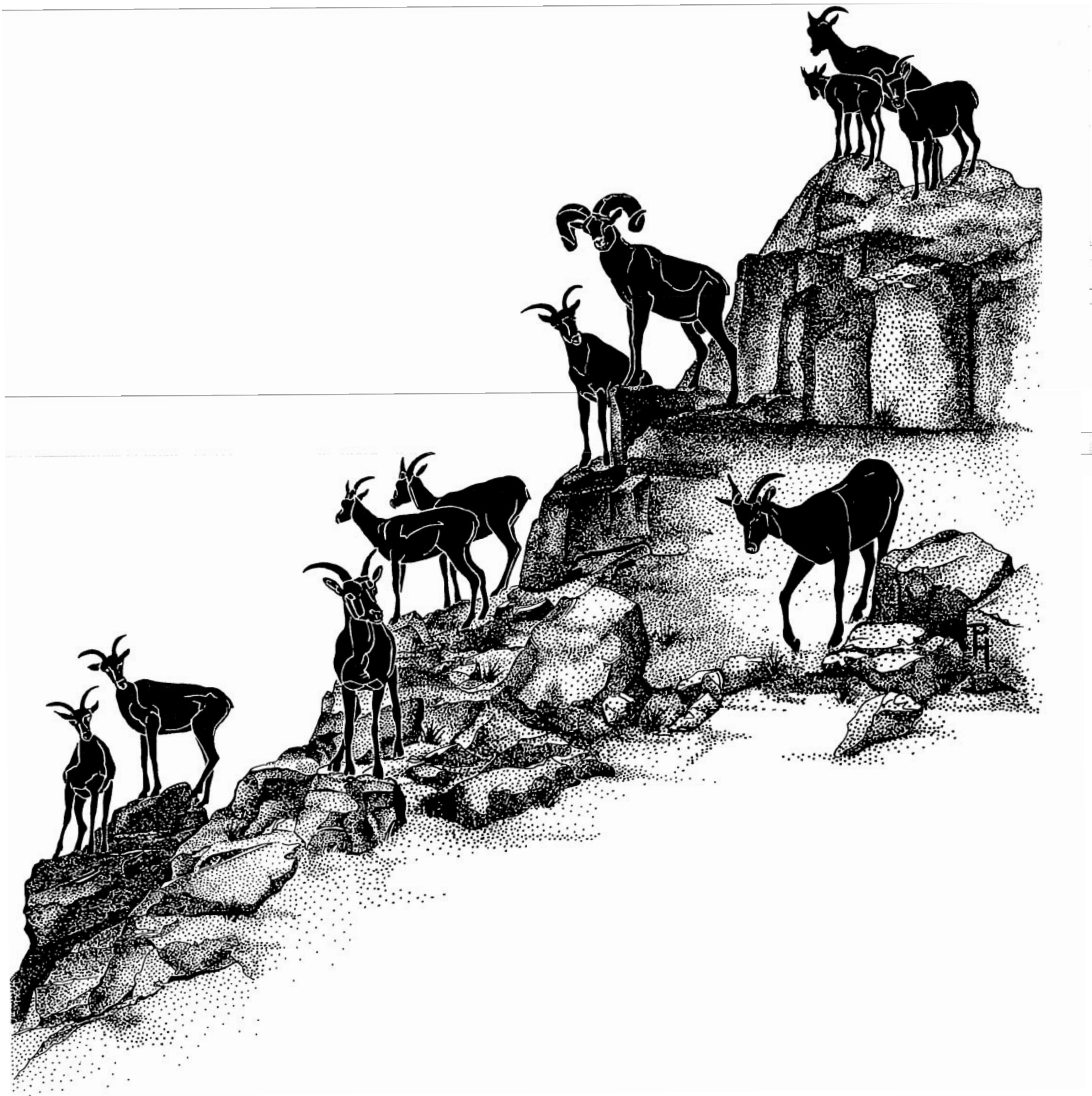

MEASURING VISUAL OBSTRUCTION CAUSED BY DISCRETE OBJECTS IN BIGHORN SHEEP HABITATS

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Desert Bighorn Counc. Trans. 36:1–3.

Abstract: Methods for measuring visual obstruction in bighorn sheep (Ovis canadensis) habitats are not clearly described in the literature, permit inter-observer differences and observer-expectancy bias, and may produce data with poor statistical properties. We propose solutions for some of these problems in measuring visibility in pinyon (*Pinus edulis*)/juniper (Juniperus spp.) habitats.

Key words: bighorn sheep, computer simulation, habitat evaluation, Ovis canadensis, visibility.

Visibility, or lack of visual obstruction by tall trees, shrubs, or rocks, is an important habitat characteristic for bighorn sheep. Bighorn behavior has been related to visibility (Risenhoover and Bailey 1980, 1985; Hansen 1982) and the value of visibility is recognized in habitat-evaluation models (Hansen 1980, Holl 1982, Armentrout and Brigham 1988). In research and management applications (e.g., habitat evaluation) it may be necessary to measure visibility in the field or from aerial photographs of vegetation.

The method of Risenhoover and Bailey (1985) is commonly used for quantifying visual obstruction in bighorn habitats (Armentrout and Brigham 1988, Dunn 1991, Haas 1991). Risenhoover and Bailey (1985) measured percent visual obstruction subjectively by standing in the center of an area to be evaluated and estimating the percent of the surrounding 360 degrees for which an object 90 cm tall and 40 m away could not be seen. The area to be evaluated was either the center of a patch of habitat or the center of an area used by a group of sheep. Risenhoover and Bailey (1985) did not specify how they selected the center of this area; however, they avoided standing very close to, or within the crowns of, trees (J. Bailey, pers. commun.). Varying the degree to which trees are avoided can produce large effects upon resulting estimates of visibility. An alternative for selecting plot centers is to use the location of one bighorn chosen at random from a band of sheep. This method cannot be used for evaluating habitat without sheep; may require unwanted disturbance of animals; and may require subjectivity in choosing the exact time at which the randomly-chosen bighorn is located.

Visual obstruction might be measured objectively using numerous placements of a "density board" (Gysel and Lyon 1980:316); but this method greatly increases the time needed to measure each plot, even if 2 workers are used. Risenhoover and Bailey (1985) chose subjective estimation of visual obstruction for its efficiency in documenting large differences among habitats. Subjective location of plot centers, and subjective evaluation of visual obstruction, permit inter-observer differences, and perhaps observer expectancy bias (Balph and Balph 1983), that may be important when evaluating visual obstruction.

We offer a method based on computer simulation for measuring visual obstruction of habitats that (1) minimizes the importance of determining the "center" of an area to be evaluated; (2) is based upon objectively measured densities and widths of trees or other discrete objects; and (3) allows estimation in the field or, in some habitats, from aerial photographs. The method is especially applicable to pinyon/juniper habitats on relatively smooth slopes where visibility is not obstructed by abrupt changes in topography, such as across a plot of 20 m radius. We also used this method to investigate relationships between distributions and densities of discrete vision-obstructing objects and resulting visibility data.

This study was part of a larger project funded by the U. S. Bureau of Land Management, the Colorado Division of Wildlife, the Rocky Mountain Bighorn Society, the Foundation for North American Wild Sheep, and the Colorado Wildlife Heritage Foundation.

METHODS

Program TSIM (Appendix) is a mathematical algorithm that calculates the visual obstruction produced by simulating a random placement of a given number of vision-obstructing objects in a circle of given radius. It applies when visual obstruction in a habitat is produced primarily by objects of similar diameter (i.e., trees and/or boulders). Program TSIM was developed for measuring visual obstruction in pinyon pine/juniper/rock habitats in the Dolores River Canyon near Slickrock, Colorado. It specifies that the center of the circle, for which visual obstruction is being measured, be at least a given distance from the nearest vision-obstructing object. In the Dolores River Canyon, 6 m was used. This was the mean distance from the nearest visual obstruction $\geq$1 m tall for bighorn sheep observed in the Canyon during 1990–91 (n = 177).

Program TSIM will accommodate study areas with different visibility characteristics. Use of a circle >20 m is suggested for comparing especially open habitats. If there is important variation in the sizes of vision-obstructing objects, TSIM may be modified to use a frequency distribution of object diameters.

Program TSIM uses the average width at 1 m high of vision-obstructing objects, and a frequency distribution of the number of objects, within circles of a given radius. The program calculates expected percent visual obstruction values (Fig. 2) from successive random placings of the given number of objects in the circle. The densities of vision-obstructing objects may be measured from plots in the field or from aerial photographs. The average width of objects at 1 m above the ground may be measured in the field; and perhaps from aerial photographs, depending upon the shapes of the objects.

We randomly located $\geq$22 points within each of 4 habitats in the Dolores River Canyon (Table 1). From each point, we estimated the percent of each quarter of the compass over which an object 1 m tall and 20 m away could not be seen. We ignored visual obstructions within 6 m of the observers, and above or below 1 m tall. The average of 4 percentages was the visual obstruction for the plot. We also counted the number of trees in each plot.

We measured tree diameters, at 1 m above ground, on transects at representative locations in the Canyon. Each transect began at the base of a slope and extended upslope to an impassable cliff face, or to the rim of the Canyon. We measured trees within 3 m of the transect (>15 trees per transect). We chose this method to test if average tree diameter varied with elevation in the Dolores River Canyon. It did not. (Tree diameters may also be measured on plots, or on aerial photos.) The average diameter of these trees, 2.54 m (n = 58), was used in subsequent TSIM simulations.

For each of 4 habitats, the frequency distribution of the number of

Table 1. Comparison of visual obstruction (vis. obstr.) in 4 habitats of the Dolores River Canyon, Colorado, as measured subjectively in the field and as predicted by program TSIM.

	Open areas[a]	Sparse pinyon-juniper	Medium pinyon-juniper	Dense pinyon-juniper
Subjective estimation[b]				
No sites	22	28	26	41
Vis. obstr. (%)				
Mean	10.3	52.5	70.2	96.1
Median	2.5	52.5	70.0	98.8
Range	0-45	20–85	38–95	76–100
Skewness	1.32	0.21	−0.24	−1.61
TSIM estimation[c]				
No. sites	400	400	400	400
Vis. obstr. (%)				
Mean	17.0	56.1	75.1	91.0
Median	16.6	56.9	75.5	92.1
Range	0–49	34–81	51–97	68–100
Skewness	0.26	0.03	−0.13	−0.55

[a] Tree densities per 20 m radius circle: open areas, <20; sparse pinyon-juniper, 20–39; medium pinyon-juniper, 40–59; dense pinyon-juniper, ≥60.

[b] Estimated by viewing a 20-m radius from each plot center, excluding trees <6 m from the viewer.

[c] Estimated by computer simulation, using mean tree diameter at 1 m high and a frequency distribution of tree densities/plot.

trees/20-m radius plot and the average tree diameter were entered into TSIM for 400 simulations of random placements of the trees. Frequency distributions of the resulting visual obstruction values were compared to distributions of the values estimated subjectively.

RESULTS

Results using program TSIM were similar to results based on field observations (Table 1). For each habitat, the difference between mean visual obstruction values, based on TSIM and on field observation, was <7%. These means were highly correlated (r = 0.99) with a slope of 1.09. Distributions of observed and simulated visual obstruction values were similar, as indicated by similar medians, skewness coefficients and ranges (Table 1).

However, both data sets (Table 1) demonstrate that visual obstruction is not normally distributed in the most open and the most dense pinyon/juniper habitats. Rather, data are skewed away from 0% and 100%, especially in data from subjective estimation in the field. Greater skewness of data from subjective estimation may be due to observer bias or to a tendancy for trees to be clumped in open areas and to be dispersed evenly in areas with high tree densities. However, the tendency toward asymmetrical visual obstruction data exists even when trees are distributed randomly by program TSIM (Table 1).

Program TSIM also demonstrated (1) a non-linear relationship between the density of discrete objects and visual obstruction (Fig. 1), and (2) the bimodal distribution of visual obstruction data resulting from considering objects near to plot centers (Fig. 2).

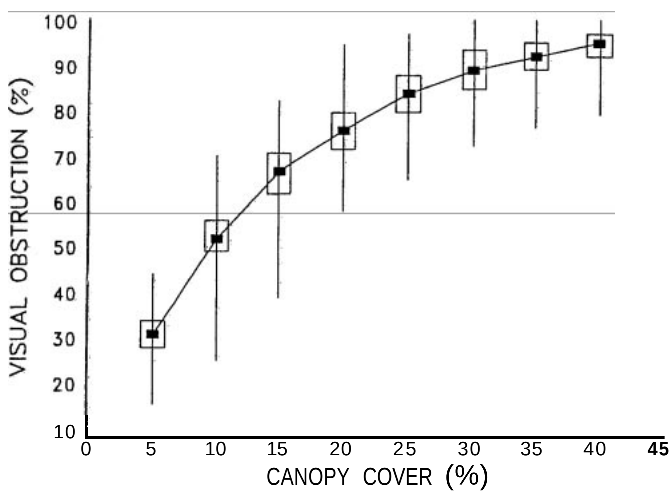

Fig. 1 Relationship between canopy cover of trees 2.5 m in diameter and visual obstruction (mean, ± 25% of median, range) as simulated for random placements (n = 400) of trees within a 20 m radius circle. Trees within 6 meters of the circle's center were not included as vision-obstructing objects.

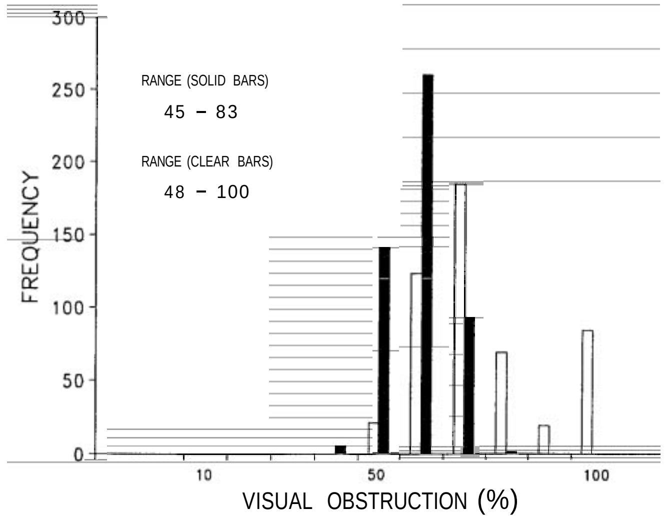

Fig. 2. Frequency distribution, from program TSIM, of visual obstruction values produced by 500 random placements of 35 trees (2.5 m diameter) per 20 m radius circle. Solid bars are values when trees within 6 m of the observer are excluded; clear bars are values when these objects are included.

DISCUSSION

While program TSIM effectively predicts visual obstruction by discrete opaque objects, it cannot be used when vision is obstructed by combinations of "partially opaque" vegetation or where topographic visual bamers are abundant. We used program TSIM by classifying habitats according to counts of trees within 20 m of randomly-located points, and within 20 m of observed bighorn. Mean visual-obstruction values from TSIM were used to represent visual obstructions at these locations. This method allowed us to estimate visual obstruction based on an objective count, avoiding subjectivity and a potential for observer-bias. In addition, we used TSIM for pinyon-juniper-rock habitats by counting vision-obstructing rocks as 1 or more trees, depending on their diameters relative to the average tree diameter.

Three characteristics of data from program TSIM suggest caution in selecting methods for measuring visual obstruction and for analyzing resulting data. These are non-linearity (Fig. 1), skewness (Table 1), and bimodality (Fig. 2).

Some habitat-suitability models for desert bighorn (Holl 1982, Smith et al. 1991:218) suggest using tree or shrub canopy cover (%) as an index to visibility. This method allows the use of aerial photos. We dislike canopy cover as a measure of visual obstruction by vegetation because (1) some tall trees contribute much to canopy cover while only the tree boles obstruct vision at 1 m above the ground; (2) we found a small range (5–20%) of canopy cover in pinyon-juniper habitat is associated with most of the variation in visual obstruction (15–95%), so that canopy cover must be measured very precisely to detect differences among habitats; and (3) visual obstruction is not linearly related to canopy cover in pinyon-juniper habitats (Fig. 1).

When measuring visibility in open or densely-vegetated areas, the resulting skewed percent data (Table 1) will require transformation before using statistical tests based on the assumption of normality. This is common practice for percent data near 0 or 100%. In some habitats, an alternative solution would be to adjust plot size to obtain visual obstruction values nearer to 50%.

The effect of 1 nearby object upon visual obstruction can be large, almost 50%. Consequently, the method for locating plot centers can be critical to measuring visual obstruction in the field. In previous literature, biologists have not clearly described their methods for locating plot centers. Subjective location of plots could cause large differences among observers. We suggest a criterion be that plot centers are at least a specified distance from the nearest vision-obstructing object. Varying this distance has large effects upon results if the distance is small. We suggest $\geq 2\times$ the average diameter of the vision-obstructing objects. Using this distance produces unimodal data (Fig. 2).

We believe it is appropriate not to consider objects very near the observer because bighorn sheep are social animals and a group of sheep is usually able to view from both sides of the centermost opaque object within the group. Further, including opaque objects very near the observer reduces the precision of estimates (Fig. 2). Therefore, even if plots are located randomly, we suggest that vision-obstructing trees or large rocks within a specified distance be ignored.

If aerial photographs are used to measure tree densities for use in TSIM, photo-interpreters must consider the effect of slope steepness upon apparent and actual plot sizes on the ground. Neglect of this bias causes significant overestimation of visual obstruction on steep slopes. (A 100 m × 100 m ground plot with 400 trees (2.5 m diam) would appear on a 100 m × 100 m aerial photoplot as 75, 78, 86, and 95% visual obstruction on 0, 30, 45, and 60 degree slopes, respectively.)

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Appendix. Program TSIM (QuickBASIC, Microsoft Corp.) for simulating visual obstruction from trees or other objects. Because the relationship between tree density and visual obstruction is not linear (Fig. 1), we do not suggest running all simulations with 1 average tree density. Rather, we suggest that simulations be proportioned according to the relative frequencies of each tree density. Thus, if 10% of plots measured in the field have 22 trees per circle, then 10% of the simulations should be run with 22 trees.

```
200  INPUT "OUTPUT FILE NAME ? ",N$
250  OPEN N$ FOR OUTPUT AS #1
300  INPUT "NUMBER OF SIMULATIONS ? ", X
350  INPUT "AVERAGE DIAMETER OF OBSTRUCTIONS (ME-
     TERS) ? ", DIA
400  INPUT "HOW MANY OBSTRUCTIONS ? ", N
450  INPUT "RADIUS OF CIRCLE (METERS) ? ", R
500  INPUT "REMOVE WHAT RADIUS (METERS) ? ", C
550  RANDOMIZE
600  FOR Y = 1 TO X
650  SUM = 0
700  FOR TREE = 1 TO N
750  M1 = RND • 100
800  M2 = RND • 100
850  A = SQR(M1 ^ 2 + M2 ^ 2)
900  IF A > R THEN 750
950  IF A < C THEN 1650
1000 IF A > 0.5 • DIA THEN 1150
1050 SUM = 100
1100 GOTO 1650
1150 AREA = 3.1416 • A ^ 2
1200 PER = 100 • (1 / 2 • DIA • A) /AREA
1250 B = RND • 100
1300 IF B > 100 THEN 1250
1350 IF B < SUM THEN 1550
1400 SUM = SUM + PER
1450 IF SUM > 100 THEN SUM = 100
1500 GOTO 1650
1550 IF SUM > PER THEN 1650
1600 SUM = PER
1650 NEXT TREE
1700 WRITE #1, SUM
1750 NEXT Y
1800 CLOSE #1
1850 END
```

EVALUATION OF MOUNTAIN SHEEP HABITAT IN ZION NATIONAL PARK, UTAH

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Desert Bighorn Counc. Trans. 36:4–9.

Abstract: We evaluated suitable mountain sheep (Ovis *canadensis*) ranges within Zion National Park, Utah with a habitat evaluation method and geographic information system (GIS) technology. We identified suitable habitat for mountain sheep as areas being in or within 300 m of escape terrain, with acceptable visibility, not comprised of excessively steep slickrock, not isolated from access by barriers, >150 m from human activity areas, ≤3.2 km of water, and void of exotic species, primarily domestic sheep. We determined that 21% of the park (12,616 ha) met these criteria. We also calculated forage availability. There was enough habitat to support a minimum population of ≥125 animals.

Key words: geographic information system, habitat evaluation, Utah, Zion National Park.

Two races of mountain sheep exist in Utah. Desert bighorn sheep (*O. c. nelsoni*) inhabit rugged canyon country in the southern half of the state and Rocky Mountain bighorn sheep (*O. c. canadensis*) exist in a few isolated mountain chains in the north. Unfortunately, humans have had a strong, negative influence on both races. Consequently, desert populations have declined appreciably, while all native Rocky Mountain populations have been extirpated. Loss of water resources, competition for space and forage with domestic livestock (particularly domestic sheep), competition with mule deer (*Odocoileus hemionus*), human harassment, poaching, and predation have been cited as factors which led to the extirpation of Zion National Park's (ZNP) native mountain sheep population in the mid-1950s (McCutchen 1975).

National Park Service (NPS) policies prescribe that park lands "shall be managed so as to conserve, perpetuate, and portray as a composite whole the indigenous aquatic and terrestrial fauna and flora and scenic landscape. Missing native life forms may be reestablished . . ." (NPS 1968). Planning for the reintroduction of mountain sheep to formerly occupied ranges within ZNP was initiated in 1964 (McCutchen 1975). Consequently, 12 mountain sheep from Nevada were released into a special enclosure in the park in 1973. The 40 mountain sheep inhabiting ZNP are descendants of this initial translocation effort. McCutchen (1975) provided a thorough review of the history of mountain sheep translocation efforts at ZNP.

Utah's unfortunate experience with mountain sheep populations has not been an isolated event as significant population declines have occurred throughout North America. Consequently, mountain sheep translocation programs are important in conservation of the species (Griffith et al. 1989). Unfortunately, many efforts have failed to establish self-sustaining herds capable of long-term persistence (Smith et al. 1988, Griffith et al. 1989, Bailey 1990). A lack of rigorous habitat assessment has been cited among likely causes for several translocation failures in Utah (Smith et al. 1988). Importantly, Griffith et al. (1989) ranked assessment release sites prior to translocation as the single-most important activity managers could do to insure translocation success.

Smith et al. (1991) recently published a habitat evaluation method for Rocky Mountain bighorn sheep that evaluates unoccupied ranges and may be used to identify factors limiting existing populations. Habitat evaluation by this method yields an estimate of abundance and distribution of suitable habitat, the abundance and distribution of seasonal ranges, and quality of these identified ranges. In this analysis of ZNP, we focused on determination only of the abundance and distribution of suitable habitat due to a lack of the more specific data required for estimating abundance, distribution and quality of seasonal ranges. Although habitats presently occupied by mountain sheep vary significantly, the habitat evaluation method by Smith et al. (1991) has utility for evaluating their ranges.

We consider mountain sheep reintroductions successful only if they result in herds that are self-perpetuating and capable of long term persistence without continual management inputs. Populations meeting these criteria were termed minimum viable populations (MVP) by Shaffer (1983). Shaffer (1983) specifically defined MVP as "the smallest isolated population having at least a 95% probability of surviving for at least 100 years." Although the precise number constituting a MVP of mountain sheep is subject to debate, several biologists have recommended that insular herds be comprised of a minimum of 125 individuals (Smith et al. 1991). Research by Berger (1990) adds strength to this concept in that his study of 122 populations revealed that those with <50 individuals went extinct within 50 years, whereas those with >100 individuals had persisted for 70, or more, years. However, the 125 sheep guideline becomes less important when gene flow exists between neighboring herds. Interherd migrations have been observed to exceed 50 km (Schwartz et al. 1986), yet mountain sheep in ZNP will most likely not benefit from distant populations and thus there needs to be a minimum population of at least 125 sheep.

Quantity and quality of forage resources play a vital role in determining how many animals a particular area can support (i.e., carrying capacity). Maximum density values for mountain sheep herds can be found in the literature. Assuming these densities represent upper limits for mountain sheep allows calculation of the minimum amount of suitable range needed to support a population of 125 individuals. Maximum densities of mountain sheep found in the literature suggest that even the most optimal ranges (i.e., those not only meeting spatial requirements but also providing abundant forage resources) should not be expected to support densities exceeding 7.7 mountain sheep per km^2. Therefore, 125 mountain sheep would require at least 17 km^2 of suitable habitat for support (Smith et al. 1991), although this would represent a maximum density situation above which the population would not be expected to increase.

Our objective was to determine the extent and distribution of potentially suitable mountain sheep ranges within ZNP using a habitat evaluation method and GIS technology. Once suitable habitats were identified, we compared their quantity to the minimum requirement of 17 km^2 needed to sustain 125 mountain sheep. We were interested in determining if enough space existed for a self-sustaining herd at ZNP. We felt that if adequate space was not available for a self-sustainable herd there would be no reason to perform additional evaluations of range quality.

This project was jointly funded by the National Park Service and Brigham Young University. We thank F. Singer and resource management specialist V. Vieira of the National Park Service for their support and friendship. We also thank P. J. Hardin of Brigham Young University for permission and assistance in using the InterGraph Laboratory for Geographic Information Analysis. Additionally, we thank J. Guymon of the Utah Division of Wildlife Resources and H. McCutchen of the National Park Service for their useful comments.

STUDY AREA

Zion National Park is in southwestern Utah. Zion is noted for its deeply carved canyons, barren slickrock, forested mesa tops, and ex-

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tremes in topographic relief. Elevations ranged from 1,100 m to 2,650 m with sheer walls often exceeding 600 m. These topographic extremes have produced many vegetational communities, some usable by mountain sheep. Springs and perennial streams provide water throughout the park. McCutchen (1982) provides a more complete description of the geology, vegetation, and climate of ZNP.

METHODS

Several data resources are required when performing a mountain sheep habitat assessment (Fig. 1). These include:

1. information on the distribution and abundance of exotic species in the vicinity of the study area,
2. digital or paper maps of study area topography,
3. location of movement barriers to sheep,
4. a determination of visibility associated with plant communities comprising the study area,
5. the distribution and abundance of water resources, and
6. identification of areas of human activity and level of intensity associated with them.

These baseline data were gathered from a variety of sources, including printed materials (e.g., topographic maps, NPS files), field surveys, aerial over-flights, and consultation with individuals in state and federal agencies. All resource data were transferred to digital format, called themes, so that GIS software could be used to perform desired analyses. Geographic information system software and hardware were used for data input (digitizing and database creation), generation of buffer zones around various habitat elements, overlay and intersection of themes. Geographic information system analysis of habitat data resulted in a map of the distribution and abundance of suitable habitat. All GIS operations were performed on InterGraph® corporation workstations using InterGraph's GIS software called Modular GIS Environment® (MGE). Thematic data required for this project included information regarding habitat visibility, movement barriers, water resources, escape terrain, human activity zones, and exotic species.

Horizontal visibility of a plant community refers to how well mountain sheep can see within that community. Horizontal visibility associated with each plant community type plays a crucial role in determining bighorn habitat quality. Habitat quality is affected by visibility because highly visible areas not only allow mountain sheep to detect predators but also to convey alarm responses to conspecifics (Risenhoover 1981). Smith (1992), Brundige and McCabe (1986), and Risenhoover and Bailey (1980) found that Rocky Mountain bighorn sheep responded in highly predictable ways to horizontal visibility values associated with the various plant communities in their respective study areas. Their work indicated that average visibility (measured from the 4 cardinal points at 14 m from the gridded target) had to be $\geq 80\%$ or mountain sheep avoided the area.

Horizontal visibility values for plant communities in ZNP were obtained for each of the main plant community types by positioning a one meter square, gridded target within the community, then recording the percentage of it visible. Unfortunately, a map of ZNP vegetation community types with which to correlate horizontal visibilities did not exist at the time of our analysis. To circumvent this problem, we mapped low visibility areas (i.e., heavily forested areas and tall shrublands) by using the green-shaded regions on USGS quadrangle maps (1:24,000 scale) for ZNP as templates. We verified topographic map accuracy by comparing them to 1:40,000 black and white aerial photographs. Field reconnaissance confirmed that use of the green-shaded areas as a template for poor visibility habitat was a reasonable approach.

Movement Barriers

Potential barriers to movement must be identified when evaluating habitat suitability. Certain types of fencing, highways, swift rivers, aqueducts, pipelines and excessively steep slickrock are a few examples of movement barriers (Smith et al. 1991). Zion is famous for its expanses of wind-polished slickrock and sheer cliff faces. These areas present barriers to movement for mountain sheep as well as bar access to isolated habitats, such as slickrock surrounded mesa tops. Hence, slickrock with slopes $>35°$ were deemed unclimbable and considered barriers to movement. In many instances, slickrock completely isolated what would have otherwise been suitable habitat so these isolated areas had to be eliminated from consideration as sheep habitat. Because digital elevation map (DEM) files for ZNP were not available at the time of analysis, cliff and slickrock areas were identified by using a combination of contour line spacing on USGS 7.5 minute topographic maps and 1:40,000 scale aerial photographs. Direct observation (e.g., helicopter overflight, automobile, and on-foot travel) and indirect observation (e.g., analysis of aerial photography) verified the presence of these areas. Barriers to movement, and the areas they isolated, were digitized from maps into the GIS database.

Water Resources

A map of 208 spring locations within ZNP was used to create part of the water resources theme. However, specific information regarding flow volume, seasonality of flows, visibility surrounding each of the springs, and access was lacking. Nonetheless, we proceeded on the assumption that water from these springs would be available to mountain sheep, an assumption that only future field work can verify. Topographic maps of ZNP (standard USGS 1:24,000 scale maps) provided precise locations of perennial streams. These spring and stream resources were digitized into the GIS database. Because studies have shown that mountain sheep distributions are generally within 3.2 km of water resources (McQuivey 1978, Van Dyke et al. 1983), all water sources were buffered with a 3.2 km zone. Areas not included within these buffered zones were discarded as unsuitable.

Rugged, cliff-escape terrain comprises core mountain sheep habitat (Van Dyke et al. 1983) and can be fairly accurately delineated with a GIS when DEM data are available. Rugged escape terrain has been defined as slopes greater than 60% that have occasional rock outcroppings allowing mountain sheep to outmaneuver predators and provides secure bedding areas (Van Dyke et al. 1983). Because no DEM files were available for ZNP at the time of analysis USGS 7.5' topographic maps of the park were used to delineate escape terrain areas by visual analysis of contour line spacing. Delineated areas of escape terrain were digitized into the GIS, thus creating an escape terrain theme. Research by Smith (1992), and others (Van Dyke et al. 1983), indicates that mountain sheep rarely venture farther than 300 m from escape terrain. For this reason, a 300 m buffer was generated around escape terrain by the GIS. Areas not within escape terrain and its buffered zones were discarded as unsuitable.

Areas of human activity may result in a loss of habitat for mountain sheep (Dunaway 1971, Light 1971), although the level of activity plays a role in determining the degree of loss. Therefore, it is important to identify the location of dwellings, campgrounds, roads, trails, ski resorts and other focal points of human activity (Smith et al. 1991). Once identified, these areas must be delineated and appropriate exclusion buffers generated around them. For example, Light (1971) recommended buffering areas of light human use (0–100 visitors per year) with 100 m zones and those of heavy human use (over 500 visitors per year) with 150 m buffer zones. Campgrounds, residential areas, visitor contact centers, roads and trails were located on USGS topographic maps and then digitized into the GIS. Buffer zones of appropriate widths were generated around each human activity area.

In the bighorn habitat evaluation method of Smith et al. (1991), the first step in range evaluation is to determine the probability of mountain sheep and exotic ungulates, particularly domestic sheep, making contact with one another. Because separation of exotics and bighorn sheep is essential for maintaining healthy mountain sheep herds (Desert Bighorn Counc. Tech. Staff 1990), we identified sources of exotic animals nearest to ZNP, determined distances between them and nearest bighorn ranges, and assessed the probability of contact.

We conducted interviews with NPS and Utah Division of Wildlife Resources (UDWR) personnel to determine if domestic sheep were in the area. Geographic information system analysis of allotments determined airline distances from each to the nearest suitable bighorn ranges.

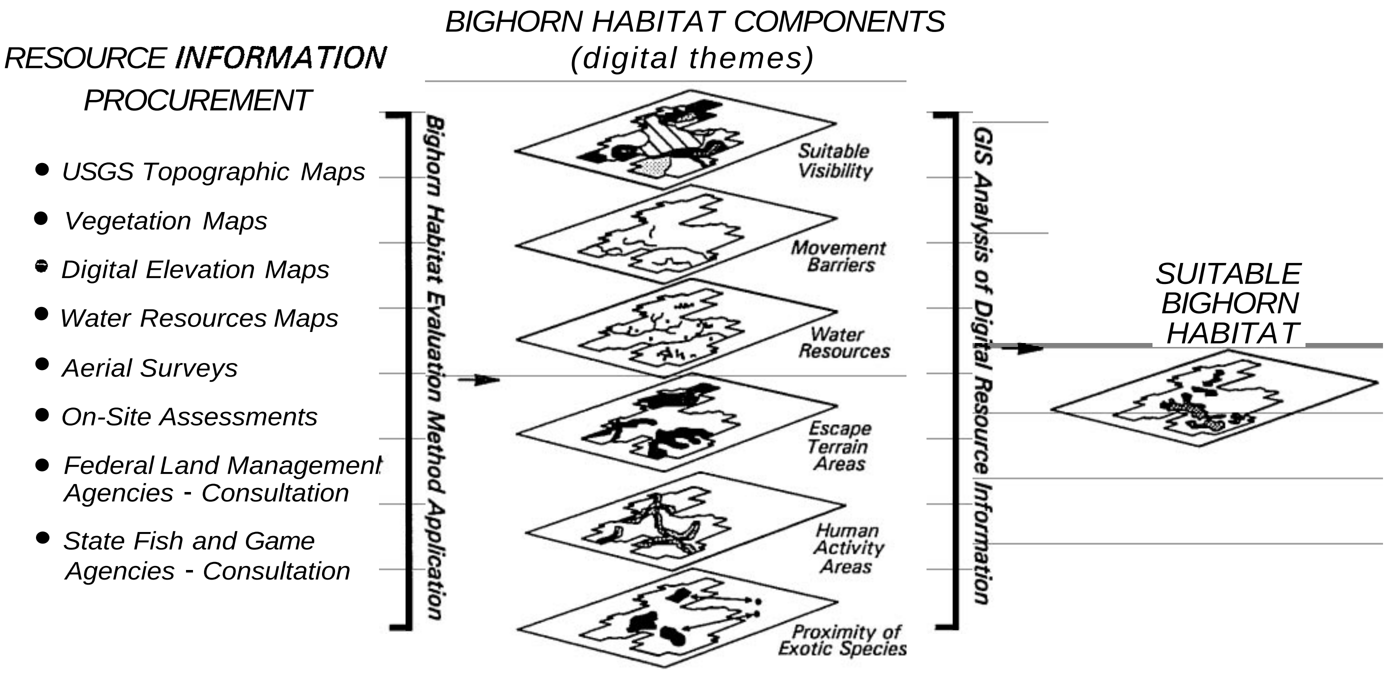

Fig. 1. An overview of the habitat evaluation process for mountain sheep range delineation.

Additionally, analysis of topographic maps and aerial photos provided information that we used to form an opinion regarding the probability of contact between domestic sheep and ZNP bighorn.

Once these 6 basic themes of resource information were converted to digital format and buffer zones generated, the GIS was used to overlay and create new polygons representing those areas meeting suitable habitat criteria (Fig. 1).

Space alone does not comprise a range capable of supporting mountain sheep so a method for estimating range carrying capacity, as a function of forage production, was utilized. In west-central Wyoming, mountain sheep of Whiskey Basin have been successfully managed by a method that uses forage production as a basis for determining annual bighorn harvests and trapping quotas (E. T. Thorne, Wyoming Game and Fish, pers. commun.). According to Thorne et al. (1979), mountain sheep carrying capacity may be estimated using the following steps:

1) determine forage (i.e., grasses, grass-likes, and forbs) production on bighorn ranges,
2) assume that the average bighorn utilizes 1.7 kg/dry forage/day,
3) allocate 50% of range forage production to bighorn use,
4) allocate 35% of range forage production to plant community maintenance, and
5) allow the remaining 15% of forage production to be used by other wildlife.

Although Thorne et al. (1979) reported that the average Rocky Mountain bighorn sheep consumes 1.7 kg of forage/day, desert bighorn are smaller than Rocky Mountain bighorn and can be expected to consume less. Hansen (1980) reported that penned desert bighorn consumed an average of 1.5 kg of dry alfalfa/day on an annual basis. Therefore, in this analysis we used 1.5 kg forage/day to calculate annual forage needs for mountain sheep at ZNP. The amount of forage needed to support 125 bighorns, while leaving half for other wildlife and plant community maintenance, was calculated according to Thorne et al. (1979) as follows:

$$(125\ \text{bighorns})(1.5\ \text{kg forage/day/bighorn})$$
$$(365\ \text{days/year}) = 68{,}438\ \text{kg forage/year}$$

Although bighorn forage requirements vary with season, age, and sex, the use of 1.5 kg of forage per day per sheep as an average value does allow biologists to roughly estimate the baseline needs for a herd of 125. The degree of difference between projected forage needs and estimated forage production for a particular site suggests the degree of deficiency, or adequacy, that site will have with regard to meeting the needs of 125 bighorns. We did not sample forage production for Zion-ranges but did use data from K. Harper (Brigham Young Univ., unpubl. data) to obtain rough estimates of forage production for thevarious plant community types and use these to estimate forage production for ZNP.

RESULTS

Habitat Visibility

Horizontal visibility sampling indicated that blackbrush shrub communities (*Coleogyne* spp.), grasslands, sparse pinyon-juniper forests (*Pinus edulis,* P. *monophylla, Juniperus osteosperma,* and J. *scopulorum*), slickrock, and talus areas had visibility acceptable to bighorns. Plant communities of unacceptable visibility included douglas fir stands (*Pseudotsuga menziesii*), ponderosa pine forests (*Pinus ponderosa*), areas of manzanita (*Arctostaphylos* spp.) and oak (*Quercus gambelii*), serviceberry shrublands (*Amelanchior* spp.), and dense pinyon-juniper forests. Elimination of these areas from consideration as potential habitat resulted in a loss of 37,163 hectares (62.3%)(Table 1).

Movement Barriers

We identified movement bamers that included extensive areas of slickrock and sheer cliff faces. The GIS could not be used to identify these bamers because an unclimbable cliff face and climbable face were not distinguishable from each another by slope category alone. Therefore, we used aerial photos and topographic maps to identify these bamers and islands of habitat made inaccessible by them. Excessively steep terrain and the areas isolated by it resulted in a loss of 9,341 ha of habitat (15.7%)(Table 1).

Water Resources

Generation of 3.2 km buffers around 208 springs and several perennial streams within ZNP resulted in nearly total coverage of park rangelands. Only 19 ha were not within 3.2 km of water resources, resulting in a loss of only 0.03% of potential habitat. Although this analysis suggests that water is not a critical limiting factor, it is important to note that specific data for each spring are needed. Poor visibility, inaccessibility, and seasonality of flows can reduce the value of a water source for desert dwelling sheep and need to be determined.

Escape Terrain

Before identifying the distribution and abundance of escape terrain, poor visibility areas were identified and eliminated from consideration. When DEM data are available for analysis, the GIS can readily identify escape terrain by slope category analysis. However, in this instance no DEM data were available so we manually identified escape terrain by digitizing it directly from 7.5 minute USGS quadrangles of park areas after unsuitable visibility areas had been delineated. This saved considerable time as areas of unsuitable visibility comprised over 62% of parklands and could be eliminated from further consideration. Because ample amounts of escape terrain were present in ZNP (Table 1), it was not considered to be a limiting factor for suitable mountain sheep habitat.

Human Activity

All roads, trails, dwellings, NPS visitor facilities, campgrounds and parking areas were digitized and buffered with zones of an appropriate width (i.e., either 100 m or 150 m widths). This resulted in a loss of 506 ha ofterrain, amounting to less than 0.1% of the park. Consequently, human activity zones were considered to have a negligible impact on bighorn habitat quality within ZNP on the whole.

Exotic Species

We interviewed NPS and UDWR personnel and identified 2 domestic sheep allotments near the park. Analysis of these allotments and the nearest bighorn habitat indicated a minimum separation of 16.5 air km. Additionally, each allotment has a fairly short period during which they are stocked with domestic sheep. The Gordon Point allotment is stocked with 100 domestic sheep from May 16 through June 30 each year, and the Table Mountain allotment has 336 domestic sheep on it from July 1 through September 30. Consideration of allotment location, seasonality of use, and nature of the terrain between allotments and the nearest bighorn habitat suggested that chances for contact were minimal and not of concern. If the chances for exotic species and mountain sheep in ZNP coming into direct contact had been high, plans for translocation of additional mountain sheep to ZNP would not have been recommended, in accordance with guidelines set forth by the Desert Bighorn Council Technical Staff (1990).

GIS Analysis of Resource Information

Geographic information system analysis of ZNP resource data identified suitable bighorn habitat (Fig. 2). These results indicate that approximately 21% (12,616 ha) of ZNP's total area (59,626 ha) satisfied criteria for suitable bighorn habitat (Table 1). Areas of unsuitable visibility comprised the greatest loss of potentially suitable habitat (37,163 ha, 62%), followed by losses due to unclimbable slickrock escarpments, cliffs and isolated terrain (9,341 ha, 16%), while losses of habitat due to areas of human activity were the smallest (506 ha, <0.01%).

Smith et al. (1991) advised that a minimum of 1,700 ha of range should be available to support the spatial needs of 125 mountain sheep. Habitat analysis of ZNP revealed that suitable ranges exceeded this minimum area requirement by a factor of 7 (12,616 ha, Table 1). Exceeding minimum area requirements reduces the need for high forage production/unit area. However, forage production of suitable ranges must be sufficient to meet the needs of not only mountain sheep but also of other wildlife species. Since the estimate of suitable bighorn habitat in ZNP is 12,616 ha, these areas would need to produce at least 10.8 kg forage/hectare/year to meet the calculated minimum forage requirements of a herd of 125 bighorns, 63,448 kg of forage/year. Precise forage production data were not available for ZNP, but preliminary measurements suggest that areas identified as suitable bighorn habitat most likely exceeded the 10.8 kg/ha production threshold (K. Harper, pers. commun.). Thus, the forage needs of a self-sustaining herd of 125 bighorn sheep can most likely be met by suitable ranges within ZNP.

Table 1. Results of GIS analysis of mountain sheep habitat in Zion National Park (ZNP), Utah.

Range	Area (ha)	%
Entire Study Area—ZNP	59,626	100.0
Areas of unsuitable visibility		
Heavily forested[1]	31,067	52.1
Dense shrub cover[2]	6,096	10.2
Excessive slope and isolated areas[3]	9,341	15.7
Human activity areas and buffered zones	506	<0.1
Area lacking in water availability[4]	19	<0.1
Total unsuitable habitat area	47,010	79.0
Total suitable habitat areas	12,616	21.0

[1]Unsuitable forested community types consisted primarily of pinyon pine, juniper, and Douglas fir.

[2]Dense shrub cover consisted mostly of manzanita, oak, and serviceberry.

[3]"Excessive slope" refers to those areas of slickrock or cliffs which are not usable by bighorn due to their steepness. "Isolated areas" refers to portions of range where steep slickrock or cliffs prohibit bighorn from accessing them.

[4]Buffering all springs and perennial streams in ZNP resulted in essentially complete coverage of the park, excepting 19 ha along the western border.

DISCUSSION

Preliminary analysis of mountain sheep habitat suitability in Zion suggests that the park should be able to support a self-sustaining herd of at least 125 animals. Identified areas of suitable habitat exceeded minimal spatial requirements. Prior to this analysis, it was believed that a lack of suitable habitat was the reason why these animals have failed to increase to >40 in the 2 decades since their release (Jim Guymon, Ut. Div. Wildl. Resour., pers. commun.). However, this analysis suggests that factors other than habitat suitability may be responsible for the small population of mountain sheep in Zion. Other potentially limiting factors include, the genetics problems associated with small populations, losses to stochastic events, and predation.

It seems likely that some genetic constraints (e.g., inbreeding depression) may be present considering that this entire herd has descended from 12 sheep, of which only 3 were males, and they were lambs at the time of release. Studies of the degree of genetic heterozygosity in the herd would be necessary to address this concern. Losses to stochastic events (e.g., fire, disease, foul weather) can have significant impacts upon small populations. Nonetheless, without detailed study this too remains conjecture. Finally, predation may also have been a contributing factor to small population size, especially since losses for a small population can have a significant influence upon population dynamics. However, without quantitative data this is merely speculation.

Having determined that ample habitat exists we have recommended that the park pursue augmenting the population with subsequent releases of sheep. We have also suggested that they consider initiating research specifically designed to investigate other possible population limiting factors, including some of the habitat related concerns mentioned above (e.g., more specific water resources data, forage production estimates).

Step-wise analysis of mountain sheep habitat generates useful information for managers. First, when an insular herd is being considered the question of habitat quantity must be addressed before that of habitat quality. There is little reason to conduct detailed evaluation of transplant sites when insufficient area exists to support a self-sustaining herd. Secondly, in this step-wise evaluation process each parameter considered relevant to mountain sheep habitat suitability is individually analyzed. As a result, biologists come to understand the deficiencies and strengths associated with each transplant site. Identification of specific range deficiencies suggests specific management options (Table 2).

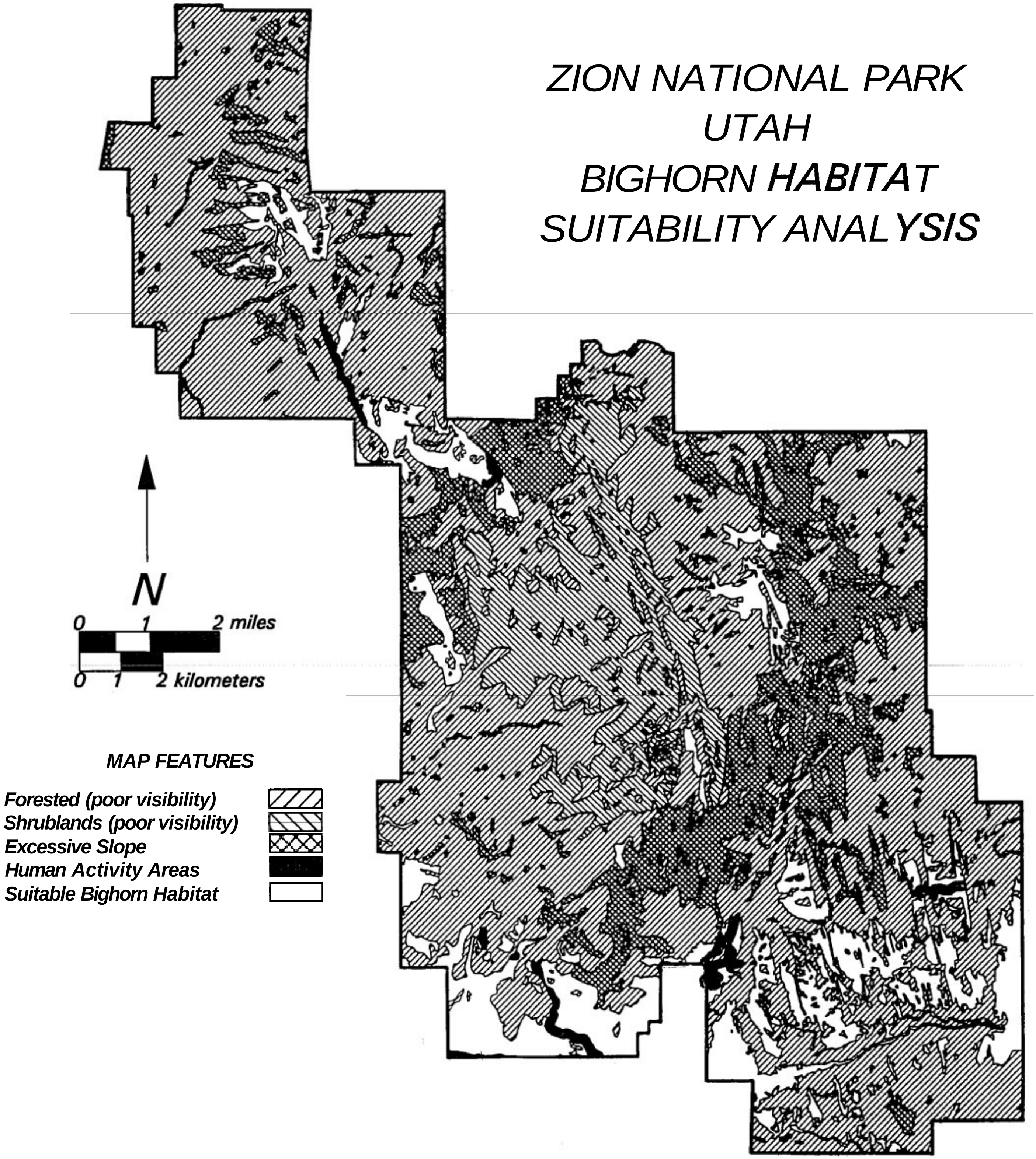

Fig. 2. Map of suitable bighorn habitat in ZNP generated by GIS overlay and intersection of the 6 basic themes of resource information.

Evaluation of mountain sheep habitat at ZNP could have been more precise and processing time shortened had the following been available:

1) DEM data, although in existence for the park, were not available at the time of analysis and would have greatly improved accuracy and speed of the evaluation.
2) An accurate vegetation map would also have resulted in more precision and speed in habitat assessment.
3) More specific data regarding water resources is essential if an accurate assessment of water resources' limitations is to be possible.

As it were, the entire analysis required 1 week of field work and 1 person 1 month to perform the GIS analyses and write the final report.

Table 2. A summary of parameters influencing mountain sheep habitat suitability, management options, and selected bibliographic references.

Habitat parameter	Management options	Selected references
Unsuitable visibility	Prescribed burning, chaining, chemical treatments, cutting	Holl and Bleich (1983), Van Dyke et al. (1983)
Movement barriers	Remove fencing, provide underpasses, elevate structures	Helvie (1971), Van Dyke et al. (1983), Graham (1980)
Water limitations	Improve springs, install dams, build guzzlers, blast potholes	Van Dyke et al. (1983), Turner and Weaver (1980), Graff (1980)
Escape terrain limitations	Improve visibility through burning or cutting for escape terrain with poor visibility	Holl and Bleich (1983), Van Dyke et al. (1983)
Human impacts	Close roads and trails, alter intensity of use of existing roads and trails, relocate campgrounds and facilities	Light (1971), Holl and Bleich (1983), Van Dyke et al. (1983), Graham (1980)
Impacts of exotic species	Eradicate exotics, eliminate allotments, fence vulnerable areas, adjust season of use to accommodate bighorns, create buffer zones	Holl and Bleich (1983), Van Dyke et al. (1983), Graff (1980)
Inadequate forage production	Remove or reduce domestic livestock usage of area, prescribed burning and seeding, range pitting or discing	Thorne et al. (1979), Holl and Bleich (1983), Van Dyke et al. (1983), Graff (1980)

The NPS is entering a new phase of management of its wildlife resources. As GIS systems become more available, easier to use and more powerful, wildlife managers will increasingly rely upon GIS to assist them in performing their duties. The utilization of mduntain sheep habitat evaluation methodologies with GIS technologies will result in better mountain sheep management.

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MOUNTAIN SHEEP HABITAT EVALUATION IN MOJAVE DESERT SCRUB

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Desert Bighorn Counc. Trans. 36:10–12.

Abstract: We studied habitat use of 12 mountain sheep (Ovis *canadensis nelsoni*) in a 3.2 km² enclosure from June 1990 to May 1991 in the Desert National Wildlife Refuge, 150 km north of Las Vegas, Nevada. We determined habitat selection based on use and availability of habitats with a 100 quadrant grid overlain on a 15' topographic map of the study area. We compared habitat used by mountain sheep with that predicted from a habitat evaluation model. Habitat use was based on 1,271 locations of mountain sheep in 4 seasons. Each quadrant was scored on topography, vegetation, precipitation, evaporation, water availability, mountain sheep use, and human use. Only scores for topography and vegetation differed in quadrants on the study area. In all seasons mountain sheep avoided quadrants with scores <80 and selected quadrants with scores ≥ 80.

Key *words:* desert mountain sheep, habitat selection, model, use versus availability.

Models that accurately predict habitat use and animal movements have become increasingly important as human development encroaches on wildlife habitat (Cunningham 1989). Habitat evaluation models rate habitat components to identify essential habitat, areas that might be improved by manipulation, and areas that might be suitable for reestablishment programs (Hansen 1980, Armentrout and Brigham 1988, Wakeling and Miller 1990).

Habitat models developed for desert races of mountain sheep (Ferrier and Bradley 1970, Hansen 1980, Holl 1982) rate forage conditions, water availability, and slope. The habitat evaluation method developed by Hansen (1980) for the Desert National Wildlife Refuge considers habitat characteristics and human values. Hansen's (1980) model was designed to assist land managers in determining the parcels of land necessary for mountain sheep, and which can be used for other programs without loss of mountain sheep habitat.

In 1990 a 3.2 km² enclosure was constructed in the Desert National Wildlife Refuge to contain a transplanted mountain sheep population for a related study. We used Hansen's (1980) model to evaluate habitat use by the captive mountain sheep.

We appreciate the assistance and advice provided by D. Delaney (deceased) and C. Stevenson, Nevada Department of Wildlife; D. Brown, B. Zeller, M. and C. Goddard, and V. Youngs, U.S. Fish and Wildlife Service. M. C. Wallace and M. J. Zine were instrumental in obtaining data for this study. The U.S. Air Force funded the project.

STUDY AREA

The Desert National Wildlife Refuge encompasses 26,000 km² and supports the largest single desert mountain sheep population in the United States. The 3.2 km² enclosure was located in the northeastern corner of the Desert Game Range (Fig. 1). The topography was varied from low, rolling foothills to steep and rocky terrain; elevation ranged from 1,267 to 1,562 m. Vegetation was typical of the desert scrub vegetation type (Allred et al. 1963, Bradley 1964). Vegetation and topographic features were representative of the sheep range where the sheep were captured, and $\geq 50\%$ of the habitat occupied by desert races of mountain sheep in southern Nevada (D. Delaney, Nev. Dep. Wildl., pers. commun.).

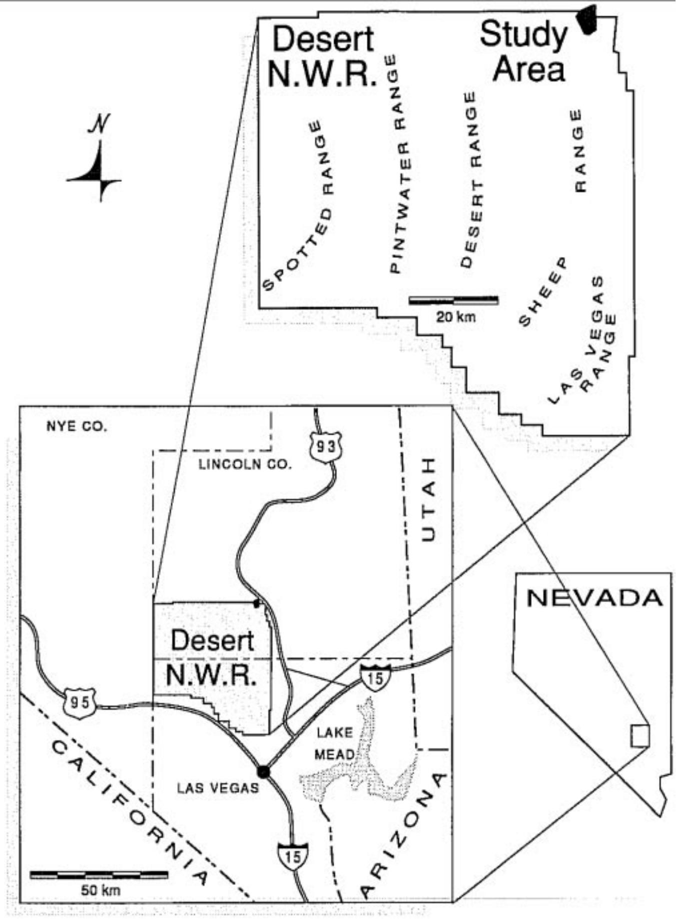

Fig. 1. Location of the mountain enclosure in the Desert National Wildlife Refuge (NWR), Nevada.

METHODS

The study area was divided into approximately 100 quadrants using a 200 m² grid overlain on a 15' topographic map. Each quadrant was evaluated according to the availability of resources in 7 categories (Table 1) following Hansen (1980). Data were obtained through field inventory,

Table 1. Habitat components and point values for desert mountain sheep habitat evaluated, Desert National Wildlife Refuge, Nevada, 1990–91 (Hansen 1980).

Habitat category		Points
I	Natural topography	0–20 points
II	Vegetation type	0–20 points
III	Precipitation	1–5 points
IV	Evaporation	1–5 points
V	Water type and use	2-40 points
VI	Bighorn use	2–20 points
VII	Human use	0–20 points

[1] Present address: CESDS, Apdo. 27-6100, Cd. Colón, Costa Rica.

Table 2. Classification of total scores for sections of land evaluated as desert mountain sheep habitat, Desert National Wildlife Refuge, Nevada, 1990–91 (Hansen 1980).

Total score	Classification
0–50	Not important to bighorn, or of high value for human use.
51–64	Buffer zone or zone of deficiency for bighorn; or area of potential economic value or of moderate human use.
65–79	Periodic use or zone of deficiency for bighorn; or area of potential economic value for occasional human use. Sections in this category should be critically examined before being removed from potentially important bighorn habitat.
80–100	Sections in this category are important to bighorn. Generally, sections in this category are in rough, mountainous terrain, or areas that are major crossings to summer and winter ranges or to water holes.
≥100	Sections in this category are vital to bighorn. On Desert National Wildlife Refuge, the only sections in this category are those with water holes.

locations of sheep, and topographic maps. Sums of the scores for evaluated quadrants were used to measure habitat suitability (Table 2). We compared scores from areas we evaluated with scores derived from Hansen's (1980) model. We compared use and availability data with the Chi-square goodness of fit test and Bonferroni simultaneous confidence intervals (95%) to determine whether use was more or less than expected based on availability (Byers et al. 1985).

RESULTS

Scores for mountain sheep use, human use, precipitation, evaporation, and water availability (Table 1) were equal among quadrants. For example, the human use category considers proximity to human development and potential for economic use of each quadrant. Because of the small size of the study area the distance to such developments was the same for each quadrant and all received the same score. Vegetation and topography did vary and were therefore used to differentiate quadrant scores.

Use of quadrants in all 3 categories (65–79, 80–100, ≥100) was significantly different than expected ($P \leq 0.05$). No quadrant scored <65 points (Table 3). Quadrants in the 65–79 point category made up 28% of the study area, contained 1% of observed locations, and were used significantly less than expected based on availability. These areas were lower bajadas and flat areas containing four-wing saltbush (*Atriplex canescens*) and creosote bush (Lama *tridentata*) associations.

Quadrants in the 80–100 point category represented 53% of scored quadrants, contained 65% of all locations, and were used significantly more than expected based on availability. These areas are midslopes, draws, and north-facing slopes in areas of high visibility. Vegetation consisted of shadscale (*Atriplex confertifolia*), flat sage (*Artemesia bigelovii*), and Mormon tea (*Ephedra nevadensis*) associations, and included ≥5% grass.

Quadrants receiving ≥100 points represented 19% of scored quadrants, contained 34% of all locations, and were used significantly more than expected based on availability. These areas had similar vegetation composition to quadrants in the 80–100 point category, but were located in the steepest and rockiest terrain on the study area.

DISCUSSION

Although we studied mountain sheep in an enclosure and did not distinguish between sex in testing Hansen's (1980) model our results compare favorably with Hansen's (1980) description of use areas for desert races of mountain sheep on the Desert National Wildlife Refuge. We also found that habitat use in an enclosure of this size (3.2 km^2) was similar to use by free-ranging mountain sheep in other desert habitats (Chilelli and Krausman 1981, Elenowitz 1984, Gionfriddo and Krausman 1986, Krausman et al. 1989).

Over 98% of mountain sheep locations in our study area occurred in habitat that rated as important to mountain sheep, while <2% of all locations were in zones of deficiency (Table 2). A more rigorous test of Hansen's (1980) model might be applied to an area containing more variation in habitat features and human use.

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Table 3. Percent habitat available, relative use, and Bonferroni confidence intervals for mountain sheep habitat in a 3.2 km^2 enclosure, Desert National Wildlife Refuge, Nevada, 1990–91.

Score	Relative area	Observed use	Bonferroni CI	Use
0–50[a]	0.0	None		
51–64	0.0	None		
65–79	0.28	0.014	$0.006 \leq P_3 \leq 0.022$	Less than expected
80–100	0.53	0.652	$0.62 \leq P_4 \leq 0.684$	More than expected
>100	0.19	0.334	$0.302 \leq P_5 \leq 0.366$	More than expected

[a] No quadrants scored <65 points.

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HABITAT SELECTION BY MOUNTAIN SHEEP IN MOJAVE DESERT SCRUB

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Abstract: We determined habitat use by 12–18 mountain sheep (*Ovis canadensis nelsoni*) in a 320-ha enclosure between June 1990 and June 1991 on the Desert National Wildlife Refuge, Nevada. The enclosure included 9 vegetation associations and 5 slope classes. We used a non-mapping technique and line transects to determine availability and composition of slope classes and vegetation associations. We determined habitat use by direct observation of radio-collared mountain sheep. Mountain sheep used midslopes and draw associations on the west side of the enclosure, and slope classes of 36–60% more than expected based on availability. Mountain sheep avoided habitats with slopes ≤36%. Habitat use by mountain sheep in the enclosure was similar to habitat use patterns described for free-ranging mountain sheep populations in Mojave desert scrub habitats.

Key words: habitat selection, Mojave desert, mountain sheep.

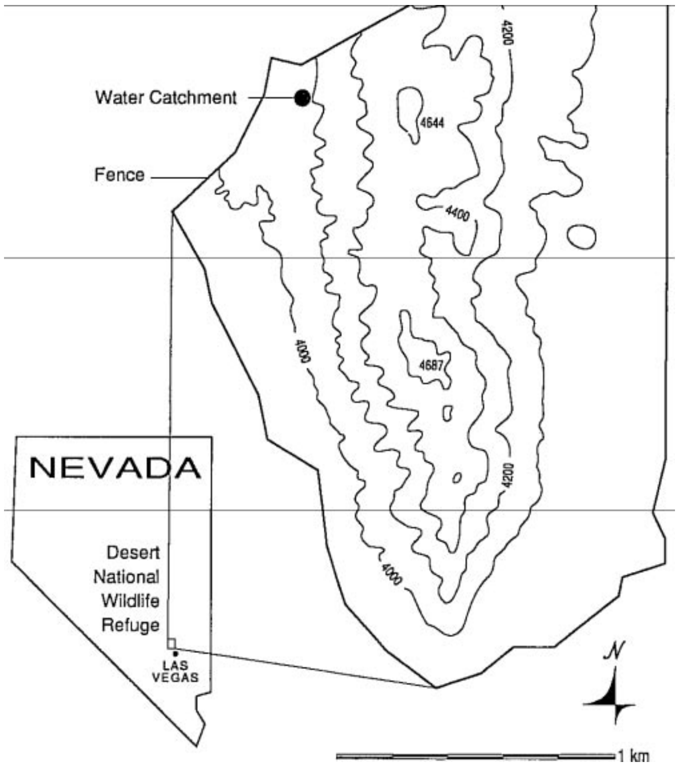

Fig. 1. Location of the 320-ha ***mountain sheep enclosure, Desert National Wildlife Refuge, Nevada,*** 1990–91.

Many difficulties exist in gathering accurate habitat use information from free-ranging ungulates (Wallmo et al. 1973). Habitat occupied by mountain sheep is often remote, and data collection is difficult because animal densities are low and home-range sizes are large (Morgart 1990). An opportunity to conduct an intensive habitat use study of mountain sheep occurred when the U.S. Air Force funded a study to investigate the effects of noise from low-elevation military jet overflights on mountain sheep in southern Nevada. During spring 1990 we constructed a 320-ha enclosure on the United States Fish and Wildlife Service (USFWS) Desert National Wildlife Refuge (DNWR) to contain mountain sheep for the overflight project (Fig. 1). Our study occurred prior to any overflights.

Restocking previously occupied habitat or suitable new habitat is used to develop new mountain sheep populations and to increase existing numbers (McCutchen 1975, McQuivey and Pulliam 1980, Kelley 1981, Elenowitz 1984, Morgart 1990). Because mountain sheep do not disperse readily (Geist 1967), reintroductions are important to mountain sheep management (Geist 1975, Hansen et al. 1980, Rowland and Schmidt 1981).

Relocated mountain sheep exhibit fidelity to release sites, and establish home ranges in the vicinity of the release (Bavin 1980, McQuivey and Pulliam 1980, deVos et al. 1981, Morgart and Krausman 1981, Smith 1985). Habitat quality and quantity should be determined for potential transplant sites before reintroductions take place (Geist 1975, Brown 1983, Miller and Gaud 1989, Stegman 1990). An understanding of seasonal habitat use and activity patterns of mountain sheep provides a measure of evaluation and management for introduced mountain sheep populations.

Advantages of studying an enclosed population include the opportunity to observe animals at close range for extended periods (Morgart 1990). The disadvantage of studying animals in an enclosure is that habitat preference and home range can not be investigated (Peek 1986: 83). The enclosure was large enough to contain a representative cross-section of available topographic features and vegetation, yet small enough to limit animal movements to an area where they could be consistently monitored. Hogan et al. (1988) reported that large enclosures allowed captive Asiatic wild horses (*Equus przewalski*) to exhibit natural activity patterns and social interactions compared to small enclosures. No attempts were made to domesticate the animals, and supplemental feed was not provided during our study.

Habitat for wildlife is the complex of physical variables on the range occupied by a species (Whittaker et al. 1973). The concept of habitat selection order is discussed by Johnson (1980). We define habitat selection as a choice among available resources, habitat preference as choice of 1 habitat area over another without regard to availability, and habitat use as occupation of a habitat without regard to preference (Peek 1986:83). Preferred habitats described for desert races of mountain sheep include foraging areas, bedding areas, escape cover, lambing areas, and water resources (Wilson et al. 1980, Scotter 1980). The objectives of our study were to 1) quantify resource availability in the enclosure for mountain sheep so we could 2) evaluate mountain sheep use of vegetation associations and topography by age, sex, and season.

STUDY AREA

Our study took place in a 320-ha enclosure in the northeastern comer of DNWR, approximately 150 km north of Las Vegas, Nevada (Fig. 1). The DNWR provides the largest continuous block of habitat for desert races of mountain sheep in Nevada, and supports the largest population of this race in the United States (Brown et al. 1977). The refuge encompassed >6,000 km² of desert and mountain habitat and was established

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Table 1. Species indicators for 9 vegetation associations in a 320-ha mountain sheep enclosure, Desert National Wildlife Refuge, Nevada, 1990–91.

Association	Availability (%)	Indicator species	Common name
Main wash	2.1	*Larrea tridentada*	Creosote bush
		Ambrosia eriocentra	Wooly bursage
		Eplzedra nevadensis	Mormon tea
West bajada	9.2	*Yucca brevifolia*	Joshua tree
		Atriplex confertifolia	Shadscale
		Ephedra rzevadensis	Mormon tea
East bajada	27.7	*Coleogyne ramosissima*	Blackbrush
		Larrea tridentada	Creosote bush
		Menodora spinescens	Spiny menodora
West midslope	15.5	*Atriplex confertifolia*	Shadscale
		Eplzedra nevadensis	Mormon tea
		Stipa speciosa	Desert needlegrass
East midslope	18.4	*Atriplex confertifolia*	Shadscale
		Ephedra nevadensis	Mormon tea
		Hilaria rigida	Big galleta
West draws	9.2	*Arternesia bigelovii*	Flat sage
		Ephedra nevadensis	Mormon tea
		Muhlenbergia porteri	Bush Muhly
East draws	9.5	*Fallugia paradoxa*	Apache plume
		Atriplex confertifolia	Shadscale
		Coleogyne ramosissima	Blackbrush
Ridgetop	2.1	*Coleogyne ramosissima*	Blackbrush
		Artemesia bigelovii	Flat sage
Blackbrush		*Ephedra nevadensis*	Mormon tea
	5.7	*Coleogyne ramosissima*	Blackbrush
		Yucca brevifolia	Joshua tree
		Larrea tridentada	Creosote bush

in 1936 primarily for the management and preservation of mountain sheep.

January and July temperatures average 7 and 30 C, respectively. Seasons were spring (Mar–May), summer (Jun–Aug), fall (Sep–Nov), and winter (Dec–Feb), based on rainfall and temperature data from Pahranagat National Wildlife Refuge, Nevada, 15 km northeast of the study area.

Rainfall varied from 2.5 to 13 cm a year, and occurred mostly during winter and spring. Snow covered the higher peaks in winter, and scattered cloudbursts occurred mostly during summer (Hansen 1980). Water was scarce; most drainages had only intermittent flows that depended entirely on local rainfall patterns. Two 10,000-L water tanks were placed on the bajada of the west-facing slope at 1,300 m and always contained water.

The elevation and vegetation characteristics in the study area were similar to most of the habitat occupied by mountain sheep in southern Nevada (D. Delaney, Nev. Dep. Wildl., pers. commun.). In addition, free-ranging mountain sheep occurred in the nearby Pahranagat and Sheep ranges (McQuivey 1980). Vegetation inside the enclosure was typical of the desert scrub vegetation type described by Allred et al. (1963) and Bradley (1964). The enclosure fenceline encompassed the south half of a steep ridge of north–south orientation. Topography in the study area varied from low, rolling foothills to steep and rugged terrain characteristic of mountain sheep habitat; elevations ranged from 1,100 to 1,500 m.

METHODS

During 1–3 May 1990 we captured 14 mountain sheep in the north end of the Sheep Range (Desperation to Lamb canyon), DNWR, Nevada. Five adult females, 3 adult males, 1 yearling female, and 1 yearling male were fitted with radio transmitters (Model HP, Telonics, Inc., Mesa, Ariz.) and released into the enclosure (Berner 1992). Two additional adult female mountain sheep were captured and released into the enclosure without collars. All animals were captured with a net-gun (Krausman et al. 1985*a*) from a Bell Jet Ranger helicopter. Captured animals were transported by helicopter-sling to a base camp where they were aged, collared, and held in a modified horse trailer until their release into the enclosure at the end of the day. The enclosure was located 60 km north of the capture site.

We visually delineated habitat associations in the enclosure. We calculated relative availability of slope and vegetation associations with a non-mapping technique (Marcum and Loftsgaarden 1980) with 525 random points (Thompson 1987) plotted on a 7.5 minute topographic map of the study area. We assigned every random point to 1 of the 9 vegetation associations and 5 slope classes, and summed the number of points in each area to calculate the relative availability of each association. Botanical nomenclature follows Kearney and Peebles (1960).

We quantified composition of vegetation associations using the line intercept method (Canfield 1941). We measured plants encountered on 16 randomly placed 30-m line intercept transects in each vegetation association during summer and winter seasons. We recorded thermal cover (any structure or vegetation ≥1-m high beneath which a standing or bedded mountain sheep could seek shelter from direct sunlight [Gionfriddo and Krausman 19861) for all transects.

We collected activity data using instantaneous scan sampling to monitor the 12 individuals, observing 1 animal at a time (Altmann 1974). We observed each group member in turn and noted the first activity that occupied that individual for 10 continuous seconds (Krausman et al. 1989). We monitored bedding, foraging, standing, and moving. We recorded animal locations and movement data on a 7.5 minute topographic map. We classified locations for each animal as to the vegetation association in which they occurred to develop estimates for the percentage of time each sex and age class spent in each vegetation association (White and Garrott 1990). We began observations of location and activity 1 June 1990 during the summer season, 4 weeks after release.

We quantified habitat use patterns for mountain sheep by season for adult males, adult females, juvenile males, and juvenile females. We used locations of undisturbed individuals to determine relative use by the 4 age and sex classes of each of the 9 vegetation associations and 5 slope classes in the enclosure. We used Chi-squared statistics to test the null hypotheses that vegetation associations and slope classes were used

Table 2. Percent cover of plant species for 9 vegetation associations in a 320-ha enclosure on the Desert National Wildlife Refuge, Nevada, 1990–91.

Species	Common name	Vegetation associations[a] 1	2	3	4	5	6	7	8	9
Shrubs										
Ambrosia dumosa	White bursage	2.0	T[b]	1.3	T	1.7	T	3.0	2.3	
A. eriocentra	Wooly bursage		12.7							
Artemisia bigelovii	Flat sage	18.1					17.8		13.8	5.1
Atriplex canescens	Four-wing saltbush			7.1	T	T				
A. confertifolia	Shadscale	3.2	T	3.1	16.9	7.6	23.4	25.1	6.5	9.5
A. hymenelytra	Desert holly			T					T	
Ceratoides lanata	Winter fat		1.0		T	6.3	T	T	T	T
Coleogyne ramosissima	Black brush	14.7	64.6		7.9	29.2		10.0		9.9
Encelia frutescens	Brittle bush	T					3.3	1.2	1.2	T
Ephedra nevadensis	Mormon tea	21.9	2.2	5.4	21.5	8.2	25.8	20.2	16.6	7.5
Fallugia paradoxa	Apache plume	1.3							11.1	21.2
Haplopappus spp.	Haplopappus								T	
Hymenoclea salsola	Burro bush	T		16.5	1.3	T	T	T	2.6	8.6
Krameria parvifolia	Range ratany	9.0		T	T	1.3	1.6	T	2.1	1.4
Larrea triderztada	Creosote bush			35.9	3.6	14.1		T		T
Lycium andersonii	Wolfberry			12.7	T	2.6			T	T
Menodora spinescens	Spiny menodora	T	2.7	T	10.8	10.7		T		1.9
Psorothamnus fremontii	Indigo bush		4.7	1.4	4.7	T	4.7	T	T	T
Salazaria mexicana	Bladder sage		1.1	T	T	T			4.8	7.0
Salvia dorii	Purple sage		T			T				1.1
Stephanomeria spp.	Stephanomeria	T			T	T	2.8	T	5.6	3.5
Tetradymia glabrata	Littleleaf horsebrush	1.4		T	4.0	T	T	2.4	T	T
T. spinosa	Horsebrush					T				
Grass										
Aristida spp.	Three-awn					T		T	T	1.2
Bromus rubens	Red brome	T				T	T	T	T	T
Erioneuron pulchellum	Fluff grass	T	T	T	T	T	T	T	T	T
Hilaria rigida	Big galleta	T	1.1	T	T	2.0		11.9	T	4.6
Muhlenbergia porteri	Bush Muhly		T		T		T	T	14.2	3.0
Oryzopsis hymenoides	Indian ricegrass	T		T		T	1.7	T	3.9	T
Sitanion hystrix	Bottlebrush						T	T		
Stipa speciosa	Desert needlegrass	9.2	T	T	T	T	9.4	1.6	6.3	5.0
Succulents										
Agave utahensis	Utah agave	T					T		T	
Echinocerus engelmanii	Hedgehog cactus						T			
Ferrocactus acanthodes	Barrel cactus	T	T			T	T	T	T	T
Opuntia basilaris	Prickly pear	T				T		T		
Yucca brevifolia	Joshua tree	1.6	21.7	1.3	22.1	11.0	T	5.7	2.4	1.1
Forbs		4.2	T	T	T	2.8	3.5	3.0	4.3	1.8

[a] 1 = Ridgetop, 2 = Blackbrush, 3 = Main wash, 4 = West bajada, 5 = East bajada, 6 = West midslope, 7 = East midslope, 8 = West draw, 9 = East draw.
[b] T = <1%.

in proportion to availability (Neu et al. 1974, Byers et al. 1984). If the null hypothesis was rejected ($P < 0.05$), we employed Bonferroni simultaneous confidence intervals to construct a 95% confidence interval for proportions of time spent in each association by each sex and age class (Byers et al. 1984, Zar 1984). If the percent occurrence of a vegetation association or slope class fell outside of the corresponding confidence interval, we considered use different from availability.

RESULTS

Habitat Evaluation

We described 9 vegetation associations using 3 dominant plant species as indicators for each vegetation association (Table 1). Dominant plant species had the highest percent cover in each vegetation association (Table 2). There was no season effect on relative frequency or percent cover of plant species ($P > 0.05$).

Terrain providing escape cover (>60% slope) was limited to 22.1% of the enclosure. Thermal cover provided by vegetation structure was available under joshua trees (*Yucca brevifolia*) on west (22.1% cover) and east bajadas (11.0% cover).

Use of Vegetation Associations

Mountain sheep use of the 9 vegetation associations was not in proportion to availability. The blackbrush (*Coleogyne ramosissima*) association, the main wash, east side bajadas, and east side draw associations were used less than expected in all seasons (Fig. 2). All other associations were used in equal or greater proportion than expected based on availability during ≧1 season by ≧1 sex or age class. All sex and age classes used the west aspect of the ridge more than the east aspect during all seasons ($P < 0.0001$).

Habitat use in summer was concentrated on the west side of the enclosure (98.2%) (Fig. 3). Bajadas, midslopes, and draw associations on the west side of the enclosure were used significantly more than

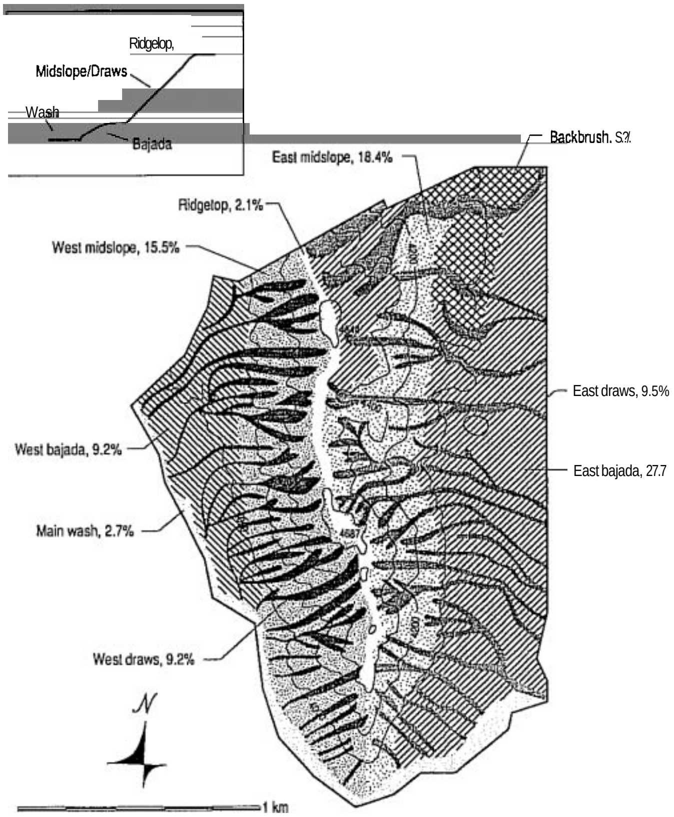

Fig. 2. ***Locations, andpercent composition of 9 vegetation associations in a 320-ha mountain sheep enclosure, Desert National Wildlife Refuge, Nevada, 1990–91.***

expected by all sex and age classes, except by adult males and thejuvenile female. Adult males used west-side draws as expected based on availability, and the juvenile female used west bajadas in proportion to availability. Use of west-side hajadas may have been affected by presence of the water catchment. The ridgetop was used less than expected by all age and sex classes except for the juvenile male, who used ridgetop areas more than expected. The east midslope association was used less than expected by all sheep during summer.

Habitat use in fall was concentrated on the west side of the enclosure (93.1%) (Fig. 4). Draws and midslope areas on the west side of the enclosure were used more than expected based on availability by all sheep. Bajadas on the west side were used more than expected by adult males, the juvenile male, and adult females. The juvenile female used west bajadas equal to availability. The ridgetop was used more than expected by all age and sex classes. The east midslope association was used less than expected by all age and sex classes during fall.

Habitat use in winter also was concentrated on the west side of the enclosure (87.9%) (Fig. 5). Midslope areas were used most (65.9%) by all sheep. Draw areas on the west side were used less than expected by all age and sex classes except adult females, who used draws more than expected. Bajadas on the west side were used more than expected by adult males and the juvenile male, in proportion to availability by the juvenile female, and less than expected by adult females. The ridgetop was used in proportion to availability by the juvenile male, and used less than expected for all other sex and age groups. The east midslope was used less than expected by all sheep.

Habitat use in spring was more evenly distributed than in other seasons, with 57.0% of all locations occurring in the 3 west-side vegetation associations (Fig. 6). West-side bajadas were used more than expected by males, and less than expected by females. Draws and midslope associations on the west side were used more than expected by all age and sex classes. The ridgetop was used more than expected by adult males, adult females, and the juvenile male, and in proportion to availability

Table 3. ***Relative availability, percent use, and 95% Bonferroni confidence intervals for 5 slope classes in a 320-ha mountain sheep enclosure, Desert National Wildlife Refuge, Nevada, 1990–91.***

Slope class (%)	Expected use	Actual use	Bonferroni CI	Use
0–10	0.219	0.066	$0.036 \le P_1 \le 0.096$	<
11–35	0.365	0.286	$0.236 \le P_2 \le 0.336$	<
36–60	0.195	0.361	$0.311 \le P_3 \le 0.411$	>
61–80	0.118	0.174	$0.134 \le P_4 \le 0.214$	>
>80	0.103	0.112	$0.082 \le P_5 \le 0.142$	=

by the juvenile female. Use of east side midslopes increased in spring compared to summer, fall, and winter seasons. Females used east midslopes more than expected during spring. Though use of east midslope associations by males increased in spring, use was still less than availability.

Use of Slope

Mountain sheep were observed on 2 slope classes (36–60 and 61–80%) more than others (Table 3). Middle slope areas (36–80%) represented 31.3% of available terrain, and contained 53.5% of all locations. Use of 5 slope classes differed from availability ($P < 0.0001$). Areas ≤36% slope were used less than expected based on availability ($P < 0.05$) in all seasons by all sheep; slopes ≥80% were used as expected based on availability.

Use of Thermal Cover

Thermal cover was most abundant where it was provided by topography in steep canyons and on north-facing slopes. Thermal cover available from vegetation structure was limited to joshua trees and large creosote bushes (Larrea *tridentada*). Joshua trees on the west bajada represent 22.14% of available plant cover for that association, and were used by bedded mountain sheep for thermal cover during 20.2% of observations of bedded individuals.

DISCUSSION

Our study was conducted in 1 of the largest mountain sheep enclosures constructed to date. The only other study of mountain sheep habitat use in a large enclosure was conducted by Morgart (1990) in the Virgin Mountains, Arizona. The size and placement of the enclosure for this study and that by Morgart (1990) ensured that preferred mountain sheep habitat areas were available (Gysel and Lyon 1980, Wilson et al. 1980). Such conditions allowed intensive monitoring of habitat use patterns of individual animals for extended periods under natural, controlled, conditions. Other translocations have used smaller enclosures (Howard and DeLorenzo 1975, McCutchen 1975, Elenowitz 1984), or provided supplemental feed (Hailey 1971, McCutchen 1975). Furthermore, these enclosure projects have concentrated primarily on producing stock for release programs, placing less emphasis on ecological investigations of study animals (Morgart 1990).

Habitat Use Patterns

In general, the enclosure was large enough and provided enough vegetation and topographic features to allow animals to exhibit habitat use patterns characteristic of free-ranging mountain sheep. Observed use of west-side bajada associations may have been affected by presence of the water catchment on the west side of the enclosure.

Numerous studies have reported that adult male and female mountain sheep seasonally segregate, both spatially and by use of habitat (Geist 1971:71, McQuivey 1978, Chilelli and Krausman 1981, Tilton and Willard 1982, Burger 1985). Ewe-juvenile groups are often found on more rugged, precipitous terrain than male groups (Geist and Petocz 1977, Lenarz 1979).

Segregation behavior was observed during winter (Dec–Feb), when

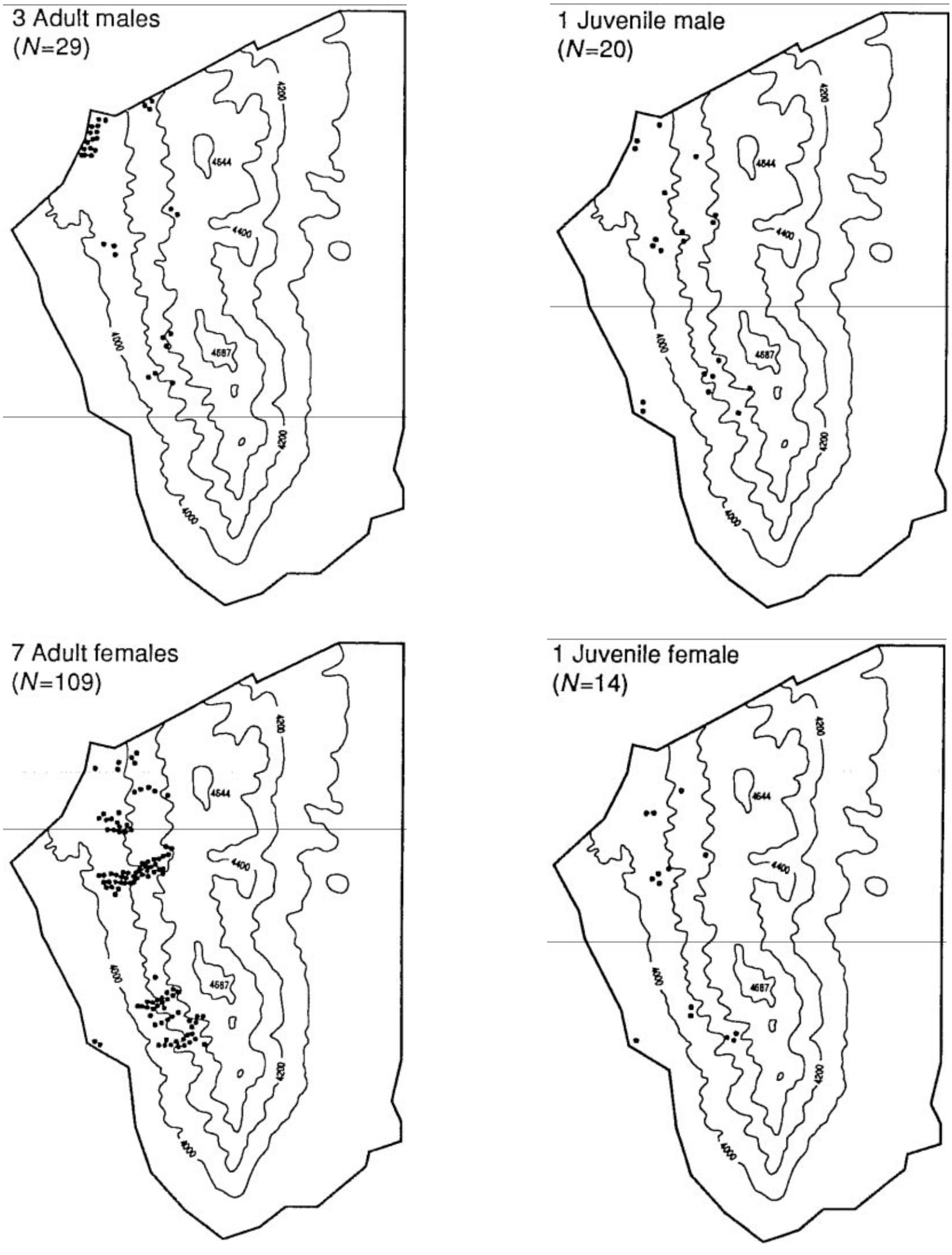

Fig. 3. Distribution of mountain sheep during summer (Jun–Aug) for 4 sex and age classes in a 320-ha enclosure, Desert National Wildlife Refuge, Nevada, 1990–91. (N = no. locations).

adult males used the west bajadas more and west draw associations less than expected, while adult females used west bajadas less and west draw associations more than expected. During the spring season (Mar–May), females used east and west bajada associations less than expected, and east and west midslopes more than expected. Males used west bajadas more than expected during spring. Elenowitz (1984) and Morgart (1990) found that females used isolated area in higher and more rugged terrain during lambing. Females remained isolated from male groups through the spring, using higher elevation areas near escape terrain, while males used bajada and lower midslope areas. One hypothesis proposed to explain seasonal segregation is that it reduces intraspecific competition for forage resources, and minimizes disturbance of pregnant or lactating females (Geist and Petocz 1977).

Use of Slope

Mountain sheep require areas of steep, rocky habitat, consisting to a large degree of rugged, broken terrain (Ferrier and Bradley 1970, Holl 1982, Krausman and Leopold 1986). The distance between broken

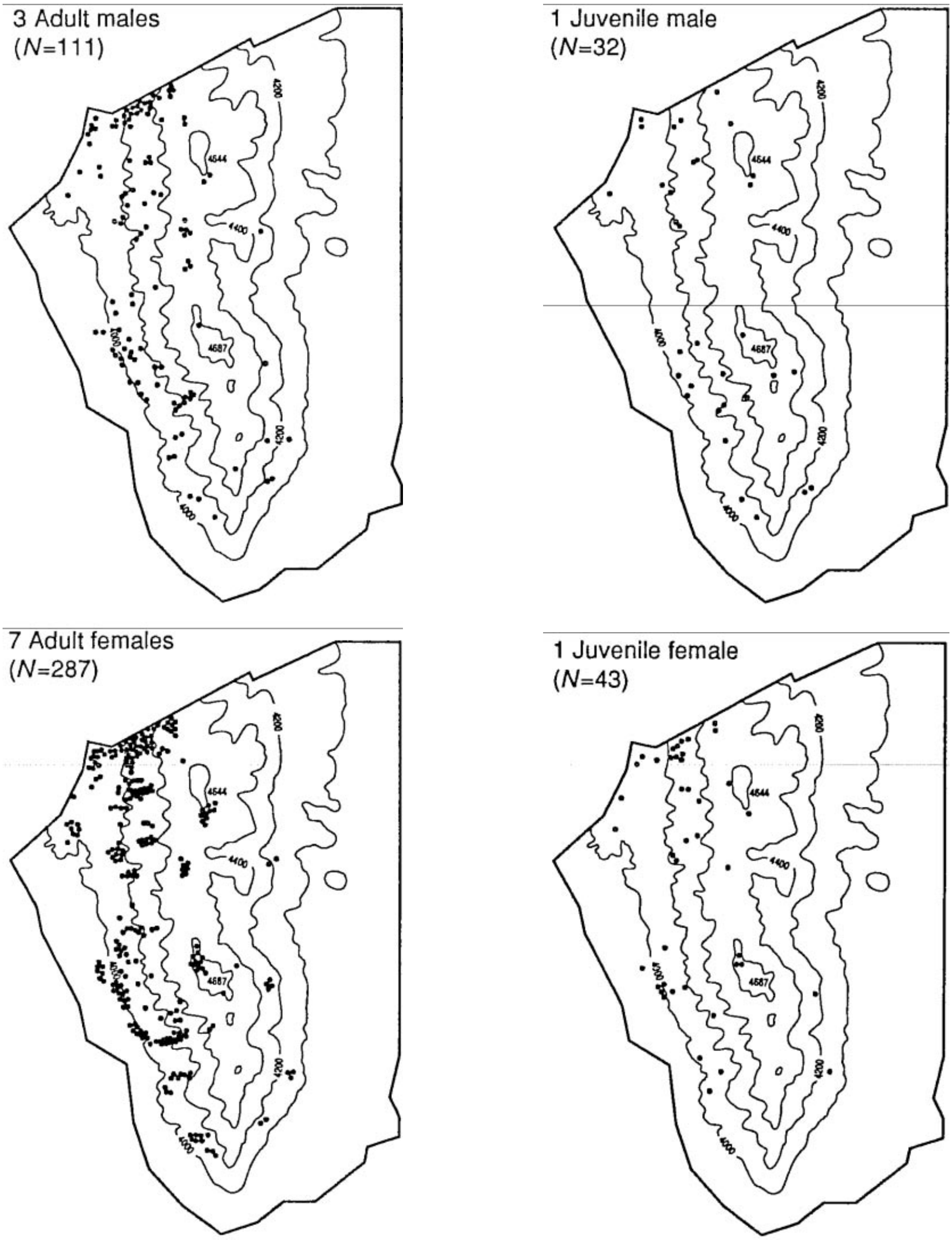

Fig. 4. Distribution of mountain sheep during fall (Sep–Nov) for 4 sex and age classes in a 320-ha enclosure, Desert National Wildlife Refuge, Nevada, 1990–91. (N = no. locations).

terrain with >60% slope and other habitat components may influence how often such components, such as forage (McQuivey 1978), or water (Douglas and White 1979, Leslie and Douglas 1979) are used. Use of 36–80% slope areas dominated mountain sheep habitat use. Similar use of slope was reported by Elenowitz (1984).

Escape terrain is defined as steep, rocky terrain on which mountain sheep would be able to safely outdistance or outmaneuver predators (Gionfriddo and Krausman 1986). Desert mountain sheep are rarely found ≥1 km from escape terrain (Jorgenson 1974, Hicks and Eider 1979, Bates and Workman 1983, Dodd 1983, Cunningham and Ohmart 1986). Although no part of the enclosure was ≥1 km from escape terrain, >95% of all mountain sheep locations were ≤0.5 km from areas of escape cover. Elenowitz (1984) documented >90% of all mountain sheep locations within 75 m of escape terrain during all seasons.

Activity Patterns

Activity patterns were crepuscular in all seasons. Krausman et al. (1985*b*) showed that mountain sheep activity is inversely correlated

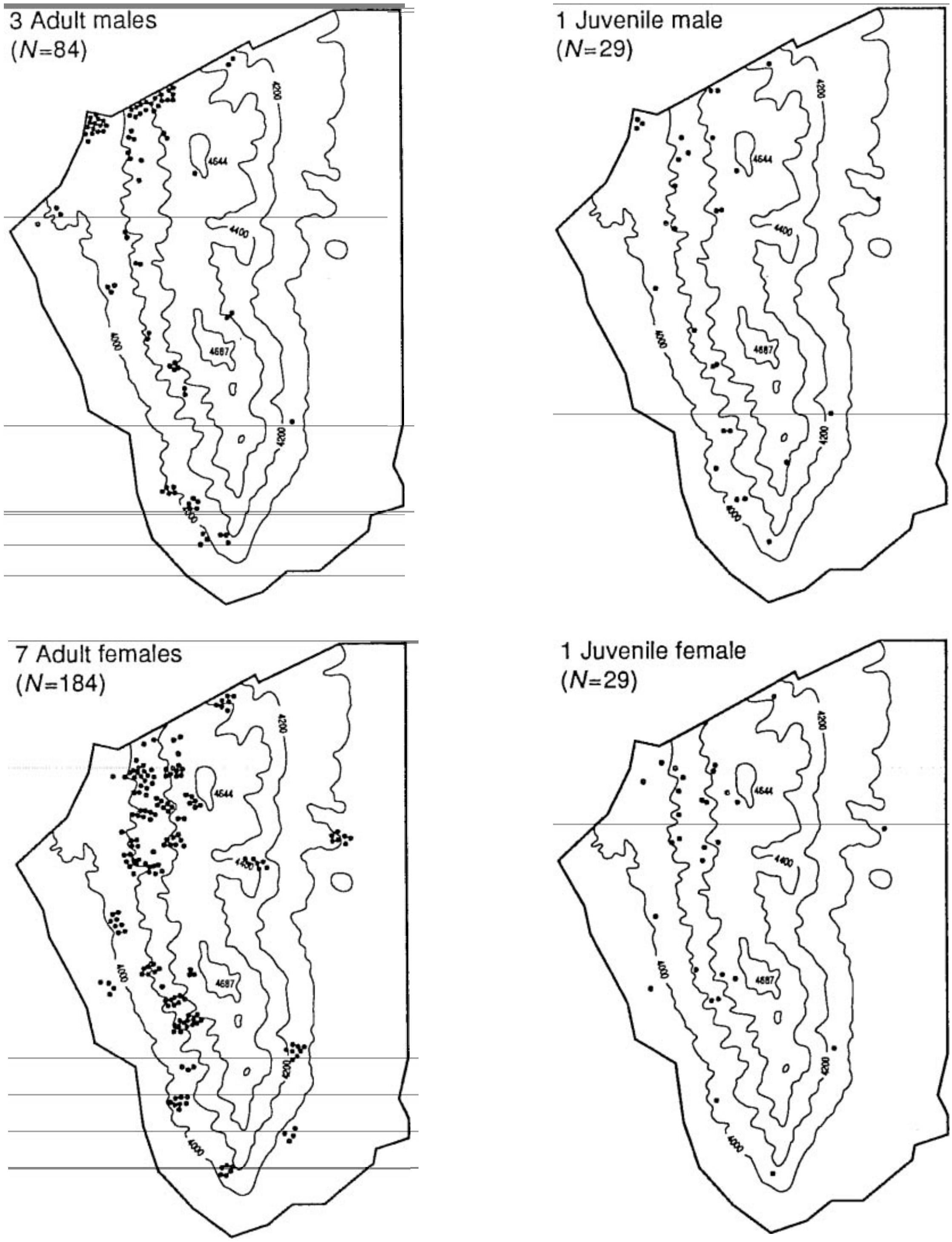

Fig. 5. Distribution of mountain sheep during winter (Dec–Feb) for 4 sex and age classes in a 320-ha enclosure, Desert National Wildlife Refuge, Nevada, 1990–91. (N = no. locations).

with ambient temperature. This suggests that crepuscular activity is a strategy used by mountain sheep to avoid excessive heat or exposure to direct solar radiation during mid-day hours. Most feeding activities occurred early and late in the day, and animals bedded during mid-day periods. Timing of foraging and bedding activities was similar for males and females. Similar activity patterns have been recorded in other studies (Wilson 1968, Golden and Ohmart 1976, Chilelli and Krausman 1981, Krausman et al. 19856, McCutchen 1984).

Large portions of the study area were not used or were used less than availability. There are several explanations for this. The availability of perennial bunch grass appears to affect microhabitat selection (Steel and Workman 1990), and has been used as an index of forage suitability for mountain sheep (Barrett 1964, Wilson et al. 1980, Holl 1982, Brown 1983). As the percentage of perennial bunch grass increases, the suitability of the area as mountain sheep habitat also increases (Femer and Bradley 1970, Hansen 1980, Holl 1982).

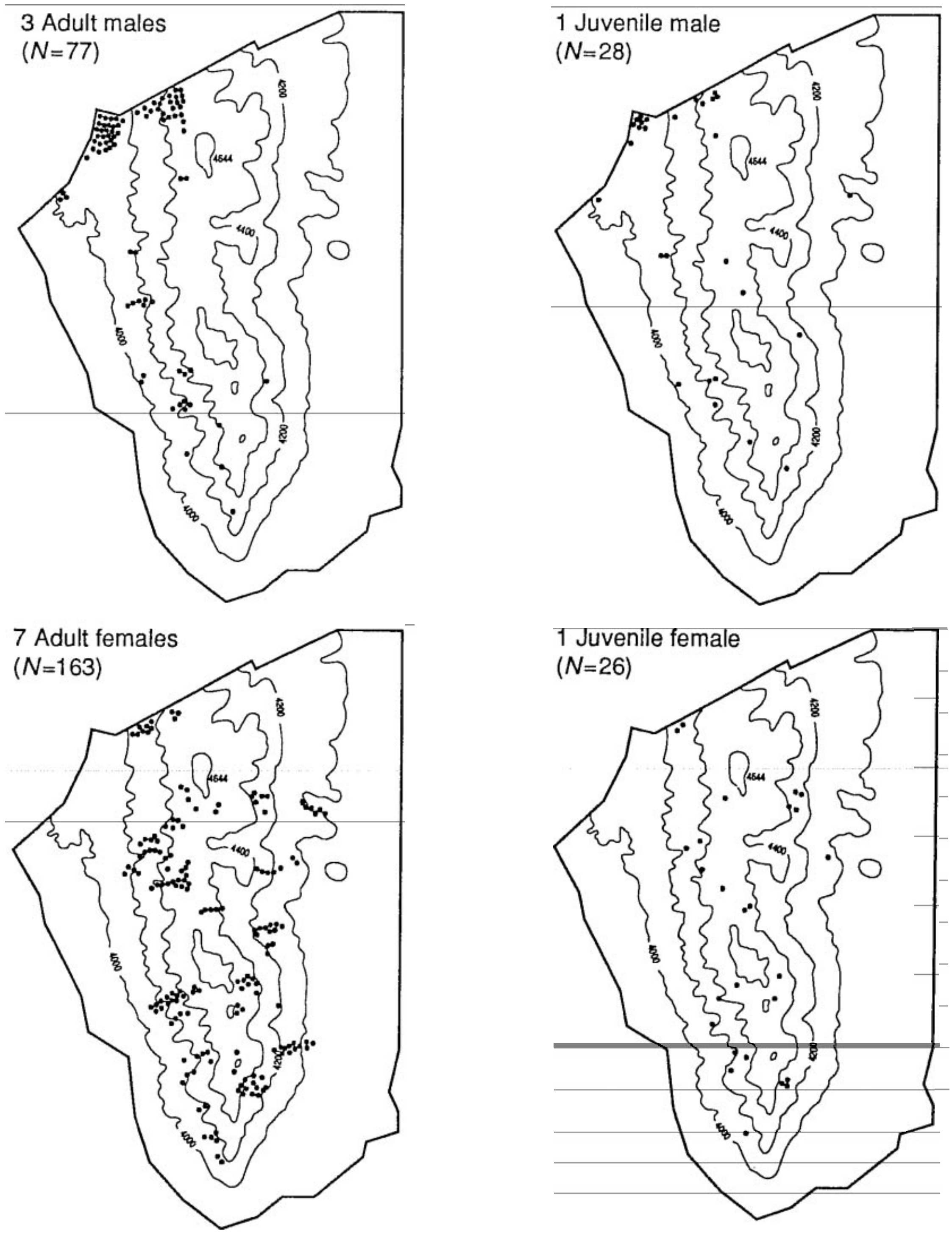

Fig. 6. Distribution of mountain sheep during spring (Mar–May) for 4 sex and age classes in a 320-ha enclosure, Desert National Wildlife Refuge. Nevada, 1990–91. (N = no. locations).

East and west bajadas had <3% cover of grass species (Table 4). West-side bajadas were the only vegetation association with <5% grass that were used more than expected based on availability. This may be due to the high percentage of bed sites on west-side bajadas, and the proximity of bed sites to available grass on the midslope. All other associations with <5% available grass were used less than expected by all sheep in all seasons. East side midslopes and draws each contained >10% grass, but neither association was used until the spring season.

Habitat use studies generally agree that forage is selected at the microhabitat level (Ferrier and Bradley 1970, McQuivey 1978, Holl 1982, Van Dyke et al. 1983, Bates 1982). However, Steel and Workman (1990) offer 3 possible explanations for situations where forage selection may not occur at the microhabitat level: 1) the forage base may be homogeneous; 2) moderate forage quantity may supply adequate nutrition for growth and reproduction; or, 3) the need for security factors is large due to reintroduction stress. We feel that habitat use was concentrated

Table 4. Relative availability and percent cover of forage classes present for 9 vegetation associations in a 320-ha mountain sheep enclosure, Desert National Wildlife Refuge, Nevada, 1990–91.

Vegetation association	Relative availability	% cover of forage classes: Shrubs	Grasses	Forbs	Succulents
Ridgetop	0.021	82.94	9.89	4.22	2.94
Blackbrush	0.057	76.78	1.38	T[a]	21.79
Main wash	0.027	98.41	T	T	1.28
West bajada	0.092	74.60	2.95	T	22.14
East bajada	0.277	83.84	2.39	2.76	11.01
West midslope	0.155	80.96	11.63	3.56	3.85
East midslope	0.184	75.41	15.59	2.96	6.04
West draws	0.092	66.29	26.28	4.29	3.14
East draws	0.095	82.8	14.26	1.78	1.17

[a]T = <1%.

on the west side of the enclosure because of the high percentage of grass species on west-side vegetation associations, and because the water catchment was located on the west side of the enclosure.

MANAGEMENT IMPLICATIONS

Construction of a large enclosure for a mountain sheep study allowed intensive monitoring of habitat use patterns during a 12-month period. Observations of habitat use patterns in the enclosure are similar to what has been described for free-ranging mountain sheep populations in other desert habitats (Chilelli and Krausman 1981, Elenowitz 1984, Gionfriddo and Krausman 1986, Krausman et al. 1989). In general, mountain sheep foraged in habitat that had >5% available grass, on slopes >36% slope, and within 0.5 km of escape terrain. Sexual segregation was observed during winter and spring months. Geist and Petocz (1977) reported similar patterns of segregation. Enclosure studies can be used to observe habitat use patterns of mountain sheep, providing that enclosures are large and contain an array of habitats. An important precursor to such studies should include a research design that simultaneously contrasts a local free-ranging population when possible. Intensive observation under controlled conditions may improve our understanding of mountain sheep habitat selection at the microhabitat level.

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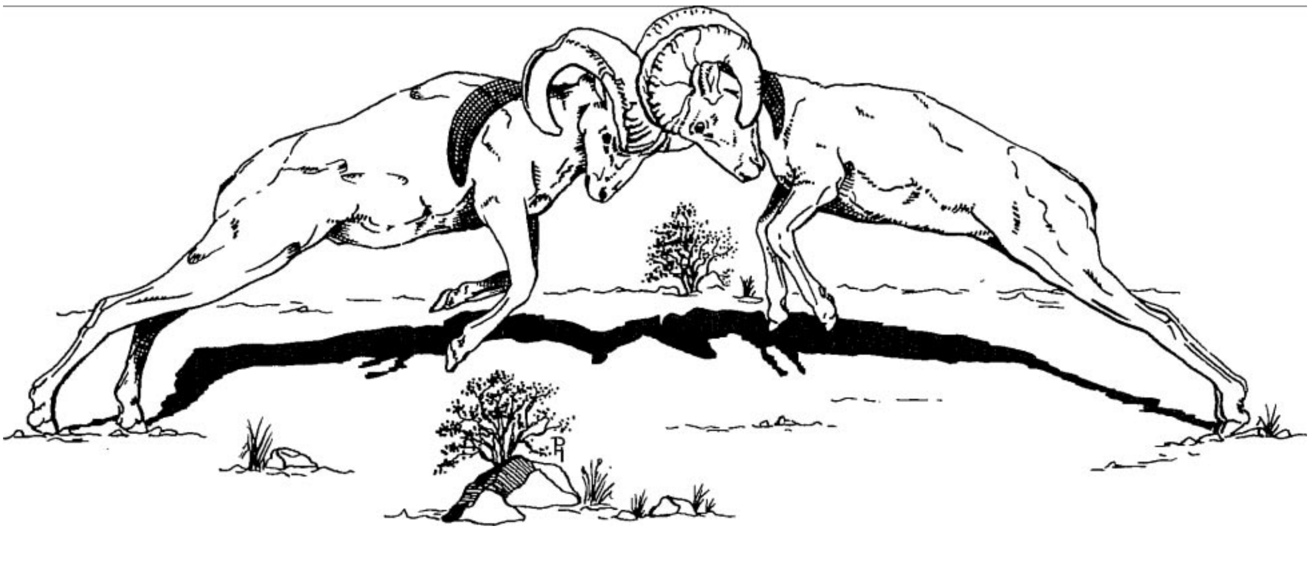

RESOURCE USE BY MOUNTAIN SHEEP IN A LARGE ENCLOSURE

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Abstract: We examined habitats used for foraging, and the forage consumed by mountain sheep (Ovis *canadensis nelsoni*) in a 3.2 km^2 enclosure on the Desert National Wildlife Range, Nevada. Sheep selected the mid-slope elevations of habitats with a western aspect for foraging; 91% of the forage sites had slopes ranging from 26 to 75%. Females foraged more on forbs during winter than did males ($P = 0.01$). Female foraging sites had more forbs during winter ($P < 0.05$), and more grass during spring ($P < 0.05$), than did male foraging sites. Forbs and grasses were selected for, and browse was selected against, in all seasons.

Key words: availability, enclosure, forage, habitat, Ovis *canadensis,* use.

Population sizes of desert races of mountain sheep are significantly smaller now than in the early 19th century and there is little sign of increasing recruitment rates, or independently increasing geographic distribution (Bailey 1980, Krausman et al. 1989). Among other things, management of these remaining populations requires an understanding of the interactions sheep have with their habitats, including the relationship between these animals and their food supply (Owen-Smith and Novellie 1982, Krausman et al. 1989).

The forage consumed by mountain sheep in the Southwest has frequently been quantified, but with few exceptions, this information has not been supplemented with data on availability of forage classes. Yoakum (1964, 1966) had small sample sizes, only examined male sheep harvested during the hunting season, and had few transects to assess the availability of vegetation over large areas. Elenowitz (1984) looked at use versus availability on an annual basis, but did not examine seasonal or sexual differences. Miller and Gaud (1989) only examined seasonal use and availability of perennial plant species, and based availability on transects covering whole mountain ranges. Morgart (1990) studied seasonal forage use of perennial plant species by male and female sheep in a 283 ha enclosure.

Our objectives were to examine: 1) habitat used for foraging relative to availability; 2) forage consumed by season for males and females; and 3) microsite forage use versus availability on a seasonal basis.

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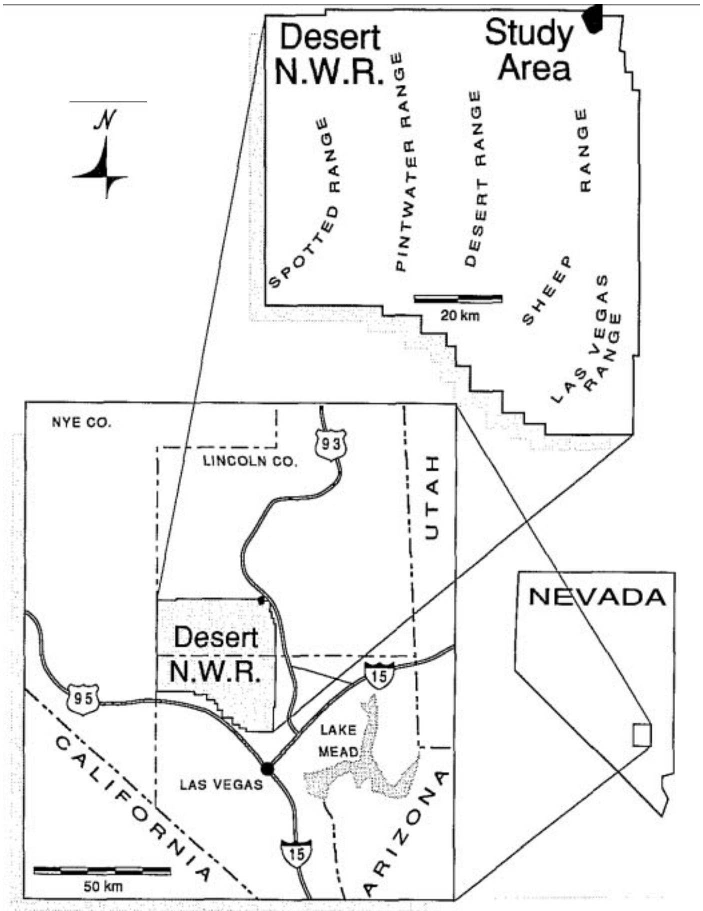

Fig. 1. Enclosure location in the Desert National Wildlife Range, Nevada, 1990–91.

STUDY AREA

A 3.2 km^2 enclosure was constructed on the northeast comer of the Desert National Wildlife Range, 150 km north of Las Vegas, Nevada (Fig. 1). This paper presents some results of research conducted from May 1990 to June 1991, which will in turn be used as baseline data for a larger project examining the effects of military jet overflights on the behavior and physiology of mountain sheep (Wallace et al. 1992).

The enclosed portion of a mountain included most of the habitats considered available to mountain sheep according to Burger (1985), with the exception of the pinyon pine (*Pinus monophylla*)/Utah juniper (*Juniperus osteosperma*) association. Burger (1985) found mountain sheep using this association less than expected based on availability in 3 of 5 seasons examined, but considered it used equal to expectancy based on availability overall. This study, therefore, examined use of habitats within the enclosure with respect to their availability, while it was known that those habitats within the enclosure did not include all of the habitats available to free-ranging mountain in the surrounding ranges.

The enclosed mountain had a north-south axis, with elevation ranging from 1,267 m in the wash along the west fence, to 1,562 m at the highest point. Two 11,400 L water tanks were placed on the upper bajada of the northwest side of the enclosure. The average daily high-low temperatures for summer (Jun–Aug), fall (Sep–Nov), winter (Dec–Feb) and spring (Mar–May) were 36–17, 26–6, 13–(−4), 21–4 C, respectively. Approximately 33% of the precipitation from May 1990 to May 1991

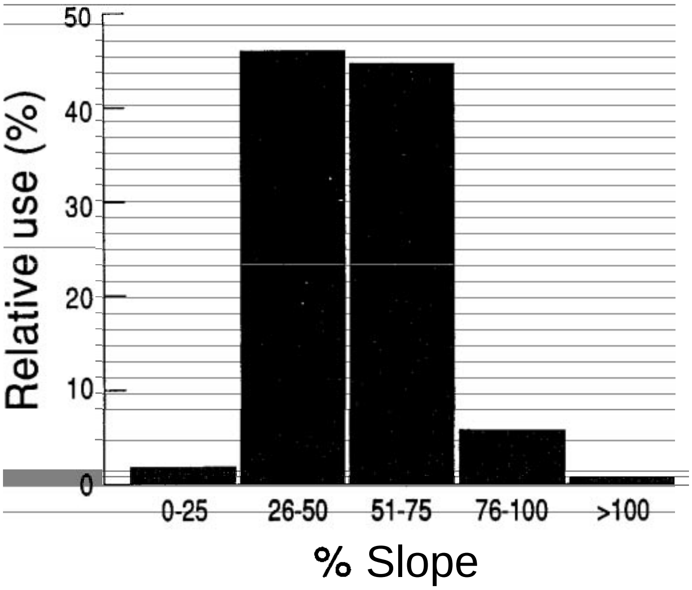

Fig. 2. The slope (%) of mountain sheep foraging sites (n = 539) in a 3.2 km² enclosure in the Desert National Wildlife Range, Nevada, 1990–91.

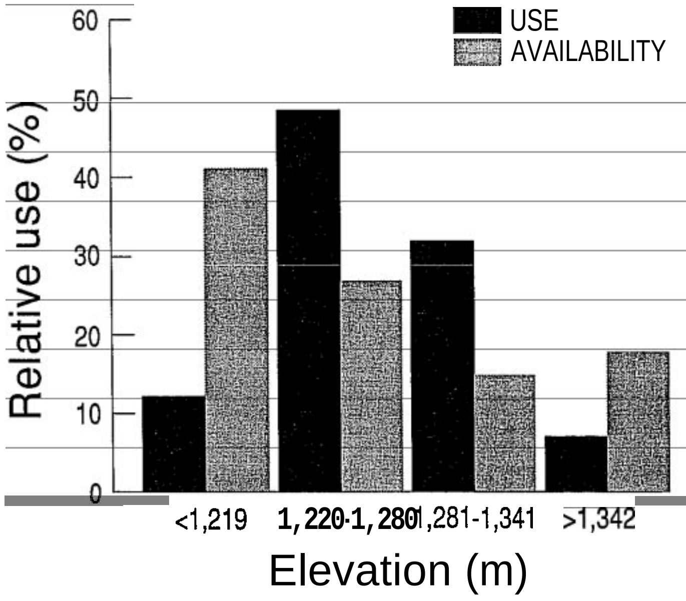

Fig. 3. The use and availability of elevation (m) for foraging by mountain sheep (n = 525) in a 3.2 km² enclosure in the Desert National Wildlife Range, Nevada, 1990–91. Elevations <1,220 m are bajadas, 1,220 to 1,341 represent midslopes, and >1,341 include ridgetops.

(12.6 cm) fell in both winter and summer, and 17% fell in both fall and spring. The rainfall for the year long study was 24% lower than the average annual precipitation of 15.5 cm for 17 years of data from 1965 to 1987.

The enclosure lies entirely within the desert scrub vegetation association described by Bradley (1964). Plants found on the flats are creosote bush (Larrea *tridentata*), and joshua tree (*Yucca brevifolia*). The bajadas are represented by big galleta (*Hilaria* rigida), bush muhly (*Muhlenbergii porteri*), and Mormon tea (*Ephedra nevadensis*). Higher up the south slopes four-winged saltbush (Atriplex *canescens*) and shadscale (Atriplex *confertifolia*) began to dominate vegetation. Winter fat (*Ceratoides lanata*) was prevalent in the washes, and blackbrush (*Coleogyne ramossissima*) was most often found on the east side. Scientific nomenclature of plants follows Bradley (1964).

METHODS

Twelve sheep were captured with a net gun (Krausman et al. 1985) on 1 and 2 May 1990, and were transported 50 km north to the enclosure and released. The population within the enclosure consisted of 1 yearling female, 7 adult females, 1 yearling male, and 3 adult males.

We radio-collared 10 of the 12 sheep with 5 differently colored collars (Telonics, Inc., Mesa, Ariz.) to assist in the location and identification of individual sheep. The 2 sheep without collars were females that were physically distinguishable. The collars were color coded so that individuals with the same color were of opposite sex. The exception to this were 2 females with the same color collar that were physically distinct.

From May 1990 to June 1991 we collected data daily on the enclosed population of sheep. We used scan sampling with 10 minute sampling intervals (Altmann 1974, Martin and Bateson 1986), and recorded the first behavior that lasted 10 consecutive seconds as foraging, bedding (plus noting whether the individual was in the shade), standing without foraging, moving without foraging, or social (i.e., interacting with another individual). If an individual was foraging, the vegetation class used was recorded as browse (woody perennials), forb (herbaceous perennials and annuals), grass, other (primarily succulents), or unknown.

We used line transects to assess the availability of the vegetation classes at the site of the first foraging scan in a foraging bout (Canfield 1941). We used universal transverse mercator (UTM) grids to record the location of the first foraging scan, and mapped specific physical features of the site to facilitate relocation. We returned to the foraging site within 48 hours and assessed the total crown area of each class (Gysel and Lyon 1980), elevation, and slope, provided that we were able to identify the vegetation class in ≥50% of the forage scans in a foraging bout. Foraging bouts were recorded as independent as long as the individual exhibited behaviors other than foraging, and/or was out of sight, for ≥2 consecutive scans, and the distance between the location of the initial forage scan was ≥30 m (the length of a transect). We determined the direction of the transect from a random numbers table.

We compared the availability of browse, forbs, and grasses at the foraging site to their use with Chi-square analysis and Bonferroni simultaneous confidence intervals at the 0.05 level of significance (Byers et al. 1984). We used Mann-Whitney U-tests to compare forage class use, and availability of forage classes at the foraging site, of male and female sheep within seasons. We used Kruskall-Wallis one-way analysis of variance (ANOVA) tests to examine forage use, and availability, between seasons for both groups. We did not include summer vegetation availability data because of small sample size.

Table 1. Habitat use by mountain sheep in a 3.2 km² enclosure in the Desert National Wildlife Range, Nevada, 1990–91.

Habitat[a]	% expected use	% observed use	Bonferroni confidence interval	U/A[b]
1	9	15	0.15 ± 0.030	>
2	16	35	0.30 ± 0.040	>
3	9	26	0.26 ± 0.037	>
4	2	1	0.01 ± 0.008	<
5	10	9	0.09 ± 0.024	=
6	18	10	0.10 ± 0.025	<
7	28	4	0.04 ± 0.017	<
8	6	1	0.01 ± 0.008	<
9	3	<1	0.004 ± 0.005	<

[a] 1 = west bajada, 2 = west midslope, 3 = west drainage, 4 = ridgetop, 5 = east drainage, 6 = east midslope, 7 = east bajada, 8 = blackbrush, 9 = flats.

[b] Use relative to availability assessed at the 0.05 level of significance for each comparison, following Byers et al. (1984).

Table 2. Forage class (median %) use by mountain sheep in a 3.2 km^2 enclosure on the Desert National Wildlife Range, Nevada, 1990–91.

	Diet					
	Browse		Forb		Grass	
Season	M	F	M	F	M	F
Summer[a]	30.00	29.45	0.00	2.35	70.00	65.80
Fall	18.35	14.65	1.05	2.30	81.65	83.20
Winter	31.35	32.45	4.40	14.80	64.25	52.00
Spring	55.55	52.40	21.95	13.75	19.45	34.55
P-value[b]	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05

[a] Summer = Jun–Aug, Fall = Sep–Nov, Winter = Dec–Feb, Spring = Mar–May.
[b] Kruskall-Wallis one-way ANOVA results of forage class use by season.

RESULTS

Mountain sheep selected habitats on the western side of the mountain for foraging (n = 1,068, Table 1), with 91% of the forage sites (n = 539) having slopes between 25 and 75% (Fig. 2). The bajada (<1,219 m) and ridgetop (>1,342 m) were used less for foraging than expected based on availability in the enclosure, and the lower (1,220 to 1,280) and upper (1,281 to 1,341) midslope elevations were used greater than they were expected based on availability ($P < 0.05$) (Fig. 3).

Males and females used each forage class differently between seasons (Table 2). Males and females used browse more in spring, and less in fall, than in any other season. Both groups used grass more in fall, and least in spring. Forb use was greatest for males and females in winter. Females used significantly more forbs than males in winter (W = 10, 4,8 df, $P < 0.01$; Table 2).

Females foraged at locations with more forbs during winter (W = 11, 4,8 df, $P < 0.05$), and more grass during spring (W = 12, 4,8 df, $P < 0.05$), than male foraging locations. Only the availability of grass at the foraging sites of male (H = 7.35, 2 df, $P < 0.05$) and female (H = 7.44, 2 df, $P < 0.05$) sheep differed between seasons, peaking in fall for both groups (Fig. 4).

Male and female sheep used browse less than expected based on availability, and forbs and grasses were used greater than or equal to expectancy based on availability in every season examined (Table 3).

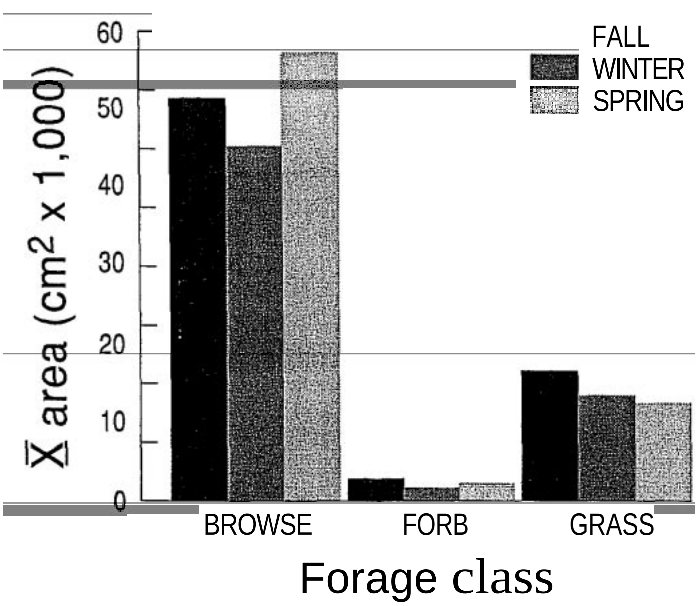

Fig. 4. The mean availability of forage classes at the foraging site (n = 525) of mountain sheep in an enclosure in the Desert National Wildlife Range, Nevada, 1990–91.

Table 3. Forage use by mountain sheep in a 3.2 km^2 enclosure in the Desert National Wildlife Range, Nevada, 1990–91.

Season[a]	Sex	Forage[b] type	Expected use (%)	Observed use (%)	U/A[c]
Fall	M	Br	68	23	<
	F	Br	74	37	<
	M	Fb	3	3	=
	F	Fb	4	3	=
	M	Gr	29	74	>
	F	Gr	22	61	>
Winter	M	Br	74	29	<
	F	Br	76	31	<
	M	Fb	3	4	=
	F	Fb	3	15	>
	M	Gr	24	67	>
	F	Gr	21	54	>
Spring	M	Br	84	55	<
	F	Br	77	53	<
	M	Fb	4	25	>
	F	Fb	3	15	>
	M	Gr	12	20	=
	F	Gr	19	32	>

[a] Fall = Sep–Nov, Winter = Dec–Feb, Spring = Mar–May.
[b] Br = browse, Fb = forb, Gr = grass.
[c] Use relative to availability measured at the 0.05 level of significance for each comparison, following Byers et al. (1984).

DISCUSSION

Mountain sheep use of elevation for foraging was similar to other studies examining general activity in relation to elevation (Elenowitz 1984, Cunningham and Ohmart 1986). Cunningham and Ohmart (1986) did, however, note mountain sheep using slopes much greater than our study for some activities.

Selection of habitats on the western side of the mountain is difficult to interpret. Foraging may have occurred primarily on the western aspects because of the availability of water on the northwest area of the enclosure, as the population of mountain sheep used water during all months of the year. On the other hand, use of the western aspects of mountains has been found in other studies (Elenowitz 1984, Cunningham and Ohmart 1986).

Beatley (1974) discussed seasonal variation in forage availability with respect to rainfall in the Desert National Wildlife Range. Because we measured availability at the foraging site, we cannot differentiate between seasonal variation in availability and selection of foraging sites. Seasonal variation in availability of browse species was noted, however, by Kirkeeng (1985), and general variation in forage availability by Miller and Gaud (1989).

The male and female mountain sheep in our enclosure only differed in forb use during winter. This is consistent with studies by Smith and Krausman (1987), Krausman et al. (1989), Miller and Gaud (1989), and Morgart (1990), who found that with few exceptions, use of forage by mountain sheep generally does not vary with respect to sex. Morgart (1990), in a similar enclosure study (<100 km from our study site), found the highest nutritional indices for forbs in fall and winter. It may be, therefore, that females utilize forbs in ways that maximize nutritional intake during pregnancy (Berger 1991), as at least 6 of the 8 females were pregnant during winter. However, because rainfall in the Mojave Desert is so closely tied to plant phenology (Beatley 1974), caution should be taken when making conclusions with the use of phenological information from other studies.

Mountain sheep are preferential grazers as indicated by this and other studies examining the forage use of mountain sheep in the Mojave Desert ecosystem. Of 13 studies examining forage use, 9 found grass making up the greatest part of the diet (Barrett 1964; Yoakum 1964, 1966; Hansen and Martin 1973; Brown et al. 1975; Brown et al. 1976; McQuivey 1976; Brown et al. 1977; Morgart 1990). Only 3 of the 13 studies found browse species consumed as the greatest percent of the diet (Ginnett and Douglas 1972, Bates and Workman 1983, King and Workman 1984). However, mountain sheep (*O. c. mexicana*) in the Sonoran and Chihuahan deserts differ in their diets when compared to those in the Mojave Desert. Browse was the dominant plant consumed in 9 of 11 studies (Russo 1956; Weaver 1973; Walker and Ohmart 1978; Seegmiller and Ohmart 1981; Elenowitz 1984; Dodd and Brady 1986, 1988; Krausman et al. 1989; Miller and Gaud 1989). Only Hailey (1968) found grass making up the bulk of the diet in Texas. Leslie (1977), Seegmiller and Ohmart (1981), and Miller and Gaud (1989) all have attributed the increased consumption of browse in the Sonoran Desert as being a function of decreased availability of grasses.

It would be constructive for future studies examining the forage use of mountain sheep to assess the availability of the forage classes as well. Furthermore, to compare results from different studies, consistency in how use versus availability is analyzed is necessary. Of the studies that have examined use of forage versus its availability in mountain sheep (Yoakum 1966, Elenowitz 1984, Miller and Gaud 1989, Morgart 1990), no consistent pattern has emerged. This may be due to the different methods of analysis and/or data collection used in each study.

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MORTALITY OF MOUNTAIN SHEEP IN THE BLACK CANYON AREA OF NORTHWEST ARIZONA

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Abstract: We monitored 49 adult mountain sheep (Ovis *canadensis nelsoni*) in the Black Mountains, Arizona adjacent to Hoover Dam from August 1989 to November 1991 to document mortality. We documented 12 mortalities: 6 were caused from vehicle collisions while animals were trying to cross U.S. Highway 93, 2 were killed by coyote (*Canis latrans*) and 1 was killed by mountain lion (*Felis concolor*). Ewes with home ranges that crossed Highway 93 had a ≥24% chance of being killed while crossing the highway each year of the study.

Key words: Arizona, Black Canyon, highway, mortality, mountain sheep, Ovis *canadensis,* predation.

In the past, biologists thought mountain sheep populations were stable when mean recruitment and assumed adult mortality rates were equal (McQuivey 1978). Murie (1944) reported age-specific mortality in male Dall's Sheep (Ovis *dalli*) with high survival in mountain sheep between 1 and 8 years of age; mortality was focused in the young and old population segments. Woodgerd (1964), Geist (1971), and Hansen (1980) found the same mortality pattern among male mountain sheep (*O.* c. *canadensis* and *nelsoni*). These studies of male mortality relied on skull collections, with the underlying assumption the population had a pyramid shaped age distribution, and that skulls of different ages were equally likely to be recovered. However, Festa Bianchet (1989) found a much higher mortality rate for males aged 3 to 7 years old than reported from earlier studies and suggested that skull collections may provide a biased estimate of natural mortality.

Natural annual mortality of adult mountain sheep has been estimated from 17 to 22% (McQuivey 1978, Hansen 1980, Leslie and Douglas 1982, Whitam 1983). McQuivey (1978) suggested that a lamb : ewe ratio of26.5:100 was needed for a stable population. Remington (1989) found that a lamb : ewe ratio of 26.5:100 was more indicative of an increasing population (20–22:100 was considered stable), and estimated an annual mortality rate of 13% for mountain sheep in the Kofa Mountains, Arizona.

Our objectives were to determine productivity and mortality rates of mountain sheep along U.S. Highway 93 in northwest Arizona. At present the Bureau of Reclamation is considering realigning U.S. Highway 93 over a bridge to reduce traffic on top of Hoover Dam.

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STUDY AREA

Our study was conducted in the northern part of the Black Mountains, northwest Arizona near Hoover Dam. The Black Mountains parallel the Colorado River for approximately 80 km. Hoover Dam is located on the Colorado River approximately 113 km northwest of Kingman, Arizona, and 32 km southeast of Las Vegas, Nevada. United States Highway 93 passes through the northern half for of the Black Mountains for approximately 20 km and crosses the Colorado River at Hoover Dam. We centered most of our monitoring activity between mileposts 1 and 6.

Elevations in the study area ranged from 194 m at the Colorado River to 1,511 m at the top of Mount Wilson. Topography varies from mountainous terrain characterized by steep talus slopes and rugged cliffs broken by washes to rolling hills in alluvial drainages. Water sources for mountain sheep are abundant along the shore line of Lake Mead and the Colorado River. The study area supported 2 basic plant communities: the creosote bush (Larrea *tridentata*) bursage (*Ambrosia dumosa*) community and the desert wash community (Brown 1982). The creosote-bursage community was found on all terrain types except washes. The desert-wash community was located along washes >2 m and generally had a greater diversity of shrubs and higher plant communities. Common species unique to the washes included cat-claw (Acacia *greggii*), cheese bush (*Hymenoclea salsola*), and mesquite (Prosopis *glandulosa*). Large predators in the area include coyotes and mountain lions.

Highway 93 is primarily bordered by creosote-bursage but does intersect several washes. Topography adjacent to the highway from Hoover Dam south for 15 km was more of an alluvial nature but there were several cuts where the highway passed through steep blocks.

METHODS

We captured 49 mountain sheep with a net gun (deVos et al. 1984), and equipped them with radio collars with mortality sensors (Telonics, Inc., Mesa, Arizona) in August, September, and October 1989; January and October 1990; and February 1991. We recorded sex and age for each sheep captured. We determined ages and classes of rams by horn characteristics (Giest 1966). Ewes were aged by dentition.

We spent >16 days/month from August 1989 to November 1991 in the study area locating mountain sheep from the ground. In addition, all collared sheep were located >1 ×/10 days from the air using a Cessna 182 or 206 with a mounted belly antenna. When a mortality signal transmitted we immediately investigated the cause of death.

We determined number of lambs born/adult female by monitoring each radio collared female 3 to 4 ×/month from February to July. We tried to locate isolated females with lambs ≥1 ×/week to determine lamb survival. If the lamb survived >6 months we considered it recruited into the population.

If we had marked all animals at the onset of the study, calculation of survival and cause specific mortality rates as simple percentages would be appropriate (Hessler et al. 1970). However, because we captured animals on 5 separate occasions, during different periods of the year when survival rates differ, simple percentages might be biased. Therefore, we used computer software known as MICROMORT (Heisey and Fuller 1985) in which time is partitioned into intervals during which daily rates are assumed to be constant. The interval rates are estimated from the length of an interval, the number of mortalities due to particular causes, and the number of transmitter days in each interval. This system also allows for calculation of variances and confidence intervals, and thus comparison of mortality rates between seasons and mortality causes.

We used seasons for interval length in examining survival rates. Summer was from 16 May to 15 September, fall from 16 September to 15 November, winter from 16 November to 15 February, and spring from 16 February to 15 May. Summer included periods of highest temperatures and water requirements, the period of greatest movement was during fall, and the spring lambing period. Hunting occurred in winter.

We analyzed mortality by examining ewes whose home range crossed the highway, those who never crossed Highway 93, all ewes collectively, and all rams collectively. Only 1 ram had a home range that did not cross Highway 93. We examined survival between Class II and Class III rams. Comparisons of survival rates were by Z-test (Heisey and Fuller 1985).

Table 1. Season and annual survival rates for female mountain sheep in Black Canyon, Arizona monitored from August 1989 to October 1991.

Group	Radio days	Survival (P)	95% CI	Mortality (P) High-way	Mortality (P) Preda-tor
Ewes whose home range crossed U.S. Highway 93					
Fall 1989	763	0.92	0.78 to 1.0	0.08	
Winter 1989–90	950	0.91	0.75 to 1.0		0.09
Spring 1990	811	0.89	0.72 to 1.0		0.11
Summer 1990	962	0.68	0.44 to 1.0	0.21	0.11
Annual Rate	3,486	0.51	0.29 to 0.9	0.24	0.25
Fall 1990	307	0.82	0.55 to 1.0	0.18	
Winter 1990–91	828	1.0			
Spring 1991	801	1.0			
Summer 1991	1,109	0.89	0.71 to 1.0	0.11	
Annual Rate	3,045	0.73	0.47 to 1.0	0.27	
Years Pooled					
Fall	1,070	0.88	0.76 to 1.0	0.11	
Winter	1,778	0.95	0.85 to 1.0		0.05
Spring	1,612	0.94	0.85 to 1.0		0.05
Summer	2,071	0.83	0.68 to 1.0	0.11	0.05
Total	6,531	0.66	0.49 to 0.9	0.20	0.30
All Ewes Combined					
Fall 1989	1,251	0.95	0.86 to 1.0	0.05	
Winter 1989–90	1,686	0.94	0.85 to 1.0		0.05
Spring 1990	1,701	0.95	0.80 to 1.0		0.05
Summer 1990	2,192	0.84	0.70 to 1.0	0.11	0.05
Annual Rate	6,830	0.72	0.55 to 0.9	0.14	0.14
Fall 1990	917	0.93	0.82 to 1.0	0.06	
Winter 1990	2,392	1.0			
Spring 1991	2,314	1.0			
Summer 1991	3,203	0.91	0.76 to 1.0	0.09	
Annual Rate	8,825	0.85	0.68 to 1.0	0.15	
Years Pooled					
Fall	2,168	0.94	0.87 to 1.0	0.05	
Winter	4,078	0.98	0.94 to 1.0		0.02
Spring	4,015	0.98	0.94 to 1.0		0.02
Summer	5,395	0.93	0.86 to 1.0	0.04	0.02
Overall	15,656	0.84	0.74 to 1.0	0.09	0.06

Table 2. Seasonal and annual survival rates for male mountain sheep in Black Canyon, Arizona monitored from August 1989 to October 1991.

Group	Radio days	Survival (*P*)	95% CI	Mortality (*P*) High-way	Mortality (*P*) Preda-tor
All Rams					
Fall 1989	244	0.78	0.47 to 1.0	0.22	
Winter 1989–90	293	0.69	0.39 to 1.0		
Spring 1990	1,246	1.0			
Summer 1990	1,633	0.93	0.80 to 1.0		
Annual Rate	3,416	0.48	0.23 to 1.0	0.22	
Fall 1990	793	1.0			
Winter 1990–91	1,391	0.93	0.81 to 1.0		
Spring 1991	1,335	1.0			
Summer 1991	1,845	1.0			
Annual Rate	5,364	0.93	0.81 to 1.0		
Overall					
Fall	1,037	0.94	0.84 to 1.0	0.6	
Winter	1,684	0.90	0.77 to 1.0		
Spring	2,581	1.0			
Summer	3,478	0.97	0.93 to 1.0		
Total	8,780	0.82	0.68 to 1.0	0.6	

RESULTS

Lamb Production and Survival

Twelve of 19 collared ewes lambed in 1990 (66%) and 11 of 25 (44%) lambed in 1991. In 1990, a maximum of 5 lambs survived resulting in a maximum lamb : ewe ratio of 26:100. In 1991, 7 lambs survived resulting in a lamb : ewe ratio of 32:100. Fourteen ewes were monitored during both lambing seasons, and only 4 lambed in 1990 and 1991. We did not observe lambs with two marked ewes either year, 2 were collared as yearlings and may not have bred in 1990 (1–2 yr old). Six of the marked ewes only lambed one of the 2 different years.

Reasons for lamb mortality are largely unknown. We documented 3 lamb mortalities from vehicle collisions on Highway 93 and 2 that fell from a cliff only 3 days after being born, but mortality sources of 6 others could not be determined. The majority died during the summer (9 of 11 known mortalities), but 2 died earlier in the spring. All ewes whose home range crossed Highway 93 freely crossed the highway in the summer with their lambs.

Mortality Rates

Ewes with home ranges that crossed Highway 93 had a significantly lower annual survival rate than ewes that did not cross the highway (0.66 to 1.0; $Z = 3.36$, $P < 0.002$) (Table 1). During 1989–90, survivorship of these ewes was only 0.51, versus 0.73 the second year ($Z = 0.98$, $P < 0.16$). The period of highest mortality was summer due to highway related mortality (21%). Fall was also a time of high mortality for ewes, and highway-related fatalities occurred in the fall of 1989 and 1990. Predation also played a role in lowering survival estimates in 1989–90 with a 25% probability of being killed by coyotes or mountain lions. The chance of predation was almost equal from winter through summer. The probability of being killed while crossing Highway 93 from 15 September 1990, to 15 September 1991 was slightly higher (0.27) than 1989–90. The 2 seasons in which highway mortality was recorded were summer and fall.

Ewes that did not cross Highway 93 did not die during the study. Overall survival of all collared ewes regardless of home range was 0.72 in 1989–90 and chances of predation and highway mortality were equal (0.14). Probability of survival was higher in 1990 (0.85) than 1989–90 but not significant ($Z = 0.53$, $P < 0.29$). The only recorded mortality was highway related.

We did not record mortality for Class II rams. One Class I and 3 Class IV rams died during the study. Because of the limited sample size of Class I and Class IV rams we did not compare rates between classes. The difference in survival for Class II and III rams was not significant so all rams were pooled (Table 2). The probability of survival was lower in 1989–90 than 1990–91 (0.48 vs. 0.93, $Z = 2.12$, $P < 0.02$). Causes of mortality included hunting, natural causes or old age, highway, and unknown. In 1990–91 we only found 1 ram mortality from unknown causes. Ram survival was not different than overall ewe survival (0.82 to 0.83). Although highway mortality was greater in ewes affected by Highway 93, the difference in overall mortality was not significant (0.83 vs. 0.66, $Z = 1.05$, $P < 0.15$).

Mortality Sources

Twelve of 49 collared adult mountain sheep died from 1 August 1989 to 1 November 1991. Six died from collisions with vehicles while crossing Highway 93. During the course of the study 18 uncollared mountain sheep were killed also while attempting to cross the highway. The 24 total were classified as 9 rams, 10 ewes, 3 lambs, and 2 unknown. The ages of collared mountain sheep hit while crossing Highway 93 ranged from 1 year to >8 years and many of them had been documented as previously crossing the highway ≥100 times before they were hit. From the 8 confirmed times we know mountain sheep were hit we found sheep were hit during all times of the day and up to 1 hour after sundown (0900 to 1930 hours). Almost all (22 of 24) of the vehicle caused mortalities occurred between mileposts 1 and 6.

Two collared ewes were killed by coyotes and one was killed by a mountain lion. Tracks indicated that a pair of coyotes chased down a ewe >8 years old in a wash. The remains of another yearling ewe were found near a waterhole and tracks also indicated she had been attacked by coyotes as she approached water. The mountain lion kill was found next to another uncollared ewe along a brushy trail heading to a water source. Tracks indicated that the lion was lying in an adjacent cave and probably ambushed the ewes as they came to water.

Two rams died from unknown causes. A Class IV ram died probably as the result of wounding during the legal hunting season. We found a blood trail leading to the carcass and the ram was found 4 days after the hunt started.

DISCUSSION

Twenty-four mountain sheep were killed in 2 years as they attempted to cross U.S. Highway 93. Without highway mortality, mortality rates for ewes would have been low (0.00–0.14). Ram mortality was highest in the first year (0.37), but low the next (0.07). Three of the 4 rams that died during the study were ≥8 years old. A yearling ram was hit while crossing Highway 93. Although only one of the 18 collared rams was hit on Highway 93, we found an almost equal percentage of unmarked rams and ewes hit during the study (9 rams, 10 ewes).

Mortality resulting from collisions between mountain sheep and vehicles is a recurring and potentially serious problem on U.S. Highway 93. Many studies have looked at the effect of highways on animal movements and mortality, particularly deer-vehicle accidents (Bellis and Graves 1971, Puglisi et al. 1974, Reilly and Green 1974, Pojar et al. 1975, Reed et al. 1979, Ward et al. 1980, Reed and Woodward 1981, Reed et al. 1982, Schafer and Penland 1985, Bashore et al. 1985). Few of the above studies documented the high rate of highway mortality (25%) that we observed. B. Sterling (Mont. Dep. Fish, Wild., and Parks, pers. commun.) has found a similar high mortality rate (between 20 and 25 a year) as Rocky Mountain sheep (*O. c. canadensis*) migrate across Montana State Highway 200 to their winter range each year.

S. C. Cunningham and L. Hanna (Movements and habitat use of bighorn sheep in Black Canyon, Arizona. Ariz. Game and Fish, Final Rep. 1990) hypothesized that age and/or experience increased mountain sheep ability to successfully cross this highway. However, we found that ewes >8 years old and Class IV rams were just as likely to be hit as younger, inexperienced sheep. Time of day was apparently not a factor either, because mountain sheep crossed the highway and were hit at all times of the day. Vehicle speed, driver visibility, road grade, presence or absence of a guard rail on either side of the road, and distance from curve or grade change are all factors with possible influences on mountain sheep highway mortality (S.C. Cunningham et al., unpubl. data).

We found the natural annual mortality rate (0.14) closer to that estimated by Remington (1989) for sheep in the Kofa Mountains (0.13) rather than mortality rates estimated in Nevada (0.17 to 0.22) (McQuivey 1978). If an additional highway related mortality rate of close to 0.25 is added then we believe the population will begin to decline. Although the mortality we documented was in a localized area, this significant decrease in survival by adults and lambs could have serious effects on local mountain sheep groups within a population or small populations in general.

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THE HEALTH OF MOUNTAIN SHEEP IN THE SAN ANDRES MOUNTAINS, NEW MEXICO

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Abstract: The population of Mexican bighorn sheep (Ovis *canadensis mexicana*) in the San Andres Mountains, New Mexico declined from 200 in 1978 to <25 by April 1991, primarily due to an epizootic of psoroptic scabies (Psoroptes spp.). Between November 1989 and November 1990, we sampled 15 mountain sheep on the San Andres National Wildlife Refuge (SANWR) to determine the incidence of scabies, identify factors that may predispose mountain sheep to clinical scabies under appropriate conditions of the host and environment, explore mite life history and taxonomy, and assess whether scabies could be eliminated from mountain sheep and/or the environment for future management and transplant decisions. We compiled a history of scabies in SANWR mountain sheep population from the beginning of the epizootic in 1978. The results of physical examination, individual animal health studies, immunology, infectious disease screening, pathogen isolation, and pathology revealed that captured mountain sheep 1) were all negatively affected by Psoroptes spp. mites; 2) were not apparently affected by viral, bacterial, or parasitic agents that cause disease in mountain sheep or other free-ranging or domestic ruminants; 3) were not producing an effective immunological response (IgG) to Psoroptes spp. mite antigen; and 4) were producing increased levels of IgE correlating with the severity of clinical signs associated with Psoroptes spp. mite infestation. We developed an effective serologic test for Psoroptes spp. mite antigen and a practical 1-time field treatment to eliminate scabies mites from infested mountain sheep.

Key words: lymphocyte blastogenesis, mountain sheep, pathogen isolation, psoroptic scabies, San Andres National Wildlife Refuge, serology.

The environmental, wildlife, and livestock grazing histories in the SANWR within the United States Army White Sands Missile Range (WSMR) are described by Sandoval (1979). Hoban (1990) briefly described the history of mountain sheep on the SANWR including group composition, reproduction and lamb survival, and mite taxonomy associated with the sheep. A review of these subjects was compiled by R. K. Clark and D. A. Jessup (Status of psoroptic scabies in and health of bighorn sheep in the San Andres Mountains of New Mexico: Final report. U.S. Dep. Interior, Fish and Wildlife Service, SANWR, Las Cruces, N.M., 1990. 165pp.).

Mountain sheep were hunted in and around the SANWR from 1968 to 1978. Prior to 1978, there were no reports of health problems in harvested mountain sheep, but during that year, all 5 rams shot had live scabies mites and active ear and/or body lesions. Meleney et al. (1980) identified the mites as Psoroptes ovis using morphological characteristics established by Sweatman (1958). The mites were morphologically similar to scabies mites of domestic cattle, sheep, and horses. Mite infestations were associated with historic mountain sheep epizootics and extirpation from many mountain ranges in North America (Lange et al. 1980, Jessup 1985, Hoban 1990).

During winter 1978–79, clinical signs of a severe and widespread infestation of mites were observed on mountain sheep in the SANWR. Mountain sheep exhibited signs of lateral and dorsal trunk alopecia, purulent effusion from and severe folding of pinnae (ears). Mountain sheep displayed intense pruritus, manifested by scratching, head shaking, coat chewing, and rubbing horns on vegetation. These aberrations and an apparent decline in the numbers of the mountain sheep in the SANWR indicated that the scabies outbreak was a serious health problem. Initial attempts to treat the herd with dust bags filled with 5% coumaphos suspended over salt blocks at 38 sites were not successful (Sandoval 1980). The 1979 hunt was canceled when prehunting aerial surveys in September revealed a 60% decline in the population; only 81 mountain sheep were estimated in the herd and no lambs were observed (Sandovala 1980).

A rescue effort was conducted by the New Mexico Department of Game and Fish (NMDGF) and the United States Fish and Wildlife Service (USFWS) from 17 to 26 November 1979 and 47 mountain sheep were removed from the SANWR and surrounding areas. Sandoval (1980) described the use of helicopter darting or helicopter hand-held net-gun with subsequent tranquilization techniques. All captured animals were infested with scabies mites and the majority were in poor condition due to Psoroptes spp. parasitic infestation and secondary bacterial infections. Mountain sheep were plunge dipped in 0.5% toxaphene at 14-day intervals while being held at a central treatment facility. Thirty-four mountain sheep survived the treatment and the 27 animals (22 F, 5 M) were transported to the NMDGF Red Rock desert bighorn propagation facility while the remaining 7 mountain sheep were left at New Mexico State University for cross-transmission studies.

Sandoval (1980) estimated that only 20 to 30 mountain sheep remained after rescue efforts in the southern San Andres Mountains during early 1980. In March 1980 19 mountain sheep were remotely treated over 2 days with ≥30 mg of ivermectin (Ivomec®, Merck, Sharpe & Dohme Research Laboratories, Rahway, N.J.) in biobullet form. Initial treatment appeared "successful" although it was recognized that it would be impossible to locate and treat every infested mountain sheep on the SANWR and that additional treatment would be necessary (A. V. Sandoval, Relative effectiveness of ballistic implants and injected ivermectin in eradication of psoroptic mites. N.M. Dep. Game and Fish, Intra-agency memo, 6 February 1981. 3pp.).

Twelve of 14 mountain sheep from the SANWR that were at the NMDGF Red Rock mountain sheep propagation facility survived a 1980 outbreak of bluetongue virus that resulted in the death of 13 of the 27 captive animals. These 12 were captured and translocated back to the SANWR in January 1981. That month, 14 previously untreated free-ranging SANWR mountain sheep were treated for scabies using ivermectin. According to population estimates, there were 35–42 mountain sheep remaining on the SANWR (A. J. Sandoval, Desert bighorn reintroduction in the San Andres Mountains, N.M. Dep. Game and Fish, Intra-agency memo, 9 February 1981. 3pp.), and approximately 95% of the population had been treated with parasiticide. Ground observations from September 1980 through August 1981 revealed "no clinical signs" of mite infestation in the approximately 40 mountain sheep observed. Biologists located 7 radio-collared mountain sheep killed by mountain lions (Felis *concolor*) on the SANWR between December 1980 and April 1981. In May 1982 a severely infested ram and a moderately infested ewe were captured. In December 1982, only 25 mountain sheep were located and 2 of 5 mountain sheep captured were heavily infested and in poor condition despite previous treatment.

Periodic treatment of mite infested mountain sheep continued through 1983, but ceased in 1984. Mountain sheep surveys and population estimates continued as did studies of mountain lion populations in the SANWR from 1984 to 1987. Mountain lions were intermittently removed from the Refuge during 1986. Several papers discussing conflicting theories on the biology of mites, and mountain sheep and mite interactions, and several management plans were written during this period (R. K. Clark and D. A. Jessup, Status of psoroptic scabies in and health of bighorn sheep in the San Andres Mountains of New Mexico: Final report. USFWS, SANWR, N.M. 1990. 165pp.).

Elenowitz and Humphreys (1989) noted that the mountain sheep population on the SANWR fluctuated between 25–30 animals since 1982 and, since 1985, adult ewe numbers varied from 9 to 13. Lamb survival was ≥50% from 1986 to 1988, and most were recruited into the yearling cohort. When lambs survived the first 6 to 11 months, their survival to adulthood was high and lamb survival did not appear to be the factor limiting the population. Adult mortality was the apparent problem. Predation and death from falls were major mortality factors. Apparently the small number of adult ewes surviving each year limit any increase in the SANWR population. Our objective was to compile a history of scabies in SANWR and determine how mites influenced the mountain sheep population.

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METHODS

Our first year goals were to capture, sample, photograph, mark, and radio collar as many of the remnant mountain sheep population (n = 28) as possible. We were to evaluate the overall health of the sampled individuals, and to determine if any factor other than scabies was affecting the health of the population. In November 1988 a helicopter net-gun capture and sampling effort was conducted using techniques described by Kock et al. (1987*a*, 19876, 1987*c*) and Clark et al. (1988). Ten mountain sheep (4 M, 5 F, 1 M lamb) were captured; 1 M adult died. The only treatments were prophylactic intramuscular injections of 1 mL vitamin E-Se (Mu-Se®, Schering Corp., Kenilworth, N.J.) and 4–5 mL of penicillin G benzathine and penicillin G procaine (Benza-Pen®, Beecham Laboratories, Bristol, Tenn.). During winter 1988 to 1989, we developed a serologic test for determining psoroptic scabies infestations (Boyce et al. 1991).

In November 1989, we conducted a second capture, sample, and radio collar effort in the SANWR and captured 9 mountain sheep (3 M, 6 F). Four of these animals had been captured in 1988. All 9 mountain sheep were treated with prophylactic Mu-Se® and Benza-Pen®, and high levels of ivermectin ranging from 45 to 100 mg subcutaneously and 75 to 243 mg topically/animal. Seven of 9 mountain sheep were affixed with pyrethrin impregnated insecticidal ear tags (Alflex®, St. Louis, Mo.). We assessed the extent of physical damage to the pinnae, exudative plugging and degree of secondary infection in the ear canals, and potential impairment of hearing was assessed visually with an otoscope.

Complete details of materials and methods used for assessing individual animal health, immune response, exposure to infectious diseases, serum electrophoretic profile, exposure to parasites, and genetic profiles are described by Clark and Jessup (R. K. Clark and D. A. Jessup, Status of psoroptic scabies in and health of bighorn sheep in the San Andres Mountains of New Mexico: Final report. USFWS, SANWR, N.M. 1990. 165pp.).

In winter 1989 to 1990, 2 hunter killed mule deer (Odocoiletts *hemionus*) from the Oscura Mountains, 13 km northeast of the SANWR, with aural dermatitis and a mule deer sampled as part of the San Andres Mountains mountain lion study, were screened for dermal mites. From west of San Andres Peak, the carcass of a mature male mule deer with generalized ear and shoulder crust and scale was discovered in January 1990.

RESULTS

Eighteen of 19 mountain sheep captured in 1988 and 1989 had dermal lesions ranging from isolated areas of crust inside pinnae to severe purulent aural dermatitis with tight exudative plugs in the distal ear canal and generalized body scale with concentrations on head, horn base, face, neck, pole, withers, flanks, and perineum. All 9 (5 first-time captured and 4 recaptured) mountain sheep captured and sampled in 1989 had crusted exudative plugs occluding the ear canals. The ear canals of 8 of 9 animals examined visually showed evidence of moderate to severe purulent otitis externa. Otoscopic examination of the ear canals of 6 of 9 showed damage and destruction to portions of the tympanic membrane.

The body conformation and condition of infested mountain sheep varied from good (n = 3), fair-good (n = 2), fair (n = 6), fair-poor (n = 1), poor (n = 5), to very poor (n = 2). No mountain sheep were considered to be in good-excellent or excellent condition. A yearling ewe (SAE-058) that was small and thin with severe generalized mite infestation in 1988 had not improved clinically 1 year later. In contrast, a ewe (SAE-033) that was well muscled and showed no clinical sign of disease in 1988 had ear canals filled with fly maggots, and was weak, ataxic, emaciated, and severely infested with generalized scabies 1 year later. All but the poor and very poor conditioned mountain sheep were sturdy and only moderately affected by the chase times required for capture.

Two ewes showed an absolute neutropenia and lymphopenia and 1 other ewe had a primary lymphopenia (Table 1). A yearling female had a primary lymphocytosis. Otherwise there were no significant findings when compared to mean values noted by Kock et al. (19876) for net-gun captured mountain sheep.

Serum total protein levels were elevated in 4 of 19 samples and ranged from 9 to 10.4 mg/dL. Those animals had elevated globulin levels, ranging from 7.6 to 8.5 mg/dL. Serum electrophoretic profiles showed large amounts of globulins in the weight ranges of IgE. Most severely infested mountain sheep had the highest immunoglobulin peaks. Mean albumin to globulin ratios (A/G ratio), as calculated by electrophoretic separation methods, were within normal limits. One ewe showed a hypergammaglobulinemia.

Lymphocyte blastogenesis testing (Beldon et al. 1990) revealed that 3 of 16 samples submitted had responses that could be considered in the normal range. The lymphocytes of the remaining 13 animals sampled yielded responses that appeared reduced when compared to those of healthy captive mountain sheep. Lymphocytosis was noted in 1 mountain sheep but this animal was negative for antibodies against bovine leukemia virus, which may be a primary cause of this finding in domestic livestock.

A complete necropsy was performed on the 1 ram that died. Those pathologic studies revealed no significant gross or microscopic lesions not related to a fatal fall except for chronic scabies infestation.

Serologic studies (Table 2) were negative for antibodies to the diseases associated with mountain sheep populations that are static or declining (Clark et al. 1985, Jessup 1985). Three of 10 mountain sheep tested in 1988 and 0 of 9 in 1989 had antibodies against Malpais Springs virus, an endemic virus in the WSMR that is not known to cause any disease process in wild or domestic ungulates. Two of 19 had antibodies against infectious bovine rhinotracheitis virus. No viruses were isolated from nasal swabs or whole blood samples.

Pasteurella haernolytica bacteria were not isolated from the upper respiratory tract from the 1988 or 1989 sample swabs. *Pseudomonas maltophilia* was isolated from nasal swabs from 2 of 9 mountain sheep in 1989. *Proteus* spp. were the dominant bacteria grown from all 6 ear swab samples taken in 1989.

Psoroptes spp. mites were isolated from the body and/or ears from 9 of 10 individuals sampled in 1988 and from all 9 samples in 1989 that included 4 recaptured individuals. All 19 samples taken from 15 individual mountain sheep in this study were serologically positive for Psoroptesspp. mite antigen. The morphologic features of the mites were comparable with and allowed identification of them as Psoroptes ovis (Boyce et al. 1990). Swabs and scrapings of crust and scale from mule

*Table 1. Complete blood counts, serum chemistry, and fecal cortisol analysis of samples taken from Mexican bighorn sheep (*O. *c.* mexicana*) captured in the San Andres National Wildlife Refuge, N.M., November 1988 and 1989.*

Parameter	*n*	$\bar{x}$	SD	Range
Cellular component				
White blood cell count (WBC) (μL)	19	8.74	4.88	2.2–15.9
Red blood cell count (RBC) ($10^6/\mu$L)	19	10.84	1.09	7.7–13.9
Hemoglobin (Hb) (g/dL)	19	16.08	1.50	13.4–18.4
Packed red cell volume (HCT or PCV)	19	44.24	4.44	32.8–45.6
Mean corpuscular volume (MCV)	19	41.38	0.97	38.0–45.1
Mean corpuscular Hb (MCH)	19	15.2	1.13	12.3–19.2
Mean corpuscular Hb concentration (MCHC)	19	36.12	3.08	32–42.8
Neutrophil absolute count	19	6,207.83	3,943.40	1,173–12,144
Neutrophil %	19	65.72	10.22	51.0–88.0
Lymphocyte absolute count	19	2,165.94	948.83	814–4,293
Lymphocyte %	19	29.78	8.19	12.0–37.0
Monocyte absolute count	19	37.06	61.64	0–184
Monocyte %	19	0.44	0.63	0.0–2.0
Eosinophil absolute count	19	338.06	441.67	0–1,419
Eosinophil %	19	3.00	3.46	0.0–11.0
Serum component				
Alkaline phosphatase (AP) (IU/L)	19	288.74	180.75	135–638
Aspartate aminotransferase (AST) (IU/L)	19	188.11	29.01	95–156
Creatine phosphokinase (CPK) (IU/L)	19	457.94	423.77	158–1,609
Gamma glutamyl transpeptidase (GGT) (IU/L)	19	31.79	8.45	16–43
Lactic dehydrogenase (LDH) (IU/L)	19	526.44	74.74	424–664
Total solids (g/dL)	19	8.51	1.24	6.3–10.4
Albumin (g/dL)	19	3.78	0.73	2.3–4.6
Globulin (g/dL)	19	4.73	1.77	2.0–7.7
Alpha-1	19	0.20	0.05	0.1–0.3
Alpha-2	19	0.58	0.20	0.3–0.8
Beta-1	19	0.83	0.50	0.3–2.1
Beta-2	19	2.07	1.72	0.4–5.2
Gamma-1	19	2.50	0.49	1.9–3.1
Gamma-2	19	0.35	0.04	0.3–0.4
Albumin/Globulin ratio	19	0.96	0.44	0.3–2.2
Blood urea nitrogen (BUN) (mg/dL)	19	16.53	3.11	15–24
Creatinine (mg/dL)	19	1.94	0.10	1.7–2.0
BUN/creatinine ratio	19	8.75	2.05	7.5–13.5
Direct bilirubin	19	0.01	0.03	0–0.1
Indirect bilirubin	19	0.06	0.07	−0.1–0.2
Total bilirubin	19	0.07	0.06	0–0.2
Glucose (mg/dL)	19	141	39.55	82–201
Calcium (mg/dL)	19	10.48	0.71	9.0–11.1
Phosphorus (mg/dL)	19	7.3	0.88	5.1–8.2
Chloride (meq/L)	19	94.74	3.14	88–99
Sodium (meq/L)	19	149.68	3.74	141–154
Potassium (meq/L)	19	6.01	1.06	3.4–7.6
Selenium (ppm)	19	0.11	0.04	0.07–0.19
Fecal cortisol (ng/mg dry mater)	19	9.95	9.69	5.8–21.4

deer on the SANWR and in the adjacent Oscura Mountains were also positive for *Psoroptes* spp. mites as described by Boyce et al. (1990).

DISCUSSION

No radio-collared animals died within 7 to 10 days post capture. Although 1 ram died from a fall, our captures and studies have had little negative influence on population trends and have not resulted in any capture myopathy or significant physical trauma. Physical examination of mountain sheep on the SANWR revealed that *Psoroptes* spp. infestation had a negative effect on their overall condition and in most cases a marked negative influence due to skin irritation and inflammation, increased energy loss and protein exudation, perceived behavior modification, distraction, and possibly hypothermia and immunosuppression.

Physical examination of infested mountain sheep, necropsy examination of 1 infested ram, review of literature, and visual assessment of forage and preferred browse (Sandoval 1979) does not support the concept that malnutrition is a contributing factor to severity of *Psoroptes* spp. infestation in the SANWR. Although infested animals were often thin, less heavily infested cohorts were in better condition. Body fat reserves were present in fair amount in the ram necropsy specimen. We feel that forage appeared to be adequate and NMDGF and USFWS

Table 2. Serum tests against antibodies to infectious disease agents in Mexican bighorn sheep (O. c. mexicana) captured in the San Andres National Wildlife Refuge, N.M., November 1988 and 1989.

Infectious agent of concern	Test type	Test location	No. pos.	% pos.
Anaplasmosis	*CARD*	UCD	0/19	0
Brucella ovis	*ELZSA*	UCD/USDA	0/19	0
Blue-Tongue Virus	*AGID*	UCD	0/19	0
Blue-Tongue Virus types 10, 11, 13 and 17	*SDPRN*	USDA	0/19	0
Caprine Arthritis and Encephalitis Virus	*AGID*	UCD/USDA	0/19	0
Epizootic Hemorrhagic Disease Virus	*AGZD*	UCD	0/19	0
EHD New Jersey and Alberta strains	*SDPRN*	USDA	0/19	0
Bovine Respiratoiy Syncytial Virus	*ZFA*	UCD	0/19	0
Infectious Bovine Rhinotracheitis Virus	*SVN*	UCD	2/19	10.5%
Ovine Border Disease/Bovine Virus Diarrhea	SVN	UCD	0/19	0
Parainfluenza 3 Virus	HI	UCD	0/19	0
Leptospira interrogans—seven serovars	ELISA	UCD	0/19	0
Chlamydia psittaci	CF	USDA	6/19	31.6%
Ovine Progressive Pneumonia Virus	AGID	UCD	0/19	0
Bovine Leukemia Virus	AGID	USDA	0/19	0
Bovine Lentivirus	AGID	USDA	0/19	0
Bovine Syncytial Virus	SDPRN	USDA	0/19	0
Progressive Pneumonia-Maedi Visna Virus	AGID	USDA	0/19	0
Malpais Spring Virus	SDPRN	USDA	3/19	16.7%

ELISA = enzyme-linked immunosorbent assay; AGID = agar gel immunodiffusion assay; IFA = indirect fluorescent antibody; SVN = serum virus neutralization; CF = complement fixation; SDPRN = serum dilution–plaque reduction neutralization tests; UCD = University of California, John E. Thurman State Diagnostics Lab, Davis, Calif.; USDA = United States Department of Agriculture, Midwest Area National Animal Disease Center, Ames, Ia.

biologists have never cited forage inadequacy as contributing to mountain sheep health problems at SANWR.

Individual animal health screening (complete blood count and serum chemistry analysis) revealed little evidence of capture stress as defined by Kock et al. (1987*a*, 1987*b*). The lymphopenia and neutrophilia seen may be due to acute and/or chronic stress probably from parasitic dermatitis caused by *Psoroptes* spp. infestation. The occasional eosinophilia seen with most parasitic infections, even in the face of increased cortisol levels that classically suppress eosinophils, may confirm this.

The degree of infection, inflammation, and resulting damage to the ears, ear canal, and ear drum suggest that many scabies infested sheep in the San Andres Mountains have moderate to severe auditory impairment. This was also observed by veterinarians and researchers at the initial capture efforts in 1979 (Williams 1980) and by Sandoval (1980) and A. J. Sandoval (Results of helicopter survey in the northern San Andres Mountains, N.M. Dep. Game and Fish, Intra-agency memo, 11 May 1982. 5pp.).

Mountain lion predation, which Elenowitz and Humphreys (1989) noted was responsible for 9 of 24 mountain sheep deaths in the SANWR from 1984 through 1989, and accidental falls that accounted for 5 of 24 deaths during this period could both be predisposed by deafness, ataxia, and weakness. Hoban (1990) in contrast found that 10 of 25 mountain sheep deaths were due to mountain lion predation and 4 of 25 were due to accidental falls from 1984 through 1989. Elenowitz and Humphreys (1989) explained that ear canals of 5 of the 9 mountain lion killed mountain sheep and 3 of 5 of fall victims were plugged with solid exudate resulting from scabies mite infestation. No mention was made of otoscopic examination of the ear canals in mountain sheep without plugged ears that may have chronic damage to the ear drum or subclinical mite infestations. Notably, early reports by W. Evans (Possible scabies-bighorn-climate associations in the San Andres Mountains, New Mexico. N.M. Dep. Game and Fish, Intra-agency memo, 5 November 1984), and the NMGF (N.M. Dep. Game and Fish, Proposed management approaches for the San Andres bighorn, 1984, 8pp.) on mortalities did not attempt to distinguish the primary and secondary effects of *Psoroptes* spp. infestation. Hoban (1990) thought that since 1980, scabies alone was directly responsible for 2 of the known mortalities in the SANWR mountain sheep population and that mountain lion predation caused 22 mortalities (51%), falls caused 4 (9%), and the cause of 7 mortalities (16%) was not determined. Elenowitzand Humphreys (1989) report that 8 of 14 mountain sheep deaths were from mountain lion kills and from falls. To review, Hoban (1990) remarked that mortalities occurred from lions (51%), falls (9%), and unknown reasons (16%). We believe that both of these reports and our observations indicate that the combined primary and secondary effects of scabies may account for 43% (57% of 0.51 + 0.09 + 0.16) of all mortalities. We know of no other normal mountain sheep population where falls and mountain lion predation consistently result in such high and disproportionate mortality. Further, these deaths are occurring in the critical adult ewe (reproductive) segment of the population.

Immunologic appraisal of mountain sheep sampled in the field is difficult and to our knowledge the work reported here is one of the first attempts to develop such an assessment in a free-ranging population. The lymphocyte blastogenesis assays used to investigate the cell mediated immune response would have been more accurate if conducted in or very near a laboratory. Obviously this was not possible. Long transport times may have caused partial loss of cell viability and early cell death in culture. Because the control samples from healthy captive bighorn were handled the same way, we feel the results are valid. Although the lymphocytes collected from 13 of 16 SANWR mountain sheep showed reduced responsiveness to lymphocyte mitogens, there appears to be no significant or generalized dysfunction in cell mediated and humoral functions of the immune response in the mountain sheep in this study.

The only immunoglobulin from ovids that can currently be quantified by commercially available tests is IgG. This is also the most important, long lasting, and protective immunoglobulin in most disease conditions. We found no evidence that IgG levels were either low or high.

In descending order of quantity, immunoglobulins G, M, E, and A are the only ones commonly found in serum. The spikes in globulins we observed could be immunoglobulin E (IgE), because IgM is larger and heavier and IgA is seldom found in high amounts in serum. The size of these spikes appears to correlate with the severity of clinical disease.

Infested animals did not have measurably increased IgG levels. The host response eventually may be to elaborate large amounts of IgE within the skin. Stromberg et al. (1986*a*) described how infested hereford calves also develop IgE-like antibodies to P. ovis antigens. If these antibodies are not effective at reducing fecundity of female P. ovis, the increased numbers of feeding and defecating mites create a hypersensitive skin reaction that manifests as cutaneous lesions (Stromberg et al. 1986*b*). In infested mountain sheep, the IgE may exacerbate localized dermal allergic response to mites, but it may not be effective at decreasing mite reproduction resulting in increased mite numbers and subsequent increased allergic reaction in the dermis.

We found no evidence that the mountain sheep on the SANWR are developing an immunity to Psoroptes spp., or that the humoral or cell mediated immune responses are grossly compromised. Fecal cortisol levels (an indicator of stress) were higher in mountain sheep on the SANWR than in hand-raised, unstressed captive Peninsular bighorn (*O.* c. *cremnobates*) in California, mountain sheep from Red Rock (*O.* c. *mexicana*) in New Mexico, and captive Rocky Mountain bighorn sheep (*O.* c. *canadensis*) in Colorado, and more comparable to purposely stressed, captive Rocky Mountain bighorn sheep (M. Miller, Colo. Div. Wildl., pers. commun., 1990). Cortisol does generally suppress both humoral and cell mediated immune responses.

We find no serologic evidence that important viral diseases known to be pathogenic to mountain sheep or those that could be immunosuppressive are prevalent in the SANWR population. Based on our serologic data and because other bacterial (including *Pasteurella* sp. in the nasal cavity), protozoal and parasitic diseases were not present we conclude that underlying diseases are not a problem. The basic infectious disease problem apparent in mountain sheep on the SANWR is generalized dermatitis and aural dermatitis due to Psoroptes spp. infestation.

P. R. Krausman and G. C. Carmichael (A bibliography of bighorn sheep and mite relationships with selected abstracts; Report for San Andres National Wildlife Refuge, N.M., School of Renewable Natural Resources, Univ. Arizona, 1987, 30pp.) list many papers on Psoroptes spp. infestations of domestic livestock and/or mountain sheep. Lange (1980) reviewed some of the historical information concerning the effect of scabies on mountain sheep populations. A fairly strong case can be made for Psoroptes spp. being the primary cause of mortality in and ultimate cause of extinction of many bighorn herds in the Mountain West and Southwestern United States (Jessup 1985), although other less easily recognized disease factors may also have been involved. Some populations in Arizona, California, and Nevada have managed to survive in the face of chronic low grade Psoroptes spp. infestation, usually confined to the ears of old rams (Mazet et al. 1992). The exact reasons for this are not known, but the basic theories fall into 2 groups: the virulent mite theory and the susceptible herd or population theory.

Morphometric classification of Psoroptes spp. mites does not correlate with apparent virulence (Boyce et al. 1990). However, it is possible that the mites in mountain sheep on the SANWR are particularly persistent and/or pathogenic. The early difficulties in transmitting these mites to cattle, sheep, elk and rabbits may be partly a reflection of techniques employed (Boyce et al. 1991). We found it relatively easy to infest a tame captive mule deer with Psoroptes spp. mites originating from a mule deer from the SANWR (D. A. Jessup and W. M. Boyce, Univ. California, Davis, pers. commun.). Once established, this infestation was not eliminated with several single injections of ivermectin at 1 or 2 x the cattle dose of 0.2 mg/kg over a 6 month period. A crucial piece of missing information is whether these mites will infest mountain sheep.

The apparent positive response of mountain sheep to low level ivermectin treatment between 1980 and 1984 may have been due to reductions in numbers of adult mites without their elimination from the animal. With a serologic test we can distinguish truly uninfested mountain sheep from those with only a few mites and no apparent clinical disease (Boyce et al. 1992). Many of the hypothetical arguments as to whether or not mountain sheep on the SANWR could or would develop individual or herd immunity might not have occurred had the current assay (Boyce et al. 1991) been available in the early 1980s. By sampling 15 mountain sheep in the SANWR we found all to be infested clinically or subclinically and seropositive for Psoroptes spp. mite infestation. It is also possible that Psoroptes spp. mites may have been eliminated from some individuals between 1980 and 1984, but that they became reinfested by association with other mountain sheep, deer, or other Psoroptes hosts.

Until DNA probes are developed to identify polymorphisms in the mites infesting mountain sheep, and until these can be compared to mites from other species and locations, we will not know if the Psoroptes spp. mites at SANWR are unique or uniquely pathogenic. On the basis of morphology alone, it is only possible to state that mites from mule deer and mountain sheep on the SANWR are similar enough to perhaps represent a single breeding group. Whether they can be transmitted between mule deer and mountain sheep can only be truly answered by proper cross-transmission trials. Until that time, we must accept the possibility that mule deer are a potentially sympatric alternate host for Psoroptes spp. mites in mountain sheep in the SANWR.

Pruett et al. (1986) suggests that P. ovis infestations fluctuate seasonally within an animal and during different seasons. W. Evans (Possible scabies-bighorn-climate associations in the San Andres Mountains, New Mexico, N.M. Dep. Game and Fish, Intra-agency memo, 5 November 1984) extended this argument to hypothesize that longer term weather changes may be influencing the mite/host relationship. We can find little evidence in domestic animal or wildlife literature or laboratory evidence to support this theory.

In year 2 of our study we treated 9 mountain sheep with injectable and slow-absorbing topical ivermectin and in 7, pyrethrin impregnated ear tags. From field treatment studies in California, these high doses of ivermectin and/or time release implants were adequate to eliminate sub-clinical scabies (Boyce et al. 1992). We were not allowed to use time release ivermectin implants in the SANWR herd, make follow-up examinations, or even "fly over" any of the mountain sheep on the SANWR after November 1989, so the effects of treatment were not properly monitored.

Whatever the percentage contribution of host response and/or mite pathogenicity to the severity of scabies mite in individuals, the net effect has been a catastrophic die-off followed by chronic persistent mortality, primarily in adults (≥2 years) due to primary and secondary effects of Psoroptes spp. Berger (1990) argues that when mountain sheep populations drop below 50 individuals the population eventually goes extinct. He does not distinguish between population size as a cause or an effect of declines. Although we know of exceptions to Berger's hypothesis, his prediction may be right and the SANWR mountain sheep population, if unaided, may be unable to sustain itself. Hoban (1990) comes to the same conclusion.

We feel that the decline of the SANWR population and current low numbers of mountain sheep on the SANWR are a result of: 1) an epidemic of scabies caused by Psoroptes spp., which began in approximately 1978; 2) continued Psoroptes spp. infestation and adult (22 years) mountain sheep mortalities through primary and secondary effects, which may account for approximately 43% of all mortalities since 1980; 3) the failure of the population to increase after mountain lion removal; 4) initial treatment with ivermectin parasiticides at sub-optimal levels; 5) 3 years of no miticidal treatment; 6) lack of effective immune response against Psoroptes spp. mites and excessive IgE production by individual mountain sheep; 7) current low numbers of adult reproductive ewes in a small population; 8) high numbers of infested mountain sheep (100%) without evidence that disease or other factors are an underlying cause of these infestations; and 9) the possibility that Psoroptes spp. is using mule deer as an alternative host.

We believe that the Mexican bighorn sheep herd on the SANWR will not recover to pre-1978 population levels on its own. The discomfort and suffering from this disease will persist in these mountain sheep and the herd will likely become extinct in the future if effective actions are not taken.

MANAGEMENT IMPLICATIONS

We recommend that all remaining individuals be removed from the Refuge and treated with avermectin compounds, in appropriate dosages and forms, until all Psoroptes spp. mites are eradicated and all individuals are seronegative. This technique should be undertaken only if the SANWR mountain sheep are deemed by the USFWS and/or NMDGF to be a valuable wildlife resource and/or possibly a unique genetic strain of mountain sheep. Although we have developed an ivermectin implant that can eliminate Psoroptes spp. mites from free-ranging mountain sheep (Boyce et al. 1992), we feel that with current or foreseen technology, the remaining SANWR mountain sheep could be more effectively treated in captivity. The apparent positive, but not dramatic, response of free-ranging mountain sheep on the SANWR to sporadic low levels of ivermectin treatment, and the elimination of Psoroptes spp. mites in mountain sheep from California using appropriate ivermectin dosages and forms, lead us to believe that treatment in a captive situation has good chances of success.

There has been concern about the SANWR mountain sheep's inappropriate immune response to the Psoroptes spp. mite and inference of genetic bottlenecking that may have left these mountain sheep with less variability for adaptation to disease agents. We recommended a study where healthy captive SANWR, Red Rock, and other desert races of mountain sheep were infested with the SANWR Psoroptes spp. mite and the progression of disease was monitored. This could rule out an environmental factor that may predispose the mountain sheep to the full virulence of the mite.

Until the questions of cross-transmission of mites between mule deer and mountain sheep, and the prevalence of Psoroptes spp. in deer have been answered, we do not recommend the release of mountain sheep from Red Rock onto the Refuge. Although it would be interesting to know if rodents or other animals in the SANWR are also potential alternative hosts, that seems almost an academic question in the face of the data we now have from mule deer.

We proposed sentinel ram studies as a means of determining eventually whether healthy bighorn can remain uninfested on the SANWR. This idea appears to have some merit, if and only if it is coupled with further investigations into the specificity and prevalence of Psoroptes spp. mites.

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COMPOSITION AND QUALITY OF MOUNTAIN SHEEP DIETS IN THE SUPERSTITION MOUNTAINS, ARIZONA

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Abstract: We quantified the nutrient quality of diets of mountain sheep (Ovis *canadensis mexicana*) in the Superstition Mountains, Arizona on a monthly basis from May 1987 to April 1989. We described diets using microhistological analysis of fecal samples corrected for differential digestibility. We conducted nutrient analyses of composited diets for dry matter digestibility, digestible protein, and metabolizable energy. We used these data to evaluate the adequacy of the diet to meet mountain sheep nutrient requirements. Shrubs were an important component of the diet throughout most of the year. Peak shrub use occurred during summer months, prior to the monsoons, and comprised approximately 92 and 74% of the diet for the first and second year, respectively. Use of grass increased during late summer, with the onset of the monsoons, and peaked in mid-winter. Use of forbs increased during spring months of both years. Energy and protein levels contained in the diet were insufficient to meet a female's nutrient requirements during lactation in the early part of the first year. Energy content of the diet was insufficient to meet female requirements during peak lactation in the latter part of years 1 and 2, but protein levels were adequate.

Key words: diet composition, energy, mountain sheep, protein, Superstition Mountains.

Habitat management for ungulates is based on the assumptions that, provided with adequate cover, water, and space: 1) the physical well being of the herd is directly related to the quantity and quality of its diet, and 2) a herd maintained on a high nutritional plane is more productive and less influenced by predation, starvation, diseases, and parasites (Nelson and Leege 1982). High quality habitat provides the propertype and amount of water, cover, space, and food. Several studies have been conducted to assess some of these attributes (Brown 1985, Cunningham 1989, Wakeling 1989, Wakeling and Miller 1990), but little has been done to assess an area's ability to provide adequate quality forage.

Our objectives were to: 1) characterize the monthly diet of mountain sheep in the Superstition Mountains, Arizona, over a 2 year period, 2) evaluate the relative importance of the major plant species contained in the diet on a seasonal basis, and 3) determine if the diets of females meet daily protein and energy requirements.

Funding for this project was provided by the School of Agribusiness and Environmental Resources, Arizona State University, and the National Rifle Association.

STUDY AREA

The study was conducted on Coffee Flat (2,760 ha) (Wakeling and Miller 1989), 95 km northeast of Phoenix, Arizona, in the southeastern portion of the Superstition Mountains. The Arizona Game and Fish Department released 30 mountain sheep into this area each year in 1984 (Lee 1985) and 1989.

Elevations ranged from 770 to 1,415 m. The area was characterized by steep slopes with rocky ridges and occasional narrow flat topped buttes. Annual rainfall at Superior, Arizona, 10 km southeast of the area, averaged 51.3 cm with the majority occurring during monsoon thunderstorms from July to September and during winter storms from December to February. Monthly temperatures averaged 10 C during the winter and 30 C during summer.

Vegetation communities represented were in the Arizona upland subdivision, Arizona Sonoran Desert scrub (on side slopes) and semidesert grassland (on ridges and mesa tops) (Brown 1982). Cover, water, and topographic characteristics of the area were described by Wakeling and Miller (1989).

METHODS

We quantified the composition of diets using microhistological analysis of fecal samples corrected for differential digestibility. We collected and composited fecal samples monthly from May 1987 through April 1989 (year 1: May 1987 to Apr 1988; year 2: May 1988 to Apr 1989). Samples consisted of 10 pellets each, collected from ≥10 individual pellet groups. We only collected fresh pellet groups to insure that the diet would be representative for the collection period.

We processed plant reference materials and monthly composited fecal material according to Davitt and Nelson (1980). We employed several important modifications in the procedure compared to other chemical epidermal preparations (Sparks and Malechek 1968, Hansen et al. 1971, Holechek 1982, Holechek et al. 1982). The fecal material was gently agitated with water at low speed in a blender for several minutes, rather than grinding in a Wiley mill through a 1 mm mesh screen, which might affect the discernibility of some fragments (Vavra and Holechek 1980, Samuel and Howard 1983). We washed the fecal material in cool water over a 200 mesh screen (75 micron openings), and stored it in 95% ethanol for ≥24 hours to remove pigments. We decanted the ethanol and bleached the residue for 5 to 10 minutes, rewashed the residue using the 200 mesh screen then placed it in a lactophenol blue staining solution for ≥24 hours. Excess stain was washed off using cool water and the epidermal and cuticle fragments were carefully transferred to a slide, covered with glycerin gel and sealed with a cover slip.

We determined botanical composition of the diets using a modification of existing relative frequency-density conversion sampling procedures (Sparks and Malechek 1968, Holechek and Vavra 1981, Johnson 1982) and frequency addition sampling procedures (Holechek and Gross 1982). We sampled a minimum of 40 randomly located fields on each of 5 slides (total of 200 views) with identifiable epidermal cell fragments. We used a 10 × 10 square grid (100 total, each 100 micron × 100 micron in size) mounted in the ocular of the microscope to measure the area covered by each positively identified fragment observed at 100× magnification. Larger magnifications (200*x* and 450*x*) and reverse phase contrast were frequently used to aid in identification of discernible fragments only. Measurements of area covered on the grid were performed at 100× magnification and recorded by plant species and plant part, or at least to genus whenever possible. Discernible, but unidentifiable, fragments were recorded by forage class.

Percent diet composition was calculated by expressing cover of each plant species relative to total cover observed for all species, as:

$$D_{if} = \frac{C_{if}}{\Sigma\,(C_{if})}, \qquad (1)$$

where D_{if} was the percent of species i in the fecal diet, C_{if} the cover of species i in the feces, and $\Sigma\,(C_{if})$ the total cover for all species. We set sample sizes to maintain standard errors of the mean at ≤10% for all species constituting >5% of the diet. We chose >5% of the diet to facilitate data collection and analysis.

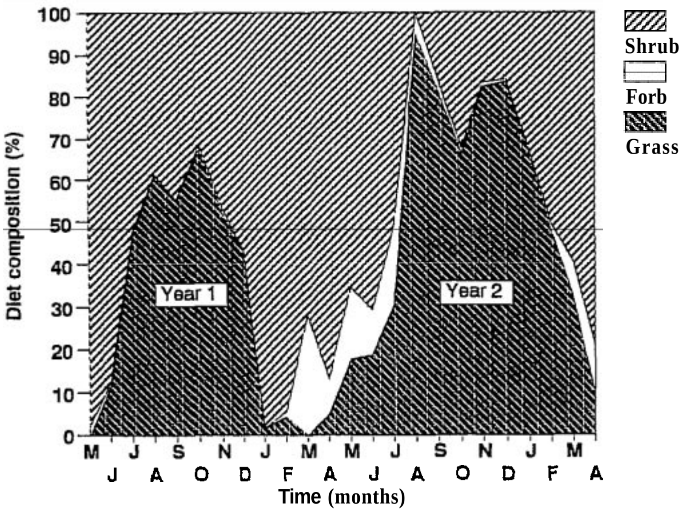

Fig. 1. Diet composition by forage class of mountain sheep in the Superstition Mountains, Arizona, from May 1987 to April 1989.

We determined relative correction factors to adjust for differential digestibility and fragmentation using a modification of Dearden et al. (1975). The in vitro procedure used was outlined by Pulliam and Nelson (1979) and Smitman (1980), and was similar to that described by Leslie et al. (1983). Each plant species was hand mixed in known proportions based on levels from the original fecal analysis estimates of diet composition. We subjected each of the monthly diet mixtures to in vitro digestion for 48 hours (Tilley and Terry 1963, Goering and Van Soest 1970) using domestic sheep rumen inoculum. Epidermal and cuticle fragments recovered from the in vitro residue were analyzed as described above. We determined cover based correction factors for each individual plant species in each diet mixture to account for both seasonal phenological changes and the associative effects of various plant mixtures on differential epidermal digestion and discernibility (Milchunas et al. 1978, Gill et al. 1983). We determined correction factors using the equation:

$$DC_i = \frac{D_{ik}}{D_{iv}}$$

where DC, was the digestion coefficient of species i, D_{ik} was the percent species i in the known diet mixture, and D_{iv} was the percent species i in the in vitro diet, calculated using equation (1). The fecal diet was corrected using the equation:

$$D_{ic} = \frac{DC_i \times D_{if}}{\Sigma\,(DC_i \times D_{if})}$$

where D_{ic} was the percent species i in the corrected diet, DC_i the digestion coefficient of species i, and D_{if} the percent species i in the uncorrected diet.

We characterized diets on a seasonal and a yearly basis. The 4 seasonal categories we used were: hot-dry (Apr–Jun); hot-wet (Jul–Sep); cool-dry (Oct–Dec); cool-wet (Jan–Mar).

Concurrent with fecal collection, we collected plant materials of all species observed (or suspected) to be used by mountain sheep. We made collections from areas mountain sheep foraged. Only those portions of each plant which were observed to have been consumed were collected to more closely approximate forage quality of the diet. All forage samples were oven dried and ground in a Wiley mill with a 1 mm screen and stored for later analysis.

We estimated diet quality from forage mixtures using forages mixed in proportions found in the corrected diets and from the same time period. We characterized nutrient content of monthly composited diets for gross energy (GE) using bomb calorimetry, crude protein (CP) using micro Kjeldahl analysis (AOAC 1980), and dry matter digestibility (DMD) by in vitro digestion (Goering and Van Soest 1970) using domestic sheep rumen inoculum. Metabolizable energy (ME) and digestible protein (DP) were adjusted according to DMD (Miller 1978).

The daily nutrient requirements of an average 45 kg female mountain sheep, with a daily dietary intake of 2.5% of body weight, conceiving in mid-September, gestating for 180 days, and lactating for 100 days were modeled using the procedure outlined by Nelson and Leege (1982) and Hobbs (1989). Activity data for standing, feeding, and movement were extrapolated from Alderman et al. (1989) and Warrick and Krausman (1987), and used to determine the energy cost of activity (Robbins 1983). We used these data in comparisons with nutrient contents of the diet to evaluate the adequacy of the diet to meet the animal's daily requirements.

RESULTS

Diet Composition

Diet composition reflected a definite yearly pattern of forage class use (Fig. 1). Use of grass species increased during July through December, while shrub use decreased. Forb use increased during March and April.

Comparison of diets within season between years revealed a seasonal pattern of forage class use (Table 1). Shrub use was highest during the hot dry season at 92 and 74%, respectively, during year 1 and year 2. Grass use was limited to 6 and 14%, while forb use amounted to 2 and 12% in year 1 and 2, respectively.

During the hot wet season the shrub component of the diet decreased and grass became the dominant forage class used (Table 1). Shrub use was 45% in year 1 and 22% in year 2, while grass use increased to 54 and 69%, respectively. Use of forbs increased from <1% in year 1 to 9% in year 2.

Shrub use continued to decline during the cool dry season (Table 1). Similarly, the grass component continued to increase. Shrub use was 45% in 1987 and 22% in 1988. Grass use was 54% in year 1 and 77% in year 2, and there was little use of forbs during this season.

During the cool wet season, the shrub class returned as the dominant forage class used (Table 1). Shrub use was 88% in 1988 and 55% in 1989, while grass use declined to 2% in year 1 and 39% in year 2. Forb use comprised 9 and 6% of the total diet in year 1 and 2, respectively.

Nutrient Evaluation

During May 1987, the DP content averaged about 5.6% and reached its lowest content at 4.5% in July (Table 2). The DP content of the diet began to increase in August of year 1 and by April–May 1988 it averaged 8.9%. The DP content of the diet remained relatively high for the remainder of 1988 and early 1989, declining no lower than 7.4% in November. By May 1989 the DP content reached its peak during the study at approximately 9.8%.

Metabolizable energy content of the diet displayed a cyclic pattern, with the periods of lowest levels occurring in July–September and highs in February–April. The lowest levels of ME (1,086 kcal/kg) occurred during the early part of the study and was at its lowest in July 1987, while the highest ME level (2,549 kcal/kg) occurred in April 1989 (Table 2).

DISCUSSION

Mountain sheep are highly adaptive and opportunistic foragers, and possess the ability to use a wide variety of plants (Miller and Gaud 1989, Krausman et al. 1989). In the southwest, mountain sheep diets appear to be dominated by shrubs (Seegmiller and Ohmart 1981, Cunningham 1982, Dodd 1987, Krausman et al. 1989, Miller and Gaud 1989). However, grasses comprise the majority of the diet throughout Nevada (Brown et al. 1977). Hansen and Martin (1973) found grasses to be a major component of mountain sheep diets in the Grand Canyon, Arizona. During our study shrubs composed 56% of the average annual diet of sheep, followed by grasses (39%) and forbs (5%); these results agree with other studies of diet composition for mountain sheep in the southwest.

Seasonal changes in use of forage classes have been documented (Browning and Monson 1980, Scott 1986, Dodd 1987, Miller and Gaud

Table 1. Seasonal species composition of mountain sheep diets, corrected for differential digestibility, on Coffee Flat, in Superstition Mountains, Ariz., May 1987 to April 1989.

	Seasons							
	Hot Dry		Hot Wet		Cool Dry		Cool Wet	
Species	Y1	Y2	Y1	Y2	Y1	Y2	Y1	Y2
Grass								
Side-oats grama (*Bouteloua curtipendula*)	2.4	3.2	30.5	10.4	29.9	58.1	t	23.3
Creeping muhly (*Muhlenbergia repens*)	t	t	2.9	t	t	t		t
Red brome (*Bromus rubens*)	t	t	t	3.5	t	t		
Wild oats (Avena fattia)			2.7	t	t	t		
Green sprangle-top (Leptochloa *dubia*)		6.3		4.4	t	t		t
Three-awn (*Aristida* spp.)		t	13.9	38.1	10.8	12.9	t	14.5
Tangle-head (*Heteropogon contortus*)		t	t	8.0	6.4	3.4		t
Others[a]	2.7	t	3.2	2.6	5.4	t	t	t
Total grass	5.9	13.9	54.5	69.1	54.4	77.4	2.0	39.1
Forbs								
Wooly Indian wheat (Plantago *insularis*)	t	2.4		t			t	t
Globe mallow (*Sphaeralcea ambigua*)	t	2.8	t	2.8				2.0
Spurge (Euphorbia spp.)		3.6		4.5		t	2.3	t
Lupine (*Lupinus* spp.)		t			t		6.6	
Bur clover (Medicago hispida)		2.3		t			t	t
Others[b]		t	t	t	t	t	t	t
Total forbs	1.7	11.9	0.5	8.9	0.8	1.2	9.8	5.6
Shrubs								
Jojoba (*Simmondsia chinensis*)	47.5	49.3	11.4	8.9	25.7	11.6	57.2	40.3
Birchleaf mtn. mahogany (*Cercocarpus betuloides*)	11.9	4.7	5.5	t	6.1	t	17.5	4.3
Arizona rosewood (*Vauquelinia californica*)	7.9	t	5.9	t	2.2	t	2.1	4.0
Hop-bush (Dodonaea viscosa)	4.7		t	t	t		t	
Turbinella oak (*Quercus turbinella*)	7.3	t	6.5	t	2.1	t	3.5	t
Cliff-rose (*Cowania mexicana*)	4.3	2.7	3.1	t	2.0	t	3.3	t
False mesquite (*Calliandra eriophylla*)	t	6.1	2.7	5.1	2.2	4.7	t	2.0
Mesquite (*Prosopis glanulosa*)	t	2.5	t	t		t	t	t
Turpentine bush (*Haplopappus laricifolius*)	3.8	2.5	4.8	t	3.1	t	3.7	t
Brittle-bush (*Encilia farinosa*)	3.9	2.6	t		t		t	t
Others[c]	t	2.3	t	t	t	t	t	t
Total shrubs	92.4	74.2	45.0	22.0	44.8	21.6	88.2	55.3

[a]Grass species averaging <2% of the diet, seasonally: cane beardgrass, foxtail brome, hairy gramma, vine-mesquite, New Mexico needlegrass, Arizona cotton-top, June grass, Bermuda grass, Curly-mesquite, unknown grass.

[b]Forb species averaging <2% of the diet, seasonally: filaree, bluedicks, mullein, milk-vetch, unknown forbs.

[c]Shrub species averaging <2% of the diet, seasonally: cat-claw acacia, wolf-berry, range ratony, cocklebur, wild-buckwheat, desert hackberry, Mormon tea, unknown shrubs.

t = <2%.

1989). Rominger et al. (1988) reported that shrubs comprised from 73 to 94% of the summer diet, and that mountain mahogany (*Cercocarpus montanus*) constituted 81% of the total diet for Rocky Mountain bighorn sheep (Ovis *canadensis canadensis*) in Colorado. In our study jojoba (*Simmondsia* chinensis) and birchleaf mountain mahogany (*Cercocarpus betuloides*) were the dominant shrub species, while side-oats grama (*Bouteloua curtipendula*) and three-awn (Aristida spp.) were the dominant grass species in the diets across all seasons and years.

Seasonal variation in mountain sheep diets has been postulated to reflect the nutritional quality of the plants contained in the diet (Hobbs et al. 1983, Goodson et al. 1991). The nutritional content of a plant affects its digestibility and palatability. Generally, as a plant matures its nutrient content declines and likewise, its digestibility and palatability decreases. However, Krausman et al. (1989) found that the seasonality of mountain sheep diets does not necessarily reflect the use of the most nutritious species.

Protein and energy are regarded as the most important nutrients to the ruminant animal. One of the major considerations of this study was the ability of the diet to meet an average female's daily nutrient requirements. With the exception of lactation in the early part of the first year, the DP content of the diet was sufficient to meet all of a female's daily protein requirements (with or without a lamb) over the entire study period (Fig. 2). A female mountain sheep without a lamb requires about 22 g of DP/day, while a female with a single lamb requires from 22 g to 76 g of DP/day (Fig. 2). During lactation (May–Jun) of year 1 of this study, the dietary DP content was not sufficient to meet the female's daily requirements.

This limited DP shortfall could be offset by an increase in daily dry matter intake. It is not unreasonable for mountain sheep to increase their consumption rate to as much as 3.5% of their body weight (Hansen 1980). If this were done, the protein content of the diet would have been more than adequate to meet daily protein needs. However, in June of 1987 the crude protein content of the diet was 4.5% with a dry matter digestibility of 28%. Because digestibility of the diet affects passage rate, which influences consumption rate, females may not have been physically able to increase their intake.

A female's ME requirements are more variable than her DP requirements. A female without a lamb requires about 1,800 kcal of ME/day, while a female with a single lamb has ME requirements ranging from 1,800 to 3,400 kcal/day (Fig. 3). In our study, the ME content of the

Table 2. Nutritional composition of mountain sheep diets, Coffee Flat, Superstition Mountains, Ariz., May 1987 to April 1989.

Month	Crude[a] protein (%)	Digestible protein (%)	Gross energy (kcal/kg)	Metabolizable energy (kcal/kg)
May 1987	7.4	5.8	4,524	1,608
Jun 1987	6.6	5.4	4,524	1,469
Jul 1987	4.7	4.5	4,199	1,086
Aug 1987	6.6	5.4	4,181	1,358
Sep 1987	6.3	5.3	4,242	1,335
Oct 1987	9.5	6.8	4,819	1,992
Nov 1987	9.8	7.0	4,343	1,833
Dec 1987	8.9	6.5	4,267	1,690
Jan 1988	13.5	8.7	4,554	2,372
Feb 1988	12.4	8.2	4,482	2,208
Mar 1988	12.1	8.1	4,213	2,042
Apr 1988	13.9	8.9	4,521	2,400
May 1988	14.1	9.0	4,344	2,328
Jun 1988	13.3	8.6	4,283	2,209
Jul 1988	12.0	8.0	4,176	2,013
Aug 1988	11.0	7.5	3,962	1,804
Sep 1988	11.6	7.8	4,088	1,928
Oct 1988	11.4	7.7	4,061	1,893
Nov 1988	10.7	7.4	4,064	1,817
Dec 1988	10.9	7.5	4,045	1,831
Jan 1989	12.2	8.1	4,171	2,033
Feb 1989	13.5	8.7	4,296	2,238
Mar 1989	15.0	9.4	4,300	2,400
Apr 1989	15.8	9.8	4,415	2,549

[a] All values are reported on a dry matter basis.

diet is sufficient to meet the energy requirements of any female mountain sheep for maintenance, activity and gestation, except during the early part of the first year (Fig. 3).

Significant periods of insufficient ME were observed during peak lactation across all years and during breeding in the first year. Energy deficiencies during these periods can have a strong influence on a female's ability to produce adequate amounts of milk, resulting in poor lamb performance. Additionally, energy deficiencies post lactation and pre-breeding can affect the reproductive potential of the female, making it difficult for the female to conceive or carry the fetus to term.

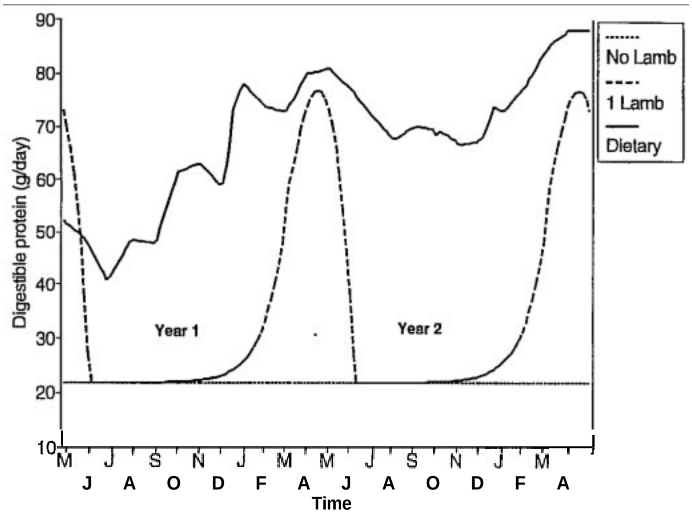

Fig. 2. Dietary protein evaluation of mountain sheep females in the Superstition Mountains, Arizona, from May 1987 to April 1989.

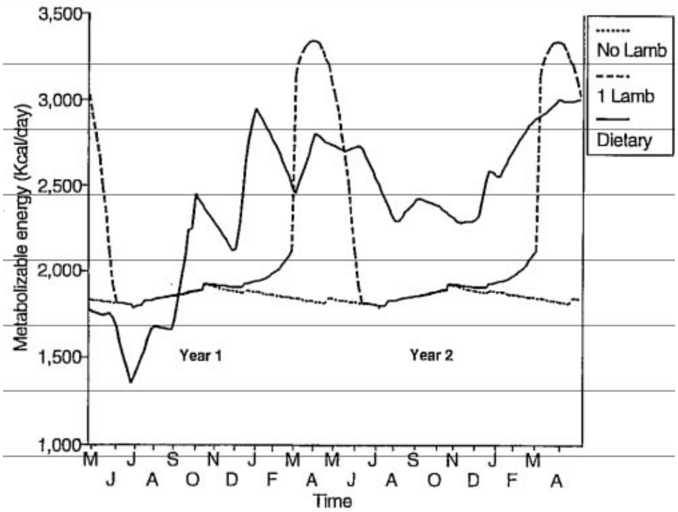

Fig. 3. Metabolizable energy evaluation of mountain sheep females in the Superstition Mountains, Arizona, from May 1987 to April 1989.

The ability of mountain sheep to increase their consumption rate to 3.5% of their body weight, coupled with increases in diet quality during periods of peak lactation, may offset potential ME deficiencies. Under these conditions, the apparent energy deficiency calculated for the latter part of years 1 and 2 may not have been as severe as it would first appear. The size and duration of the ME deficiency estimated in the early part of year 1, however, may have been too large to compensate for by increasing daily dry matter intake.

Generally, ruminants in poor physical condition prior to breeding may delay or skip estrus during periods of nutrient stress, thus affecting lamb recruitment. Clutton-Brock and Albon (1989) examined the energy costs of red deer (*Cervus elaphus*) gestation and lactation and reported that lactating females had lower fecundity than non-lactating females. The difference in conception success was attributed to overall body condition, which is directly affected by diet quality and quantity. During our study, fewer lambs were observed at the end of the first year than in the second (Wakeling and Miller, unpublished data, 1989). If females were stressed physically in the early part of year 1, they may have produced fewer lambs during the following gestation.

During gestation and lactation of year 1 (latter part) and year 2, the quality of the forage had improved so that females would have been able to recover from any nutritional deficiency. Thus, the ewe's ability to conceive, or the survivability and recruitment of lambs probably would not have adversely been affected during the latter part of this study.

MANAGEMENT IMPLICATIONS

We believe that the technique described in this paper provides the basic methodology for evaluating the adequacy of a habitat to meet the nutritional needs of mountain sheep. Diet composition estimates from our study area support the concept that mountain sheep are highly adaptive and opportunistic foragers, and will change diets in accordance with individual plant species availability and palatability. The quality of forage available to mountain sheep on this study area appears adequate to meet the protein requirements, when consuming at 2.5% of body weight/day. However, during extended periods of drought conditions, the decreased forage quality may effectively inhibit the ability of mountain sheep to meet their protein needs, thus adversely impacting the short-term recruitment of lambs into the population.

The energy requirements are more variable, and have a higher impact on female performance. The estimated energy content of the diet during our study was adequate to meet the female's needs except during lactation. Energy deficiencies during this phase were of sufficient magnitude to mildly impact females with single lambs. In situations where twin lambs were present, energy levels similar to those we reported could have resulted in the loss of one or both lambs. This may be a partial explanation for the limited recruitment observed in some mountain sheep populations.

Traditional techniques for the evaluation of mountain sheep habitat have centered on cover, space, and water. We believe that in order to completely evaluate habitat quality, data on the forage availability and nutritional quality is necessary.

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AN ANALYSIS OF FORAGE USED BY MOUNTAIN SHEEP IN THE EASTERN MOJAVE DESERT, CALIFORNIA

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Abstract: We describe monthly moisture content, crude protein level, and digestibility of 20 forage species consumed by mountain sheep (*Ovis canadensis nelsoni*) in the eastern Mojave Desert, California. Differences existed in mean monthly moisture content for 15 plant species collected from male and female ranges, but only moisture content of triple-awned grass (Aristida adscensionis) differed on an annual basis. Crude protein levels were greater on an annual basis for triple-awned grass, California buckwheat (*Eriogonum fasciculatum*), winter fat (*Eurotia lanata*), and *Krameria parvifolia* collected from female ranges, and for Mormon-tea (Eplzedra spp.), bedstraw (*Galium* spp.), and blackbush (*Coleogyne ramosissima*) collected from male ranges. Digestibility was greater for Mormon-tea and desert-mallow (*Sphaeralcea ambigua*) collected from male ranges. We tabulated our results for comparative use by other investigators.

Key words: crude protein, digestibility, forage quality, Mojave Desert, mountain sheep, Ovis *canadensis nelsoni*, sex differences.

Forage quality potentially influences population dynamics of wild ungulates (Leopold 1933), including desert-dwelling mountain sheep (*Ovis canadensis* spp.) (Bleich 1986, Douglas and Leslie 1986, Wehausen et al. 1987). Nutritional quality of mountain sheep forage is receiving increasing attention as investigators seek to understand the population dynamics of these large herbivores (Miller and Gaud 1989, Wehausen and Hansen 1988, Wehausen 1988, 1990).

Several investigators (Barrett 1964; Brown et al. 1976, 1977; Deming 1964; Ginnet and Douglas 1982; Kirkeeng 1985) described the diets of mountain sheep from Mojave Desert ecosystems. However, only Morgart et al. (1986) and Kirkeeng (1985) examined the quality of the forage consumed by mountain sheep in the Mojave Desert. Seegmiller et al. (1990) and Miller (1987) provided data for forage species consumed by mountain sheep in the Sonoran Desert. In addition, Krausman et al. (1990) and Rautenstrauch et al. (1988) reported the nutritional quality of mule deer (*Odocoileus hemionus crooki*) forage plants from the Sonoran Desert, many of which probably are eaten by mountain sheep. With the exception of Krausman et al. (1989), no data are available on the quality of forage species collected from ranges used differentially by male or female desert-dwelling mountain sheep.

The objective of our investigation was to quantify, on a monthly basis, the moisture content, protein content, and digestibility of some important plant species in the diets of mountain sheep in the eastern Mojave Desert, California.

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STUDY AREA

Our study was conducted at Old Dad Peak and the Kelso Mountains, San Bernardino County, California. Elevations ranged from 400 to 1,600 m. Average annual precipitation at Baker, California (30 km NW of the study area) is 8.33 cm. Average temperature at Baker is approximately 10 C and 34 C in January and July, respectively (Curry 1983). Martens and Baldwin (1983) described 7 plant communities in the study area, including creosote bush (Larrea trideiztata) scrub, Yucca-Ephedra scrub, transition zone, rupicolous scrub, wash scrub, partially stabilized dunes, and stabilized dunes. Approximately 360 adult mountain sheep inhabit the study area (Jaeger et al. 1991). Plant nomenclature follows Munz (1974); absence of common names indicates that none were recognized by Munz (1974).

METHODS

We collected twenty forage species based on the results of mountain sheep fecal analyses and direct observations of foraging sheep (V. C. Bleich, unpubl. data). We collected plants from 2 areas used almost exclusively by females (except during the rut) and 2 areas used primarily by males. Sampling sites on female ranges were located in the rupicolous scrub. On male ranges, sampling occurred in the transition zone and in *Yucca-Ephedra* scrub. The selection of male and female sampling areas was based on 3,026 aerial telemetry fixes for 27 male and 17 female mountain sheep, 874 aerial observations of mountain sheep groups, and 544 ground observations of mountain sheep groups obtained from 1981 to 1991 (V. C. Bleich, unpubl. data). All 20 plant species did not grow in any single area in either the male or female ranges; therefore, we obtained samples from 2 locations each within areas occupied by males and females.

We collected forage samples from June 1990 to May 1991. We collected succulents, annuals, and deciduous perennials only when appropriate plant parts were available. Not all forage species occurred in both male and female sampling areas. Catclaw (Acacia greggii) and desert-lavender (*Hyptis emoryi*) were found only in male areas, and mesquite (Prosopis *glandulosa*) and dropseed (*Sporobolus flexuosus*) were found only in female areas.

We collected primarily green leaves, grass seed heads, flowers, and/or new growth from each plant. We collected 5 samples of each forage species, weighing 50–100 g each, from male and female ranges. As samples were collected, they were placed in paper bags and weighed to

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Table 1. Percents moisture, crude protein, and in vitro *dry matter digestibility of selected mountain sheep forage plants from male and female ranges, Old Dad Peak and the Kelso Mountains, San Bernardino County, California, 1990–91.*[a]

	% Moisture[b]				% Crude Protein		% Digestibility	
	Male		Female					
Month	$\bar{x}$	SD	$\bar{x}$	SD	Male	Female	Male	Female
Catclaw *(Acacia greggii)*								
Jun	48.5	2.5			15.43		30.2	
Jul	41.8	2.5			14.44		22.9	
Aug	47.5	4.2			14.92		26.5	
Sep	43.1	2.2			12.72		40.5	
Oct	42.7	0.9			12.37		39.9	
Nov	42.0	3.5			10.78		41.2	
Dec	24.7	8.0			10.16		38.9	
Burro-weed (Ambrosia dumosa)								
*Jun**	72.6	2.3	66.2	2.0	22.53	17.67	72.2	64.2
Jul	52.3	1.5	57.1	7.9	12.81	12.26	57.1	55.2
*Aug**	55.6	3.6	47.2	7.6	10.68	11.76	59.2	55.5
*Sep**	60.2	2.8	44.5	3.3	13.67	12.33	65.9	56.6
*Oct**	58.1	3.6	46.7	5.2	12.75	9.65	57.6	59.4
Nov	42.2	7.3	34.6	4.5	9.74	9.84	51.0	48.8
Dec*	28.7	2.5	43.3	4.5	9.35	9.17	48.5	49.4
Jan	24.8	1.0	27.3	3.0	7.43	9.57	38.6	45.2
*Feb**	16.1	3.7	52.7	9.2	6.20	14.78	34.3	52.2
*Mar**	50.4	2.4	58.8	2.8	12.15	15.52	52.4	55.5
Apr*	80.2	3.4	70.9	5.6	28.06	22.35	71.2	67.3
May	68.7	5.8	60.4	5.6	19.65	18.15	68.8	69.2
Triple-awned grass (Aristida adscensionis)[c,d]								
*Jun**	27.1	9.6	46.0	7.9	6.14	9.72	39.9	43.6
Jul*	21.3	10.1	45.6	6.9	5.14	7.32	33.3	31.1
*Aug**	34.8	22.4	52.5	8.7	6.34	9.76	29.3	47.6
Sep	32.8	6.7	36.7	10.9	5.83	7.50	37.0	41.3
Oct	26.6	8.2	29.4	4.2	5.42	5.93	38.9	40.1
*Nov**	24.5	4.0	13.9	4.6	6.13	5.00	34.4	66.8
Dec*	14.7	1.7	28.8	4.1	3.94	6.08	36.3	65.7
Jan	24.3	2.5	23.3	2.2	4.81	5.03	39.3	36.6
Feb	21.6	2.5	28.2	9.0	4.93	6.99	35.5	38.2
Mar	30.4	11.1	34.0	8.6	6.35	6.66	36.8	35.9
*Apr**	28.0	4.2	54.8	8.1	5.49	10.56	36.9	37.2
May	38.8	7.9	40.9	4.6	5.53	5.79	41.8	39.2
Desert-holly (Atriplex hymenelytra)								
Jun	57.6	2.1	56.6	0.9	10.65	10.84	63.3	64.0
Jul*	26.5	3.3	49.8	2.3	9.42	7.12	64.4	57.6
Aug	46.2	20.2	51.2	4.4	12.10	10.31	62.1	67.3
Sep	*ND*		54.2	3.2	9.66	11.86	71.1	72.1
Oct	44.4	3.2	44.9	2.6	12.02	12.44	74.7	70.1
Nov	42.5	3.5	44.3	3.5	12.74	10.85	66.8	69.6
Dec	40.4	3.5	38.5	3.6	12.87	9.33	65.7	60.1
Jan	60.4	5.1	57.0	3.9	13.51	12.59	76.0	73.7
Feb	51.0	5.0	55.9	1.3	12.88	13.01	67.4	68.5
Mar	67.6	4.5	70.0	4.3	14.79	13.88	65.9	66.0
Apr	71.9	4.1	74.4	4.8	13.61	15.29	73.2	75.3
*May**	67.8	2.9	79.3	0.8	11.29	12.22	71.4	70.2
Grama grass (Bouteloua sp.)								
Jul	74.0	3.1	67.4	9.5	ND	14.97	ND	51.0
Aug	63.8	20.5	55.1	1.8	15.07	15.11	53.3	45.3
Sep	49.2	11.2	45.5	5.6	10.34	11.13	37.4	46.1
Oct	23.8	2.5	13.4	14.5	4.93	7.85	40.0	48.1
Nov	13.1	2.6	11.5	7.0	5.24	7.00	39.3	53.4
Dec*	2.6	2.8	9.1	3.7	5.93	5.07	55.2	46.3

Table 1. Continued.

	% Moisture[b]							
	Male		Female		% Crude Protein		% Digestibility	
Month	$\bar{x}$	SD	$\bar{x}$	SD	Male	Female	Male	Female
Winter fat (Eurotia *lanata*)[d]								
Jun*	39.8	11.0	55.5	2.0	12.19	18.45	44.5	48.5
Jul	41.0	7.8	44.8	2.4	12.35	11.63	36.8	55.1
Aug*	45.1	5.3	32.6	17.7	12.18	13.40	44.0	46.5
Sep*	68.5	4.0	41.6	3.7	15.28	15.03	45.2	45.9
Oct	40.6	5.2	ND		12.81	ND	49.0	ND
Nov	24.4	2.8	26.2	3.3	10.34	12.15	39.6	38.6
Dec	22.6	8.4	17.2	3.2	7.31	6.75	38.4	21.5
Jan	31.3	5.1	32.8	5.6	7.96	13.18	34.5	40.3
Feb	38.5	3.4	41.3	1.8	9.79	11.92	40.0	32.9
Mar	50.7	4.1	53.3	4.7	14.12	15.47	42.4	40.0
Apr	59.8	5.5	66.5	4.3	17.61	20.19	52.3	52.9
May*	53.3	3.1	47.1	1.5	18.14	19.68	57.4	60.8
Blackbush (*Coleogyne ramosissima*)[d]								
Jun	30.8	1.2	34.8	1.4	5.72	ND	30.2	28.9
Jul*	49.8	2.3	26.5	3.3	5.47	5.15	19.7	29.5
Aug*	41.5	22.1	28.0	5.3	5.89	4.78	29.1	26.8
Sep*	51.0	3.6	29.5	3.5	6.11	5.71	30.1	30.1
Oct	40.8	5.2	ND		5.99	ND	30.8	ND
Nov*	32.4	3.2	20.9	1.4	4.78	4.66	23.7	22.6
Dec	28.1	5.2	24.5	3.5	4.77	4.42	26.4	25.7
Jan	32.5	2.2	29.4	2.2	4.78	5.08	23.7	23.1
Feb	31.2	2.3	25.9	3.6	5.36	5.12	27.0	23.0
Mar	36.7	1.9	34.7	1.9	6.15	5.89	27.4	25.4
Apr*	55.6	3.4	42.5	2.2	10.72	6.59	30.3	51.8
May*	59.0	1.8	38.5	2.4	9.95	6.92	55.0	39.2
Brittle-bush (Encelia spp.)								
Jun*	46.3	4.7	70.5	3.3	10.39	16.88	58.4	54.3
Jul*	47.4	6.1	58.1	2.0	11.35	11.39	68.3	58.8
Aug	62.3	4.1	55.6	12.6	10.73	10.60	61.5	63.2
Sep	60.4	9.6	58.1	3.7	13.65	10.14	67.3	51.3
Oct	63.8	3.7	52.6	19.7	11.96	10.06	60.9	48.5
Nov	48.4	8.8	43.0	12.0	8.22	10.17	57.7	62.9
Dec	48.3	11.0	46.0	11.0	8.01	9.14	59.9	56.3
Jan	20.8	3.2	35.1	10.2	4.91	11.46	37.3	53.9
Feb*	27.0	3.5	12.4	3.5	5.50	10.08	38.0	44.5
Mar*	34.6	1.7	68.6	3.4	6.15	17.29	34.9	67.0
Apr	73.3	4.8	74.7	2.2	20.75	20.98	66.2	68.4
May*	73.8	2.9	62.1	4.1	21.83	13.12	67.7	40.2
Mormon-tea (Ephedra spp.)[d,e]								
Jun	34.7	2.4	38.1	2.1	6.31	6.29	32.1	31.4
Jul*	34.2	1.5	41.8	4.0	9.85	6.28	41.8	30.5
Aug	49.0	13.0	42.9	18.9	9.54	9.03	35.3	26.1
Sep	41.2	6.8	37.6	3.3	9.00	6.81	41.1	37.9
Oct*	32.3	8.2	46.4	1.2	9.26	8.85	40.7	40.6
Nov	41.9	3.9	38.6	1.7	10.48	7.55	42.1	34.3
Dec	40.6	2.8	44.7	1.7	8.95	9.02	42.5	34.6
Jan*	36.3	8.7	44.1	2.0	11.18	8.08	52.6	32.2
Feb	39.5	2.9	42.7	1.9	9.28	7.15	28.4	31.7
Mar	40.9	2.8	41.1	2.6	10.78	6.62	47.5	34.6
Apr*	41.8	0.8	45.7	3.3	10.94	6.86	49.6	40.4
May	53.2	3.2	43.4	6.6	13.31	7.09	60.1	35.6

Table 1. Continued.

Month	% Moisture[b] Male $\bar{x}$	Male SD	Female $\bar{x}$	Female SD	% Crude Protein Male	% Crude Protein Female	% Digestibility Male	% Digestibility Female
California buckwheat (*Eriogonum fasciculatum*)[d]								
Jun	36.8	1.0	42.4	4.7	6.15	7.94	26.8	24.5
Jul*	30.6	5.0	49.2	9.0	5.09	6.25	18.2	19.6
Aug	40.5	15.2	37.3	10.6	6.18	6.33	16.4	23.7
Sep*	42.3	1.7	29.4	4.8	5.88	6.80	23.7	30.9
Oct	38.6	2.8	34.4	3.2	6.04	6.55	24.5	28.0
Nov	36.1	6.2	31.6	2.3	6.67	7.10	26.3	23.4
Dec	28.4	7.4	34.6	4.5	7.56	6.67	23.8	23.8
Jan	31.0	5.2	27.8	6.5	6.09	5.92	24.8	22.5
Feb	38.1	2.0	36.0	7.3	6.38	7.52	25.0	22.7
Mar	48.4	3.4	49.0	3.5	9.60	9.45	28.9	35.8
Apr	58.6	4.0	58.9	2.7	10.41	11.22	32.8	32.6
May	65.3	1.6	59.8	4.7	9.70	10.23	26.7	36.6
Bedstraw (*Galium* spp.)[d]								
Jun*	30.7	7.4	55.8	6.2	8.41	9.11	46.5	46.3
Jul*	23.9	4.5	44.2	7.6	5.63	7.63	37.1	43.5
Aug*	47.9	5.8	26.8	5.4	8.21	6.05	47.5	36.3
Sep*	53.5	5.2	40.5	9.1	9.03	8.04	50.4	50.3
Oct	40.4	13.8	25.0	6.0	8.95	6.98	52.2	43.1
Nov	29.8	8.2	17.1	4.5	8.44	7.95	54.5	50.7
Dec*	31.7	2.8	23.2	4.6	7.67	6.34	53.9	37.6
Jan	25.6	5.1	27.2	6.5	7.13	6.02	47.5	35.7
Feb*	42.6	13.0	19.3	8.6	9.03	5.94	39.2	42.3
Mar	53.5	7.3	41.6	18.3	9.77	7.60	41.3	41.8
Apr	73.5	2.2	72.9	3.5	19.22	16.19	59.7	61.6
May*	67.2	1.9	60.4	1.4	10.31	9.99	53.6	54.0
Galleta (*Hilaria rigida*)								
Jun	ND		64.4	1.7	ND	13.05	ND	52.9
Jul	ND		50.1	5.9	ND	7.25	ND	30.8
Aug*	50.1	10.1	29.8	6.2	6.46	5.24	41.9	37.3
Sep*	60.7	7.2	36.6	10.8	8.47	5.72	40.9	42.2
Oct*	48.7	4.2	12.6	2.6	6.49	3.79	39.0	42.1
Nov*	17.8	1.3	11.9	3.2	3.66	3.54	37.3	36.6
Dec*	19.6	2.7	14.1	2.3	3.48	3.80	37.4	41.4
Jan*	19.9	2.0	12.5	1.4	3.22	3.43	35.8	32.4
Feb*	5.1	0.6	13.9	3.0	3.52	3.82	27.7	33.0
Mar	17.5	13.5	24.9	3.3	3.56	3.66	34.2	32.0
Apr*	5.8	1.3	63.2	2.8	7.98	3.51	31.3	49.9
May	35.8	11.7	47.9	4.7	7.14	6.41	38.0	38.8
Desert-Lavender (*Hyptis emoryi*)								
Jun	47.8	0.2			8.70		32.4	
Jul	48.2	4.9			8.98		30.7	
Aug	59.9	6.0			10.66		30.7	
Sep	ND				11.24		38.9	
Oct	58.5	4.2			8.80		34.4	
Nov	50.0	6.9			8.99		43.8	
Dec	47.0	8.2			8.07		42.8	
Jan	46.6	2.8			7.72		44.8	
Feb	52.9	3.4			8.84		46.0	
Mar	56.2	2.3			9.50		45.9	
Apr	57.6	14.1			11.09		50.9	
May	77.4	1.9			11.66		45.6	

Table 1. Continued.

	% Moisture[a]				% Crude Protein		% Digestibility	
	Male		Female					
Month	$\bar{x}$	SD	$\bar{x}$	SD	Male	Female	Male	Female
Krameria parvifolia[d]								
Jun*	42.2	1.5	52.6	1.8	9.00	11.32	27.3	25.3
Jul*	35.8	2.8	46.6	4.1	8.03	9.01	16.7	23.6
Aug*	49.6	6.7	38.3	8.9	8.86	10.04	27.9	25.7
Sep*	52.6	1.5	42.4	4.3	8.49	8.61	23.5	26.3
Oct*	40.2	2.9	26.4	4.1	8.31	8.04	26.2	27.4
Nov	25.5	2.4	24.0	2.4	6.29	5.65	21.5	19.3
Dec	28.8	2.5	33.1	7.4	6.07	6.44	24.9	24.9
Jan	27.6	1.8	27.5	1.6	6.03	6.65	18.6	19.3
Feb	27.4	2.4	25.8	3.4	6.06	6.75	19.5	17.9
Mar*	32.8	4.2	25.7	2.0	6.48	7.31	16.5	20.0
Apr*	28.3	0.7	36.2	5.2	6.49	8.40	22.1	24.5
May	50.0	0.8	48.7	4.0	9.48	12.23	38.8	39.2
Muhlenbergia rigens								
Jun	44.1	8.5	ND		8.77	ND	44.5	ND
Jul*	32.1	5.7	59.1	5.0	5.17	10.90	28.4	33.8
Aug	40.7	23.5	40.7	8.1	7.37	8.06	41.2	39.5
Sep	ND		ND		ND	ND	ND	ND
Oct	ND		ND		ND	ND	ND	ND
Nov	ND		ND		ND	ND	ND	ND
Dec	ND		ND		ND	ND	ND	ND
Jan	ND		ND		ND	ND	ND	ND
Feb	ND		ND		ND	ND	ND	ND
Mar*	8.4	3.0	22.3	3.6	4.81	4.06	27.9	27.8
Apr*	7.3	3.1	41.8	5.0	4.64	7.98	25.8	28.2
May	42.8	9.4	39.6	5.4	7.00	6.62	40.3	29.0
Beavertail cactus *(Opuntia basilaris)*								
May	92.6	0.6	86.7	16.1	10.32	11.33	75.8	ND
Mesquite *(Prosopis glandulosa)*								
Jun			ND			ND		ND
Jul			52.1	6.6		18.23		51.4
Aug			52.6	4.0		14.85		51.4
Sep			47.3	4.5		19.31		57.2
Oct			55.0	4.6		18.74		65.4
Nov			53.1	3.6		17.79		56.4
Dec			48.5	2.4		15.99		58.7
May			75.5	1.9		31.30		67.9
Desert-mallow *(Sphaeralcea ambigua)*[d]								
Jun*	53.4	0.4	64.7	2.2	13.94	18.44	60.0	58.3
Jul	60.9	8.6	52.4	11.8	17.92	10.87	59.5	43.8
Aug*	56.8	2.0	46.0	23.2	15.67	14.06	55.5	49.9
Sep	67.4	13.8	54.3	6.3	14.76	14.04	51.9	48.0
Oct*	57.1	3.2	51.3	2.3	13.64	12.26	49.3	51.1
Nov	46.2	4.2	40.2	4.7	11.15	9.99	50.9	42.3
Dec	43.2	1.4	35.9	7.3	8.50	7.33	45.6	46.1
Jan	34.3	18.8	44.9	4.6	10.89	13.53	47.7	44.4
Feb	65.3	2.2	56.4	7.0	16.07	13.66	47.9	46.9
Mar	63.6	4.7	61.4	2.5	15.89	15.33	56.3	52.6
Apr	74.7	4.6	70.5	6.0	20.87	17.30	73.0	59.4
May*	75.9	1.1	63.4	1.6	19.42	16.09	60.1	59.7

Table 1. Continued.

	% Moisture[b]							
	Male		Female		% Crude Protein		% Digestibility	
Month	$\bar{x}$	SD	$\bar{x}$	SD	Male	Female	Male	Female
Dropseed (*Sporobolus flexuosus*)								
Jun			54.2	6.6		10.60		45.0
Jul			54.5	12.5		9.67		41.5
Aug			47.6	9.3		8.82		50.8
Sep			35.5	5.2		8.15		46.2
Oct			8.6	4.4		6.09		41.4
Nov			7.3	1.7		6.81		41.4
Dec			14.9	7.2		4.61		39.9
Jan			10.8	2.3		4.50		36.6
Feb			12.0	1.3		5.14		38.9
Mar			10.8	4.5		3.96		40.4
Apr			69.4	2.7		17.96		62.7
May			46.6	10.0		6.78		45.5
Needlegrass (Stipa *speciosa*)								
Jun	30.4	5.2	41.1	6.5	6.62	9.52	45.5	41.2
Jul	21.7	7.9	30.7	6.9	5.88	5.78	40.9	38.5
Aug	28.1	6.7	32.4	33.9	5.50	5.07	40.8	44.7
Sep*	52.4	2.6	30.9	8.3	7.58	7.95	41.5	39.3
Oct*	42.6	3.4	11.6	3.9	9.04	4.58	40.0	48.7
Nov	31.6	4.5	24.6	9.6	6.32	6.90	42.1	39.2
Dec*	27.8	2.8	18.4	5.9	6.34	5.52	40.3	44.7
Jan*	19.8	4.2	26.3	2.3	6.68	6.09	40.0	40.6
Feb	30.9	3.9	26.9	3.8	5.16	6.94	37.8	37.0
Mar	38.5	4.1	37.5	2.1	8.09	9.79	41.6	45.2
Apr	51.9	3.3	56.4	11.6	9.64	13.37	46.7	48.5
May	51.4	5.2	50.5	3.0	8.21	9.11	46.6	47.2

[a]Completely empty columns exist when a species was present either at collection sites for male or female ranges but not for the other. For months when samples either were not obtained or data were accidentally destroyed, ND appears. Missing values under each species indicate that appropriate samples were not available during those months.
[b]Monthly differences in percent moisture are indicated by an asterisk (*).
[c]Difference in percent moisture on an annual basis.
[d]Difference in percent crude protein on an annual basis.
[e]Difference in percent digestibility on an annual basis.

the nearest 0.1 g. Samples were air-dried and stored until further processing was possible.

We determined dry matter by heating individual samples in a convection oven at 50 C until a constant weight was achieved. We calculated moisture content using the difference between wet and dry weights. We ground individual samples to a 1 mm particle size using a Wiley mill. After grinding, we took equal volumetric measures from each sample and created a composite sample for each forage species. We used composite samples to determine crude protein (CP) and *in* vitro dry matter digestibility (IVDMD). This procedure was completed separately for samples from male and female ranges on a monthly basis.

We determined percent nitrogen using micro-Kjeldahl digestion and an autoanalyzer (at the University of Alaska Agricultural Experiment Station, Palmer, under the supervision of R. Candler), and converted to CP (nitrogen × 6.25). We determined IVDMD according to the technique of Tilley and Terry (1963), using rumen liquor from domestic sheep (at the Wildlife Habitat Laboratory, Washington State University, Pullman, under the supervision of B. Davitt).

We compared mean monthly moisture content for each species collected from male and female ranges using the Mann-Whitney U-test. We compared paired monthly data for mean percent moisture, CP, and IVDMD for each species using the Wilcoxon Matched-Pairs Signed-Ranks Test, to determine if overall differences existed between male and female ranges. All tests were 2-tailed, and differences were considered significant if $P \leq 0.05$.

RESULTS

We noted differences in moisture content in ≥1 month for 15 species collected from male and female ranges (Table 1); however, only triple-awned grass exhibited a difference in moisture content on an annual basis. Overall, CP was greater on female ranges for triple-awned grass, California buckwheat, winter fat, and *Krameria parvifolia.* Crude protein was greater for blackbush, Mormon-tea, and bedstraw from male ranges (Table 1). Overall, IVDMD was greater for Mormon-tea and desert-mallow collected from male ranges (Table 1).

Forage quality generally peaked in the early spring, and then declined through the summer; some species showed a slight increase in quality during early fall (Table 1), probably as a result of summer rains during 1990.

DISCUSSION

Our data supplement those of Morgart et al. (1986) and Kirkeeng (1985), who reported on the quality of mountain sheep forages from 2 other Mojave Desert mountain ranges. Thus, our data will be useful in evaluating the relative quality of mountain sheep habitat in the eastern Mojave Desert.

Krausman et al. (1989) examined 11 forage species collected from high (>1,400 m; M ranges) and low elevation ranges (<1,400 m; F ranges), and found that plant species were similar, with minor exceptions, in their nutritional value. Because similarities in plants from low and high elevations were so consistent, in comparison to the minor differences observed, Krausman et al. (1989) concluded that no biologically meaningful nutritional differences existed between forage plants collected from male and female ranges.

In contrast, we noted significant annual differences in the protein content of 7 mountain sheep forage species collected from male and female ranges. The interpretation of these data is problematical, however, because protein content was greater for some species on male ranges, and for other species on female ranges (Table 1). Higher digestibility was found for 2 species on male ranges, and some significant monthly differences in moisture content occurred for 15 species. Only triple-awned grass, however, exhibited an annual difference in moisture content, and that was higher on female ranges (Table 1).

Based on our findings, it would be presumptive to suggest that forage quality contributes to the differential use of habitats by the sexes of mountain sheep. Nevertheless, our results are consistent with the general hypothesis (Geist 1971) that forage quality differences exist between male and female ranges. Moreover, our data are consistent with Shank's (1982) finding, in a northern mountain ecosystem, that at least some forages consumed by male mountain sheep differ in quality from those eaten by sheep on %on-male" ranges. Similarly, our findings are consistent with Wehausen's (1980) observation that forage quality differences exist for male and female mountain sheep in the Sierra Nevada during periods of sexual segregation.

It is probable that there are site-specific differences in forage quality between and within mountain ranges. For example, Krausman et al. (1989) found that protein content was higher for *Krameria parvifolia* collected from male ranges than female ranges; we found the opposite to be true. Moreover, it is probable that differences in forage quality occur from year to year, because of differences in the timing and amount of annual rainfall, and temperature differences within the growing season (Wehausen 1992). Beatley (1974) noted that the timing and amount of precipitation were important factors determining phenological changes in Mojave Desert ecosystems; both the timing and amount of precipitation would be expected to vary somewhat between years (Jaeger 1933). Consequently, some variation in forage quality would be expected between years and seasons (Miller and Gaud 1989).

Krausman et al. (1989) based their sampling scheme on an altitudinal gradient, using elevation and sheep distribution to distinguish between male and female ranges. In contrast, we collected samples from specific areas used almost exclusively by one sex or the other during penods of sexual segregation. Edaphic conditions clearly differed between ranges used by male and female mountain sheep in our study area, probably a result of the underlying geological differences described by Dunne (1972, 1977). However, multiple factors potentially contribute to the observed differences, emphasizing the need to evaluate forage quality on a more localized scale than the ecosystem level.

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THE USE OF DESERT BIGHORN COUNCIL TRANSACTIONS

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Recently, members of the Desert Bighorn Council have discussed various aspects of publishing the *Desert Bighorn Council Transactions (Transactions)*;i.e., length of volumes, value of status reports, and the peer-review process. The length of volumes and number of technical papers depends upon the number and quality of those submitted. The *Transactions* have been peer reviewed since the late 1970s. Douglas (1979) indicated that "Peer review has been used for a number of years . . .". Douglas' (1979) note acknowledged the importance of peer-review and he revised the *Transactions* so reviewed articles were presented first followed by status reports (that are not peer-reviewed). This practice was continued when the *Transactions* were divided into sections: technical papers, status reports, case histories, and comments in the late 1980s.

The issue of peer review has been addressed by Douglas (1979), Smith (1988), Guthery (1988), Capen (1988), and Bissonette (1988). The general agreement is that peer review is not perfect but it is the best system to present scientific material; it is a critical part of the scientific process. I predict that peer review will continue to be a source of discussion; peer review is critical for the *Transactions* to continue to develop and be considered an important source of literature.

In reviewing the Literature Cited sections of the *Transactions* it was obvious that authors used the *Transactions* as a source of information. However, I was curious as to how biologists used papers presented in the *Transactions*. To answer this question I examined 4 other sources of literature that publish articles about mountain sheep *(Ovis canadensis): The Transaction of the North American Wild Sheep Conference* (1971, 1976), *The Northern Wild Sheep and Goat Council* (1980, 1982, 1984, 1986, 1988, 1990), and articles in *The Journal of Mammalogy* and *The Journal of Wildlife Management* since 1957 that were related to mountain sheep.

Authors used over 170 sources when writing about mountain sheep. Peer-reviewed journals (e.g., *J. Wildl. Manage., Desert Bighorn Counc. Trans., J. Marnrnal.)* were the most commonly cited sources (Table 1). Other sources (e.g., M.S. Thesis, Ph.D. Thesis, state and province reports) also were used commonly (Table 1). I answered my question by compiling this list and finding that, overall, the *Transactions* were the sixth of over 170 cited sources of literature and the second most commonly cited source among peer-reviewed journals. Either way, this compilation indicates that the *Transactions* are used and are an important source of literature.

The *Transactions* are the most important part of the Desert Bighorn Council and they provide a service to the scientific community. The management of all species, including mountain sheep, will require information based upon research. The *Transactions* can continue to play a role in that process.

Table 1. The most commonly cited literature used by authors writing about mountain sheep in the* Transactions of the North American Wild Sheep Conference *(1971, 1976), the* Northern Wild Sheep and Goat Council *(1980–90), and* The Journal of Mammalogy, *and* The Journal of Wildlife Management *since 1957.

Source	No. references to source
J. Wildl. Manage.*[a]	591
72 peer-reviewed journals (<25 citations/J)*	556
M.S. Thesis	386
Proc. Bienn. Symp. North Wild Sheep Goat Counc.	352
28 state and 11 province reports	327
Desert Bighorn Counc. Trans.*	144
Ph.D. Thesis	139
Proc. Intl. Mountain Goat Symp.	129
J. Mammal.*	127
J. Wildl. Diseases*	105
J. Range Manage.*	95
Mountain sheep: a study in behavior and evolution	90
Canada J. Zool.*	85
Wildl. Monogr.*	77
Canada Field Nat.*	46
Ecology*	46
J. Am. Vet. Med. Assoc.*	45
Trans. North Am. Wildl. Sheep Conf.	40
Nat. Park Serv. Fauna Series*	39
Proc. Bienn. Symp. North Wild Sheep Counc.	39
8 popular magazines	38
Wildl. Soc. Bull.*	36
3 published books (<25 citations/book)	33
Trans. North Am. Wildl. and Natur. Resour. Conf.*	30
Am. Midl. Nat.*	27
Big Game of North America	27
Am. J. Vet. Res.*	25
J. Anim. Sci.*	25
4 U.S.D.A. For. Serv. reports	22
2 Canada Wildl. Serv. reports	19
11 misc. conferences	18
4 Canada For. Serv. reports	6
2 U.S. Fish Wildl. Sew. reports	4
1 Bur. Land Manage. report	1

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ACTUAL COSTS OF BIGHORN SHEEP WATER DEVELOPMENTS

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The construction of wildlife waters in the southwestern deserts has become an accepted method to ensure maintenance and promote range expansion of many native wildlife populations. Cooperative programs between state and federal resource agencies and nonprofit conservation organizations have been developed to provide an effective means of developing wildlife waters by distributing the costs and efforts among those involved. Frequently, some of the resources required to develop a new water source, or to renovate an existing water, are offered by conservation organizations such as the Foundation for North American Wild Sheep or their state-level counterparts. Wildlife resource managers have recognized the need for cooperative relationships with the public, and the need for additional funds to accomplish their habitat enhancement work. Partnerships with conservation organizations seem to be the perfect way to meet both objectives.

The resource manager should fully realize the commitments being made when entering into such partnerships. Upon agreeing to a project on public lands, you have not only made commitments that your agency must fulfill, but you have essentially made commitments for people in other agencies as well. The intent of this paper is to make agency representatives aware of the workloads and budgetary considerations being committed to, from the conceptual stages for a development through the planning, construction and maintenance obligations.

METHODS

Agency administrative requirements and procedures for obtaining approval to develop waters on public lands for two recently constructed water developments were examined. Actual or estimated time requirements to produce each necessary document, including field studies and related expenses, were determined from the appropriate state and federal agency files and were verified by conducting interviews with the personnel involved. The Gray Tank and Bunyan Peak water developments, built during weekends in January and March 1990, were selected for this review.

RESULTS

Bunyan Peak

Bunyan Peak, located about 160 km southwest of Phoenix in the Gila Bend Mountains, was first surveyed from the air in March 1987 as a potential site for a bighorn sheep water development. This survey flight was done in conjunction with other sheep water maintenance work in the area, so a majority of the cost for the flight was absorbed by this other activity. One year later, in March 1988, the project was discussed and proposed during the regional Arizona Game and Fish Department (AGFD)/Bureau of Land Management (BLM) coordination meeting held in Yuma. The purpose of the Bunyan Peak sheep water was to develop a reliable water supply for a series of future desert bighorn sheep transplants into the Gila Bend Mountains. Initial ground surveys of the area in March 1988 were conducted by Phoenix District BLM biologists. Two marginal sites were identified outside the prime bighorn sheep habitat. Interagency consensus discounted the adequacy of these site locations for a transplanted population. Eleven months later, during the February 1989 regional coordination meeting, the necessity for a water development at Bunyan Peak was again stressed because the first sheep transplant into the area had been approved for November of that year. In March 1989 a helicopter was contracted by BLM to transport site assessment crews from both agencies to the summit of Bunyan Peak. During this visit, a suitable site was located, the environmental assessment data were collected, and a suitable design for the water development was agreed upon.

Between March 1989 and March 1990, the environmental clearances were approved, materials were acquired and project construction scheduled. The Bunyan Peak water development was constructed using volunteer labor provided by the Arizona Desert Bighorn Sheep Society (ADBSS). The result is a water collection and storage system made up of an artificial apron, three 2150-gallon fiberglass water storage tanks and a small fiberglass drinker. The development site is enclosed by a steel pipe-rail fence to exclude use by domestic and feral livestock.

Files containing documents resulting from project planning and construction were reviewed to identify the sequence and chronology of tasks involved. The work-hours associated with these tanks were established by the agency conducting them. The BLM has established a work-month as consisting of 173 work hours and that the personnel costs for this type of work is $3,100 per work month. So that actual personnel times dedicated to the project divided by 173 hours per work month and multiplied by the $3,100 per work month gives the estimated direct personnel costs. This amounted to $4,964 for 277 work-hours dedicated to Bunyan Peak. Clerical support and indirect costs to BLM were calculated as 20% of the total direct personnel costs, or about $1,000. BLM's requisitions were also examined to determine charges for materials and contracted helicopter support services. The cost of materials to BLM for this project was $10,595. Aircraft support and equipment costs came to $5,382. Total project costs to the BLM for planning and construction were $22,689. Personnel costs for time expended by BLM for post-construction maintenance has been an additional $409.

Costs to AGFD for the Bunyan Peak sheep water development were determined by examining project completion reports, requisitions and cost accounting printouts of the special accounts established for water development work. AGFD expended $10,952 for personnel, equipment and helicopter support during the planning and construction phases of the Bunyan Peak Project. An additional $5,110 was spent on post-construction maintenance and modifications. Indirect administrative and support costs for AGFD were calculated as 29% of project-related direct labor costs. Total cost of the project to AGFD for this project has been $16,062. The combined agency costs for BLM and AGFD for the Bunyan Peak project was $39,160.

Its important to note that time expenditures and monetary costs to each agency vary widely from project to project, based on agency budgets and negotiated pre-project arrangements.

The use of volunteer labor during water development construction is extremely vital as it reduces agency costs, thus allowing additional waters to be budgeted for a fiscal years. The Bunyan Peak development was constructed using a labor force provided by the ADBSS. This force consisted of 76 volunteers who commuted more than 22,679 round-trip miles to work on this project. Using the $.245 per mile AGFD allows its personnel for personal vehicle mileage, $5,556 was the estimated travel costs for the ADBSS members. For this project an average of 1 work day was spent per volunteer for a total of 76 work days (608 work hours) on project construction. Using the AGFD base hourly pay rate for habitat development technicians performing the same type of work ($6.80 without benefits), the estimated value of volunteer labor came to $4,134. The combined value of volunteer mileage and labor was $9,691 for this project, placing an overall cost of the development at $48,852 at the time it was constructed in April 1990.

Gray Tank

The second water project reviewed is located in the Eagletail Mountains about 130 km west of Phoenix. The Gray Tank development is a 3 m high by 5 m wide dam erected directly downstream from a natural tinaja water catchment. Materials for the project consisted of concrete and cinder blocks reinforced with re-bar and concrete. Dam surfaces were plastered with mortar and sprayed with a sealant to prevent leakage. The pre-planning and coordination procedures parallel those of the Bunyan Peak water development.

The initial site visit and evaluation was made in August 1989 by BLM and AGFD personnel. The initial design proposal called for a pipe-rail exclosure fence and a shade constructed of lumber fastened to a welded 2" pipe support frame. BLM's Surface Protection Specialist was concerned about cumulative visual impacts, and recommended the elimination of the exclosure fence and shade. However, these items have been made optional in the environmental assessment should circumstances reveal their necessity at a future date.

AGFD expended 281.5 direct personnel hours on the project at a cost of $3,344. An additional $970 in administrative and support costs was calculated as 29% of the direct labor cost. Equipment costs for transporting personnel, construction equipment and materials to the project site was $1,047. Helicopter support charges for the project was $6,578 and cost of materials was $1,863. The total cost to AGFD for the Gray Tank project was $14,754.

BLM expenses for Gray Tank included personnel, related administrative support and transportation costs. These totalled $2,025, $405 and $213, respectively, for a total of $2,643. Combined project expenses to BLM and AGFD for planning and construction was $17,397.

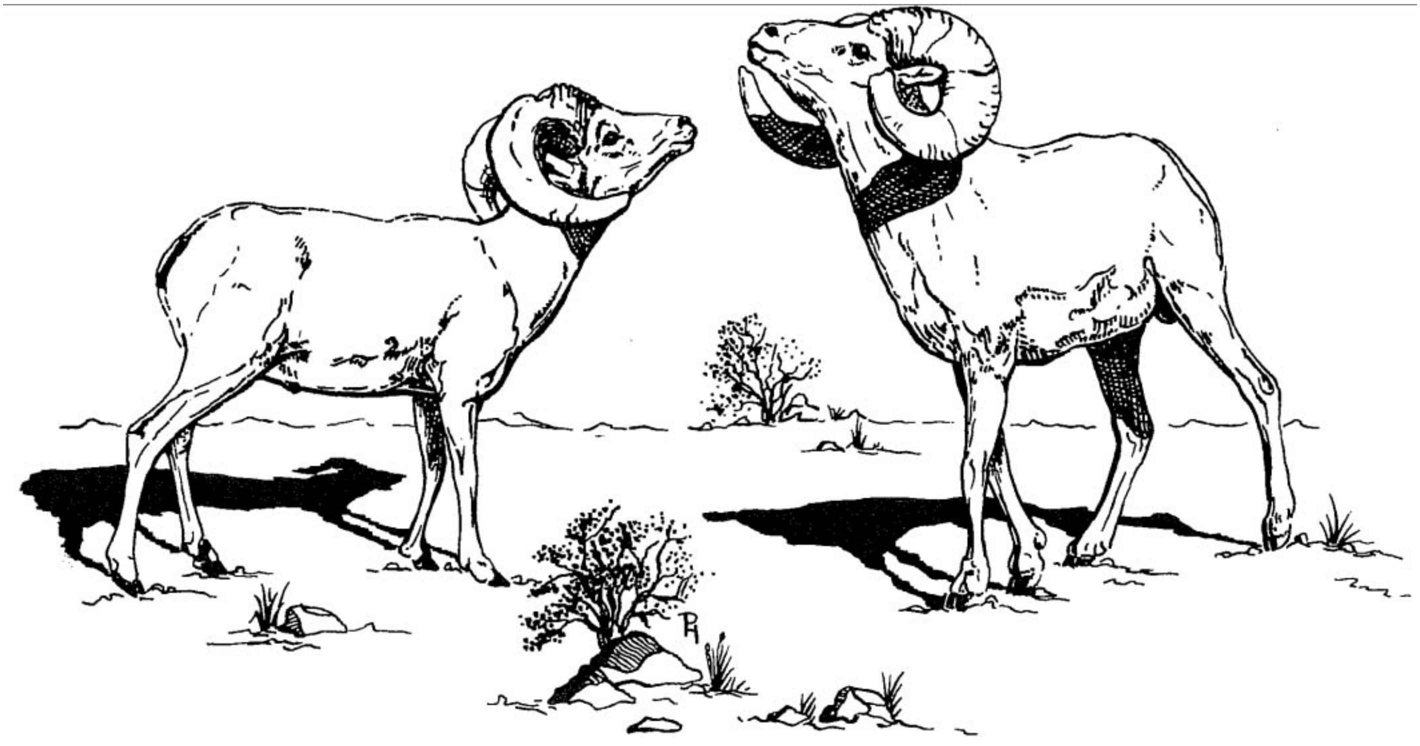
The ADBSS once again provided the volunteer labor force for the construction phase of the project. Forty-four volunteers commuted an average of 184.5 miles and worked an average of 16.25 hours each. Using the $.245 mileage allowance and the AGFD's $6.80 per hour pay rate for technicians, volunteer contributions were calculated to be $6,847. Combining agency costs to the volunteer labor values, the Gray Tank water development project can be valued at $24,244.

DISCUSSION

Many activities of the AGFD are partially funded by federal aid monies; including salaries of the personnel directly involved in the water development projects and vehicle equipment costs. When a project is to be constructed on federal lands or using federal aid dollars and site disturbances are anticipated, National Environmental Policy Act (NEPA) compliance requirements must be met. For sheep water developments, this minimally requires an Environmental Assessment to be completed by personnel within the federal land administration agency. Because these are federal expenses, the agency becomes a financial partner in the project.

When $5,000 or more of federal aid money is used during the planning or construction of a capital asset, the state wildlife resource agency is legally obligated to maintain the structure as fully functional throughout the project's life-span. For bighorn sheep water developments, this life span is reached 20 years after project completion. If maintenance of a project becomes necessary to maintain its functionality, and more than $5,000 of federal monies are spent, the amortized life of the project is extended an additional 20 years from the time of maintenance completion. From a practical standpoint, the state agency's obligations for maintenance become indefinite as long as the development can still serve its intended purpose.

The costs of materials for Gray Tank and Bunyan Peak were about $2,000 and $10,000, respectively. The monetary values, all things considered, are placed at $25,000 and $50,000. This does not include the average annual maintenance costs. When agreeing to cooperatively develop a water source, you are committing your's, your agency's, the cooperating agency's and sportsman groups' time and expenses that we have found to run up to 15 times the cost of the materials alone. From a practical standpoint, these commitments can go on indefinitely.



PROBLEMS ASSOCIATED WITH HEART RATE TELEMETRY IMPLANTS

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Recent concerns about environmental noise and its effects on wildlife have prompted activity in 2 different spheres of research: the intentional influences on pest species (Bomford and O'Brien 1990) and the possible effects of physiological or psychological stress to species inadvertently caused by human activities (Fletcher and Busnel 1978, Borg 1981, Fletcher 1988). Noise is effective as a short term deterrent to pest species but is most effective when it resembles natural alarm calls made by the species (Bomford and O'Brien 1990). Stress is considered a body's non-specific response to an insult, such as noise (Sapolsky 1990). Difficulties measuring stress in wild populations led researchers to remote sensing techniques that reduce the animals response to the observers themselves. Heart rate is a descriptive measure of animals response to disturbances (Ward and Cupal 1979, MacArthur et al. 1982). MacArthuret al. (1979) found telemetered heart rates of mountain sheep were related to activity and the degree of transient stimuli animals experienced. Harlow et al. (1987) documented a linear relationship between heart rate and blood cortisol levels in domestic sheep and suggested that remote monitoring of cardiac frequency was a potential gauge of an animal's physiological condition under stress.

Our objectives were to document the distance that signals from RT and T transmitters could be received, the causes of transmitter failures, and to describe the modifications we made to protocols used to implant heart rate and temperature transmitters into mountain sheep and desert mule deer (Bunch et al. 1989).

We acknowledge the support and assistance provided by the Nevada Department of Wildlife, the U.S. Fish and Wildlife Service, and the Experimental Surgery and Clinical Services Section of the University of Arizona's University Animal Care. We thank S. Cameron, and V. Patula who assisted with surgery and care of captive animals and C. Hayes for observations of wild mountain sheep. Dr. O. E. Maughan was instrumental in project administration. This study was supported by the U.S. Air Force, Noise and Sonic Boom Technology Program, and the University of Arizona.

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METHODS

We used captive and semi-free ranging animals in this study. Captive mountain sheep (n = 5) and desert mule deer (n = 6) were held at the University of Arizona Wildlife Research Center, Tucson. All animal care and treatment followed guidelines established by the American Society of Mammalogists (1987). Captive animals were not tame. Their intractability necessitated immobilization for capture or treatment and often limited prophylactic treatments. We used free ranging mountain sheep captured in 1990 (n = 3) and 1991 (n = 5) from the Sheep Range, Nevada and released them into a 3.2 km^2 enclosure in the Desert National Wildlife Refuge, Nevada. These animals were not recaptured.

Heart rate (model ECG-2) and temperature transmitters (model TTE-lg; J. Stuart Enterprises, Oceanside, Calif.) were calibrated and checked before use (Jacobsen and Stuart 1978, Jacobsen et al. 1981). Transmitters were sewn into a nylon mesh fabric and sterilized with ethylene-oxide and placed in an aerator >12 hours prior to surgery.

We immobilized captive animals between March 1990 and February 1991 with ketamine hydrochloride (HCL) and xylazine HCL (Del-Giudice et al. 1989). We monitored respiration and general condition of immobilized animals was monitored during transport to the University of Arizona Animal Care surgical lab where anesthesia was induced or deepened with halothane by face mask induction. Mean time from restraint to halothane induction under veterinary care was 22 ± 8 minutes. While the animal was under anesthesia we used an electrocardiogram to continuously monitor heart rates for arythmia and to check HR accuracy. Animals were endotracheally intubated and the hair from the ventral abdomen and right thorax was clipped. The exposed areas were scrubbed with alcohol and povidine-iodine antiseptic. We modified surgical procedures from those previously described (Jacobsen et al. 1981, Bunch et al. 1989). A 9-cm ventral midline incision was made through the skin and body wall. Transmitters that were surrounded by fabric were sutured immediately caudal to the sternum to the ventro-lateral body wall with 0 polypropylene. Teflon coated-stainless steel leads from HR transmitters exited the body cavity through a separate stab incision through the skin adjacent to the initial mid-line incision. Stab incisions were made at the mid-point of the sternum and two-thirds of the dorsal distance along the tenth or eleventh right rib (Cassireret al. 1988, Bunch et al. 1989). Sub-cutaneous dissections were made from the stab incisions to the mid-line incision with a 71.1-cm trocar. Transmitter leads were passed through the trocar to the sternum (reference lead) and right lateral thorax (measurement lead) and were attached with 0 polypropylene sutures. Initially, we sutured the leads but found that sutured leads contributed to lead failure. Upon discovery we looped stainless steel suture in, out, and around the end of the lead. Incisions in the body wall were closed with 0 polyglactin absorbable sutures and skin incisions were closed with 0 polypropylene or nylon sutures. All animals were intra-muscularly (IM) provided a long-acting penicillin. Halothane anesthesia was terminated and animals were transported back to study pens where yohimbine HCL was administered intravenously (IV) to reverse the effects of the xylazine immobilization (Mech et al. 1985).

Wild mountain sheep were captured in 1990 (n = 14, 3 of which were selected for surgical implants) and 1991 (n = 5) with helicopter and net gun from the Sheep Range, Nevada. In 1990, sheep were immobilized as above after helicopter net-capture and transported 258 km to the veterinary clinical facility at Nellis Air Force Base, Las Vegas, for transmitter implantation and then returned to the release site. In 1991, sheep were not immobilized, but were transported via helicopter to a field surgical station 14.5 km from the release site. Anesthesia was administered and surgery done in the field surgery station established in 1991. After transmitter implantation mountain sheep were released into a 3.2 km^2 enclosure in the Desert National Wildlife Refuge, Nevada.

Surgical facilities at the University of Arizona Health Sciences Animal Care Center included a pre-surgery preparation room and sterile operating theater. Surgery in 1990 for animals captured in Nevada was performed at the Nellis Air Force Base Veterinary clinical facility. In 1991, field surgery was conducted near the release site in the refuge office area and garage workshop. The office was used as the surgeons

Table 1. Animal mortalities associated with a study involving surgical implantation of heart rate and temperature transmitters in mountain sheep and desert mule deer, 1990–91. Phase I animals were semi-tame mountain sheep and desert mule deer held at the University of Arizona Wildlife Research Center, Tucson, between Jan 1990 and Dec 1991. Phase II animals were wild mountain sheep captured from The Sheep Range, Nevada, and held in a 3.2 km² enclosure, Desert National Wildlife Refuge, Nevada, between May 1990 and May 1992.

Species	Sex	Mortality date	No. days in study	Probable cause of mortality[a]
Phase I				
Mountain sheep	M	14 Aug 1990	118	Died after accidentally breaking leg in fence in Tucson
Mountain sheep	F	29 Mar 1991	354	Died from peritonitis, from prolonged exposure of open incision
Mountain sheep	M	6 Sep 1991	526	Found moribund after termination of study. Died because of long-term kidney failure
Mule deer	M	28 May 1991	153	Asphyxiated on rumen contents during transport after immobilization
Phase II				
Mountain sheep	F	1 May 1990	0	Died during transport to Nellis Air Force Base (NAFB) veterinary lab
Mountain sheep	M	1 May 1990	0	Died after surgery and transport to and from NAFB veterinary lab
Mountain sheep	F	7 Jun 1991	<67	Found dead in field enclosure. Transmitters still working

[a]Cause as determined from necropsy of animals or from examination of remains found at field mortality site.

preparation area. The garage for pre-surgery animal preparation and the workshop were cleaned and fitted with mobile lights, tables, and complete supplies to create a sterile field for surgery. All surgeries were performed by the same surgical team at both sites.

RESULTS

Captive mountain sheep ($n = 5$) were immobilized 13 times with ketamine HCL ($\bar{x} = 6.0 \pm 1.4$) and xylazine HCL ($\bar{x} = 4.3 \pm 0.8$ mg/kg). Captive mule deer ($n = 6$) were immobilized 16 times with ketamine HCL ($\bar{x} = 4.5 \pm 1.7$) and xylazine HCL ($\bar{x} = 3.0 \pm 1.0$ mg/kg). The drug dosages we used were based upon our previous experience (DelGiudice et al. 1989) immobilizing desert mule deer and mountain sheep. Each individual captive animal could experience several surgeries ($\bar{x} = 2$, range = 1–6) to replace failed transmitters or determine causes of transmitter failures.

Initial trials on the flat areas surrounding the Tucson study site suggested that reliable HR and temperature signals could be detected for ≤0.5 km. In the steep terrain that is characteristic of mountain sheep habitat in Nevada, signals were reliably detected ≤1.3 km. However, it was essential that a direct line-of-site between transmitter and receiver be maintained. Any solid obstacle severely reduced reception.

Reasons for transmitter failures or complications related to implants are reported only for captive animals because we did not recapture animals in Nevada. Early failures (≤38 days) of HR ($n = 7$) were due to leads breaking or disconnecting from transmitters ($\bar{x} = 8.3$, range = 2–38). Seven transmitters short-circuited ($\bar{x} = 261.43 \pm 60.14$ [SE] days, range = 126–509 days) because body fluids leaked into them along HR leads. Nine transmitters were still functioning when they were removed, 5 ($\bar{x} = 129.60 \pm 41.87$ days, range = 90–153) from animals that died and 4 ($\bar{x} = 131.50 \pm 16.19$ days) from healthy animals that were removed from the study for other uses. Transmitters were still functioning in 1 captive mountain sheep (456 days) and 1 wild sheep (328 days) at the end of this study.

Heart rate and T transmitters that were implanted too near the mid-line were engulfed by the weight of the rumen. The HR leads for a mountain sheep found in the abomassum were digested and failed after 145 days, while those of a mule deer found in the rumen were still functioning after 195 days. Temperature transmitters in both animals were still functioning properly, though the paraffin-elvax coatings were partially digested. Herniation or extrusion of transmitters through the ventral body wall also occurred when placement of transmitters was too near the mid-line where the weight of the rumen may have pushed them through the body wall. One transmitter still worked though it was pushed through a herniation of the peritoneum and another worked while hanging on the leads entirely outside the integument.

Seven animals died during the study (Table 1); 3 captive mountain sheep, 1 captive mule deer, and 3 wild mountain sheep. However, only 1 death was attributable to complications related to implants. An infection in a captive mountain sheep resulted from the exposure of a wound caused by the extrusion of a HR transmitter through the body wall. The transmitter was till functioning so the wound was irrigated with saline, disinfected with povidine-iodine solution, the transmitter replaced, and the wound sutured closed on-site. Because the animal would not permit handling without restraint we administered a 1-time injection of antibiotics, 1 gm chloramphenicol and 8 cc benzathine penicillin, and gave trimethoprim and sulfamethoxazole orally with her food. Despite treatments the ewe died 25 days later of peritonitis. One wild mountain sheep died while unattended during transport to surgery in 1990. A second was alive after surgery and release at enclosure site but exhibited opisthotonus, rear limb weakness, and inability to stand. This animal died before further assistance could be rendered. The carcass of a third wild mountain sheep was found 29 days after surgery and release but cause of mortality could not be determined. The captive mule deer asphyxiated on his rumen contents during transport to surgery after immobilization and could not be revived. One captive mountain sheep died after accidentally breaking his leg in a fence and the other was found moribund 4 months after the conclusion of the study. Necropsy determined his death was due to long-term kidney failure.

DISCUSSION

This is 1 of the largest known samples of surgically implanted biotelemetry transmitters into wild ruminants. Effective ranges of transmitters were adequate for our studies of animal heart rates, temperatures, and behaviors in large enclosures.

Complications encountered during implant surgeries included profound bradycardia, including 1 mule deer that had to be completely resuscitated, and slow recovery from immobilization. Bradycardia occurred only while animals were deeply under halothane anesthesia. To counteract this problem yohimbine ($\bar{x} = 0.23$ mg/kg) was administered immediately after halothane induction and atropine was administered after xylazine reversal if needed to speed up heart rate (Booth and McDonald 1988).

Modifications were made in handling protocols that were effective in speeding recovery from immobilization and anesthesia. The most effective combination we found was IV administration of yohimbine HCL ($\bar{x} = 0.23$ mg/kg) immediately after induction by halothane to counteract the xylazine. We administered doxapram HCL ($\bar{x} = 2.42$ mg/kg) (IV) as a respiratory stimulant to help eliminate halothane (McGuirk et al. 1990) and naloxone HCL ($\bar{x} = 0.44$ mg/kg) as a narcotic reversal agent (Booth and McDonald 1988) upon release. Maloxone was given even though no narcotics were used because evidence suggests that ketamine HCL may act on the same opiate receptor sites (Booth and McDonald 1988).

Early failures of HR transmitters due to lead breakage were corrected by modifying the surgical technique after Bunch et al. (1989). Reference and measurement leads were not sutured in place but, were wrapped with additional stainless steel suture and left unfastened in situ before suturing the incision. Failures due to fluids seeping through the paraffin-elvax encapsulant were not remedied during this study. Promising new transmitter encapsulants, that should solve this problem, are currently being tested (Telonics Inc. Mesa, Ariz.). Maximum battery life for the transmitters used in this study is not yet known. However, 2 HR transmitters are still working after 328 and 456 days, respectively. Signals from the 1 temperature transmitter still implanted became too intermittent for accurate use after 310 days. We do not know why this transmitter failed because this semi-free mountain sheep has not been recaptured.

Sterile surgical procedures are essential to successful use of this new technology. Our modified surgical protocols worked well. Heart rate data can be collected under field conditions. However, transmitters still failed because of encapsulant leakage.

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IMPLICATIONS OF CAPTIVE BREEDING PROGRAMS FOR THE CONSERVATION OF DESERT BIGHORN SHEEP

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Captive breeding and release are used to maintain population densities in the wild. For example, the release of captive bred mountain sheep (Ovis *canadensis*) has been used recently in California (Weaver 1989) and New Mexico (Elenowitz and Humphreys 1987). When maintaining relatively large numbers of individuals in wild populations through translocation, managers need to consider the genetic consequences of these programs on the long-term health and management of the wild herds. For example, Ryman and Laikre (1991) suggest that captive propagation programs may have negative effects on effective population size (N_e) and may thereby influence the amount of inbreeding experienced by the augmented wild populations. Inbreeding and the consequent decline in heterozygosity have been cited as contributing to the decline of several wildlife species (O'Brien et al. 1985, Packer et al. 1991), and additional negative effects may result from the relaxation of natural selection.

We address some of the potential effects of captive breeding on effective population size by using a hypothetical scenario in which captive bred mountain sheep are released into a wild population. The potential importance of inbreeding in mountain sheep and other large vertebrates will be briefly reviewed. We will suggest a scenario of selection, focusing on host (mountain sheep) genetic factors associated with a disease process, and outline the potential outcome of relaxed selection on the frequencies of beneficial and deleterious alleles. Finally, we will reiterate the main benefit to be derived from captive breeding programs; i.e., maintenance of viable population size.

EFFECTIVE POPULATION SIZE

To understand the population genetics of a system, we must make assumptions about various parameters of the population. These assumptions include: 1) population size does not fluctuate over time, 2) mating is random (panmixia), 3) there is no migration, 4) the sex ratio is even, 5) generations are non-overlapping, and 6) reproductive success for the population can be described with a Poisson distribution. With respect to these assumptions, adjustments can be made to the magnitude of the actual population size to produce N,. Briefly, the most significant effect of a fluctuating population size can be seen as the disproportionate effect of periods of small population size on N_e over time (roughly, the harmonic mean of population sizes of individual generations over time), and is commonly considered with respect to genetic bottlenecks. Assuming that males move between estrous females in a random fashion we suggest that random mating is sufficiently approximated. The third assumption of no migration has been addressed by Schwartz et al. (1986), however their suggestion that migration rates are sufficient to ovemde other factors defining N_e may not hold in declining populations in which captive breeding would be appropriate. If population decline is regional in extent, then populations within the region may not be prolific producers of dispersing individuals. Likewise, if population decline is due to degraded environmental quality that can be perceived by dispersing individuals, these areas and populations may be avoided by dispersers. For mountain sheep, it is also difficult to determine the effects of overlapping generations given the paucity of necessary information (Lande and Barrowclough 1987).

The hypothetical populations that we use to examine the result of captive breeding on N_e include a wild population of 150 adult individuals (40% M, 60% F). The size class distribution of the males is 9 (15%) class IV rams, 15 (25%) class III rams, and 36 (60%) class II rams. Differential mating success of males has been addressed by Hogg (1984), however actual numbers of successful rams are typically unknown. We assume a certain amount of increased reproductive success for class IV rams; therefore, they achieve ⅔ of the available matings. Class III rams achieve ⅔ of the remaining matings, leaving 10 unmated females that mate with class II rams. The actual number of successful males in this population of 60 males is therefore 34. Using the equation of Roughgarden (1979) for adjusting N_e for sex ratio, $N_e = 4N_mN_f/(N_m+N_f)$, where N_m and N_f represent the numbers of males and females, respectively, we amve at an effective population size for the wild population of 98.7 individuals.

The hypothetical captive population is composed of 33 adults, 3 of which are class IV rams and each male mates with 10 females. We calculate the N_e of the captive population, adjusting for sex ratio, to be 10.9 individuals. We assume that members of the captive herd are unrelated because relatedness among the captive stock could further decrease N,. Captive-reared lambs are then released into the wild to augment the wild population. We now determine the relative contribution of the captive herd to the number of surviving offspring in the wild herd. If lamb survival in the wild is 30% and all of the captive females produce lambs that are used to augment the wild population, then the relative contribution of offspring by the captive herd to the wild herd is 50%. We use the equation suggested by Ryman and Laikre (1991) to adjust for captive herd contributions,

$$\frac{1}{N_e} = \frac{X^2}{N_c} + \frac{(1-X)^2}{N_w}, \tag{1}$$

where X is the decimal fraction of offspring contributed by the captive breeding program (0.5), and N_c and N_w represent the effective population size of the captive and wild herds, respectively. Solving equation (1) with appropriate values gives an N_e of 39.3 individuals, a value roughly 40% of the effective population size of the wild herd prior to the release of captive bred lambs. Using N_e from our hypothetical situation in conjunction with established population genetics models that address the effect of N_e on heterozygosity (Roughgarden 1979), an augmented wild population with N_e of 39 loses heterozygosity much faster (i.e., in fewer generations) than the wild population without augmentation (N_e = 99) (Fig. 1).

INBREEDING AND HETEROZYGOSITY

What deleterious effects might such a reduction in N_e have on desert races of mountain sheep? Inbreeding and loss of heterozygosity associated with a small N_e remain topics of debatable importance in the mountain sheep literature (DeForge et al. 1979, Skiba and Schmidt 1982, Schwartz et al. 1986). Sausman (1984) documented that for captive mountain sheep, lamb survival is significantly reduced in inbred populations versus those captive populations with inbreeding coefficients of zero. Although Hass (1989) concedes that inbreeding presently contributes in only a minor way to lamb mortality for a population of mountain sheep in Montana, she suggests that N_e for this population also may be approaching a critical level.

Loss of heterozygosity may have detrimental influences on population viability by decreasing the adaptability of mountain sheep to changing environments (disease processes can be considered an aspect of such environmental variability). Also, as individuals become homozygous for increasing numbers of loci, the effects of deleterious recessive alleles occurring in a homozygous state become more prevalent. What do we

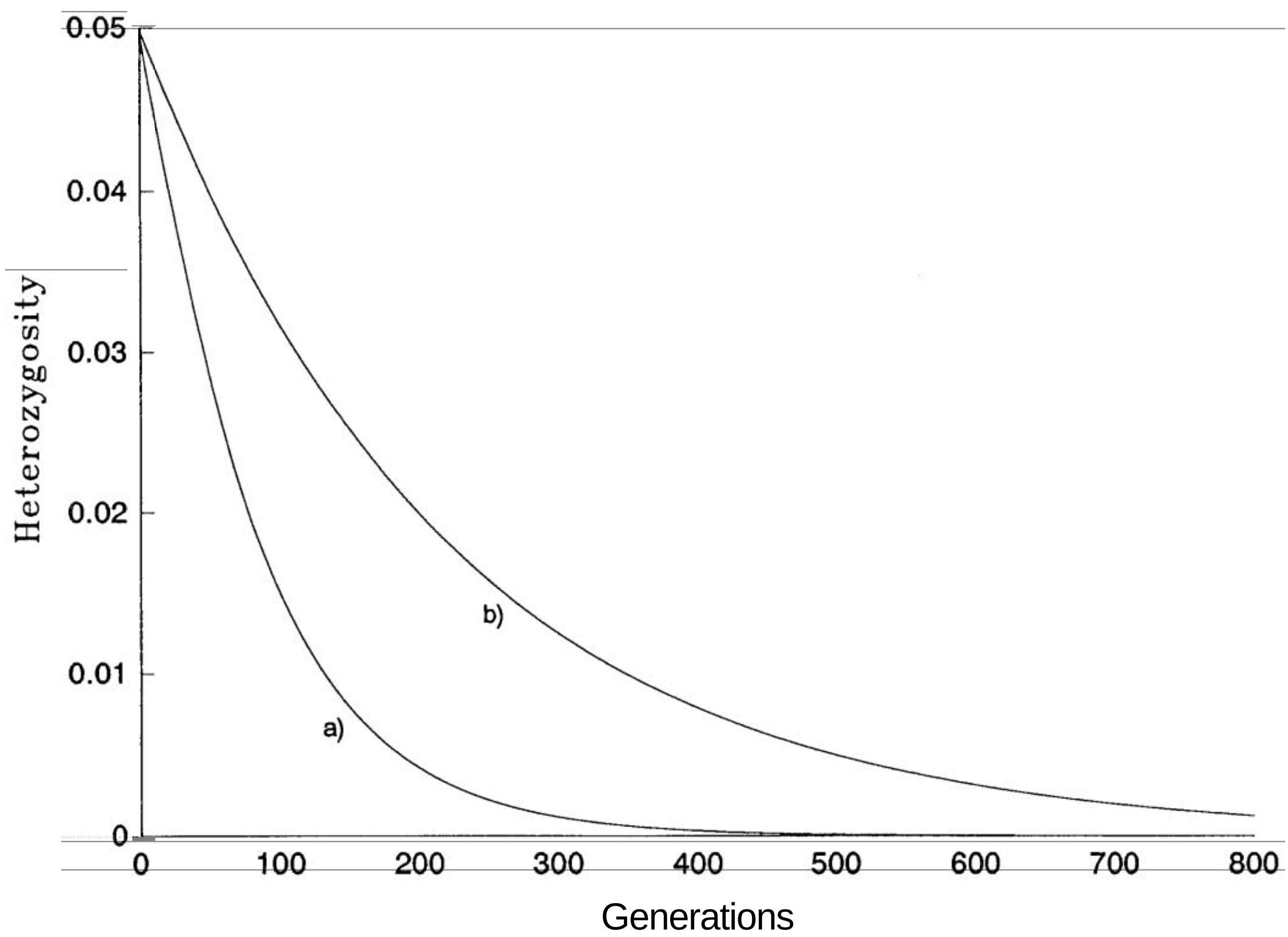

Fig. 1 *Effect of captive breeding on heterozygosity (measured as no. heterozygotes/total no. sampled individuals averaged over all loci) as a function of time (in generations). Change in heterozygosity is indicated for a) the hypothetical wild population augmented with captive-bred stock ($N_e = 39$), and b) the hypothetical wild population without augmentation ($N_e = 99$).*

know about wild sheep in regard to this issue? Sage and Wolff (1986) report a heterozygosity for Dall's sheep (*O.* c. dalli) of 0.015 relative to an average for mammals of around 0.04. They suggest that this reduced heterozygosity resulted from historical fluctuations in the species' range due to glaciation events, and desert races of mountain sheep apparently have a similarly low level of heterozygosity (R. R. Ramey, Genetics and conservation of North American mountain sheep: implications for management on BLM lands. Unpublished report to the Bureau of Land Management, Riverside, Calif., 1991, 26 pp.). This naturally low heterozygosity suggests that they may be less susceptible to the deleterious effects typically associated with inbreeding because deleterious recessive alleles occur at lower frequencies, having been eliminated from the population by previous events, and are therefore less likely to be found in a homozygous state even in small populations (Templeton and Read 1984).

In some cases, reduced N_e may lead to fixation of alleles that contribute positively to population fitness. The probability of fixation of alleles becomes proportional to the frequency of the alleles with decreasing N,. Therefore, if beneficial alleles occur with relatively high frequencies in a small population, such alleles have a consequent high probability of becoming fixed in the population thereby conferring beneficial attributes to all members.

The relative importance of N_e, inbreeding, and heterozygosity continues to be a point of debate when considering management policies for the conservation of biodiversity (Lande 1988). For example, the decline of cheetah (*Acinonyx jubatus*) populations has been attributed to lack of heterozygosity caused by an apparent population bottleneck. The effects attributed to reduced heterozygosity include reduced resistance to disease (particularly feline infectious peritonitis) and decreased spermatozoa1 concentrations in ejaculates (O'Brien et al. 1985). A similar phenomenon has been demonstrated for lions (*Panthera leo*) from the Ngorongoro crater of Tanzania (Packer et al. 1991), and decreased heterozygosity has been associated with increased disease susceptibility in other species (Ferguson and Drahushchak 1989, Lively et al. 1990). On the other hand, a population bottleneck and decreased heterozygosity in the northern elephant seal (*Mirounga angustirostris*) has had little apparent detrimental effect on populations (Bonnell and Selander 1974).

RELAXED SELECTION WITH CAPTIVE BREEDING

Next, we consider selection as it relates to disease processes that may be occurring in wild mountain sheep populations. To increase the effectiveness of captive breeding programs, females and/or lambs may be given vaccines and/or antibiotics to improve reproductive output and increase lamb survival. This practice may have unplanned consequences when these individuals are released into a wild population where they may be exposed to enzootic infectious disease cycles. The major potential problem with this practice is that selection for increased disease resistance, or decreased susceptibility, has been temporarily bypassed. Given a genetic component to disease resistance, beneficial disease re-

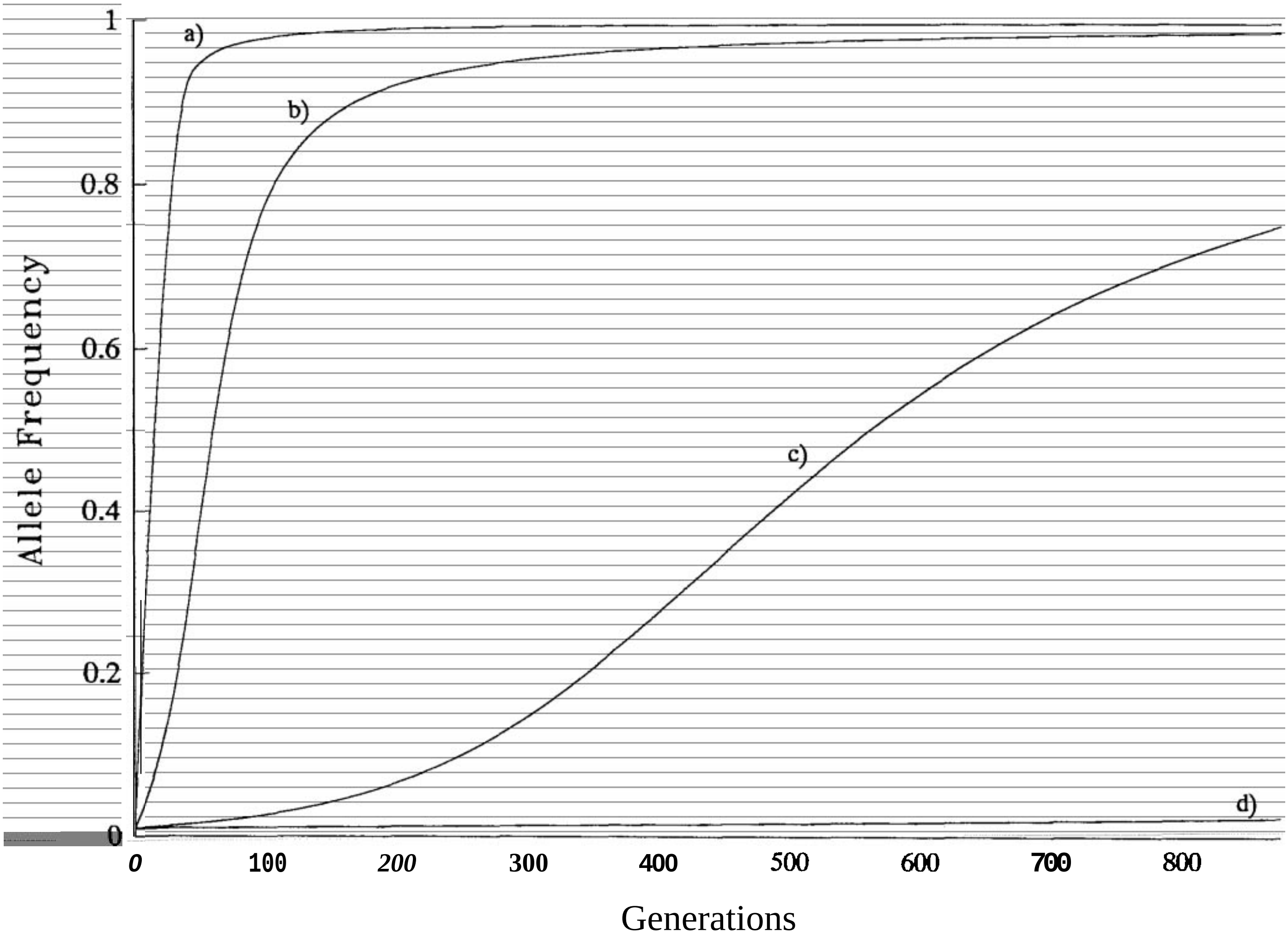

Fig. 2. Change in frequency over time of a beneficial, disease resistance allele among 4 populations. Within each of thepopulations, individuals that posses the allele successfully raise a) 100%, b) 10%, c) 1% or d) 0.1% more offspring than individuals lacking the allele. Curve a) represents the scenario that would be expected in an unaugmented wild population where disease resistance confers greatly enhanced successful reproduction. Curve d) represents a captive population (with vaccine and/or antibiotic treatments) where the allele offers little enhancement.

sistance alleles will be artificially maintained at a low frequency. Again, we use population genetic theory (Roughgarden 1979) to illustrate the change in frequency of a dominant beneficial allele in populations with various degrees of relative reproductive success for individuals possessing the allele (Fig. 2). In the context of captive breeding, we consider the curves further to the left as those representing a wild population. Individuals possessing the disease resistance allele may produce 10 to 100 percent more offspring that reach reproductive maturity than those that show little or no resistance and whose offspring eventually succumb to disease. The curves to the right represent captive populations in which individuals possessing the disease resistance allele do little better than those without it because the selective effect of infectious disease is minimized by vaccine/antibiotic treatments. It is clear then that the frequency of disease resistance alleles will remain low for an extended period in populations where the relative reproductive advantage of such an allele is reduced by captive breeding. Similarly, the frequency of recessive "susceptibility" alleles declines at slower rates when the selection coefficient is reduced by allowing individuals possessing such deleterious alleles to produce offspring at rates comparable to those lacking the alleles.

Augmentation of wild populations using captive-bred individuals may have negative effects by reducing N_e such that the detrimental effects of inbreeding, and the consequent loss of heterozygosity, may be manifested. Captive breeding may also relax selection and thereby maintain beneficial disease resistance genes at artificially low frequencies or maintain deleterious susceptibility genes at higher frequencies. It is clear, however, that maintenance of population sizes at levels that ameliorate the effects of demographic stochasticity is an important concern in conserving populations (Lande 1988, Berger 1990). Given that captive breeding may be required to maintain viable wild populations, biologists should monitor the relatedness of captive breeding stock through pedigree analysis to reduce the potential liabilities associated with decreased N,. Biologists should also be cognizant of the fact that levels of management resources required to maintain populations through captive breeding/augmentation may escalate due to relaxed selection in captivity and the unabated continuation of infectious diseases in the wild.

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PANEL DISCUSSIONS

During the 1991 Desert Bighorn Council meeting 2 panels discussed stress and minimum viable population size. Both discussions were recorded. Speakers had the opportunity to edit their comments that are presented in this volume.

STRESS AND BIGHORN SWEEP

Moderator: Walter Boyce, University of California, Davis
Panel: Tom Bunch, Utah State University; Stan Cunningham, Arizona Department of Game and Fish; Jim DeForge, Bighorn Institute–California; David Jessup, California Department of Fish and Game; John Wehausen, University of California, White Mountain Research Station

Walter Boyce.—We all have different perspectives on what stress is. I am going to read a paragraph out of a report that Tom Bunch provided to me this morning called "Stress and the Free Ranging Animal." It's a western regional research publication (No. 646) published by New Mexico State University, College of Agriculture and Home Economics. "Any prolonged or intense stimuli that are perceived by an animal as deviating from normal levels can be considered a stressor" (i.e., an intense stimuli or a prolonged stimuli).

> "Exposure of an animal to a stressor results in a series of physiological and behavioral responses which enables the animal to either cope with the stress by eliminating the source, and/or by restonng homeostasis," that is, the normal state of affairs, the normal physiologic condition.
>
> "The initial effect occurs via the sympathetic nervous system and results in behavioral arousal, increases in respiration and heart rate, and redistribution of the blood supply to central organs, and this prepares the animal for the flight or fight response. Within a few seconds these effects are potentiated and prolonged by the release of the catecholamines (epinephrine and norepinephrine) from the adrenal gland. Shortly thereafter hypothalamic corticotropin releasing factor stimulates the production of pituitary adrenocorticotropic hormone (ACTH) and this in turn induces the release of glucocorticoid hormones such as cortisol from the adrenal gland. Glucocorticoids act primarily to increase blood glucose."
>
> "Stress responses are adaptive. They are a normal response of the animal and they are intended to be adaptive, therefore they should benefit the animals. When stressors are persistent or extreme, however, the associated prolonged glucocorticoid secretion may have a number of deleterious effects. These effects include the impairment of immune function, gastric ulceration, and perturbation of the secretion of the pituitary hormones which influence growth and reproduction."
>
> "Some stress is inevitable and in fact can be beneficial. For example injections of ACTH and hormones such as cortisol have been reported to improve learning and memory. Poultry housed in both high and low stress environments showed impaired immunocompetence, while those housed in a moderately stressful environment appeared to respond optimally to immune challenge. Beneficial stress has been referred to as *eustress* while stress which has a negative physiological and behavioral impact on the animal has been referred to as *distress* or *over-stress."*

What I would like to do at this point is give the panel participants their first shot at defining stress.

John Wehausen.—The definition of stress you just heard derives from Hans Selye who really started the whole concept in 1936 with a paper in *Nature.* What I am going to do is to read a few quotes from various sources as Walt just did; it puts the burden on somebody else's shoulders in a sense. I would like to read something from Hans Selye to start out. What I am concerned about are definitional problems, as Walter just mentioned, and some of the scientific implications. Selye opens a paper (that he wrote many years later) from his first one with the following statement: "Everybody knows what stress is and nobody knows what it is. The word stress, like success, failure, or happiness, means different things to different people and, except for a few specialized scientists, no one has really tried to define it, although it has become part of our daily vocabulary" (Selye 1973). I think this is the problem we are up against..

I was glad to hear the definition just given as being deviation from something called normal. We have now the problem of what we define as normal. Hans Selye defines stress with a very specific, or you might say nonspecific, definition: "stress is the nonspecific response of the body to any demand made upon it" (Selye 1973:692). "Nonspecific" means that the whole endocrine system is activated by numerous different things; it is not specific, it is not a specific homeostatic mechanism to a specific cause, although it is homeostatic in nature. Then he finally says, "complete freedom from stress is death" (Selye 1973:693). What 1 want to do here is read somebody else's thoughts about it. This is from a book published in 1989 by F. H. Bronson titled *Mammalian Reproductive Biology.* It has a section titled *The Concept of Stress.* He takes a fairly critical attitude toward it. ". . . stress is used in so many different ways now even by endocrine physiologists its application to any situation is confusing. . . . stress was originally defined endrocrinologically in relation to a common set of stereotyped nonspecific responses to diverse noxious agents, at the core of which was increased adrenal activity," and he referenced Selye. "Today stress seems to be defined in two markedly different ways. First it is defined classically as hyperactivity of the corticotropin-releasing hormone, ACTH, caused by some change in the animal's internal or external environment." Adrenal-steroid axis is what you just heard about.

> "Alternatively, stress is often defined arbitrarily by an experimenter in relation to his or her subjective evaluation of the environmental change itself. That is, any perturbation of an animal's environment that is deemed noxious by an experimenter will evoke a condition of stress in that animal at least in the mind of the experimenter, regardless of what happens to secretion of ACTH and the adrenal steroids. The result of this semantic difference is an exceptionally confusing literature in which one is never quite sure how a particular author is using the term."
>
> "There is no doubt that diverse kinds of stimulation can enhance the secretion of ACTH and the adrenal steroids. These range from sexual arousal in the male mouse, to the immobilization by cold exposure of a rat, to pre-exam anxiety in a medical student."
>
> "Stimuli that have been deemed stressful by endocrinologists, whether or not the adrenal activity is elevated, include the following conditions: caloric deficiency, nutrient deficiency, infectious disease, electro-ejaculation, hypoxia, the sound of a bell ringing, transfer between animal rooms, capture in large cages, fighting, social subordination without physical contact, exposure to low air pressure, removal of offspring from their mother, sudden exposure to the sun, gentle handling early in life, inserting gauze under the skin, foot-shock, exposure to nembutal or ether, intense exercise, noise, surgery such as laparoscopy or ovariectomy, broken bones, and exposure to high or low temperature. A common presumption pervading the field of stress endocrinology is that all these stimuli yield a stereotypical set of common, nonspecific, endocrine responses that have adaptive consequences. To biologists this makes little sense."
>
> "Evolutionarily, mammals have not had to deal with most of the stimuli employed by endocrinologists in the laboratory. On the

other hand, they have had a great need to evolve adaptive ways of regulating their reproduction in relation to variation in food availability and ambient temperature. This, along with survival, is the core challenge for evolutionary success, and a genetic solution should have been relatively specific. Thus, looking for commonality in a mammal's reproductive response to low temperature, nembutal, and loud noise, for example, seems biologically irrational. Likewise, conceptually linking a mammal's response to sexual arousal, surgery, and food shortage simply because all these conditions cause an increase in circulating adrenal steroids, also seems of questionable evolutionary significance."

That may or may not be the case, but he's at least taking a critical view of the whole thing, which is what I think we need to do. I would like to go on and talk a little bit about the definitional problems that Bronson dealt with. He talked about 2 categories: the classical definition that we heard earlier, and subjective definitions. I think the latter is a problem. I would like to go to an example with bighorn sheep I think could be termed the subjective definition. This is something that happened early last decade. Starting in December 1981, there was a series of all-age die-offs of northern sheep populations that spread through various areas of Canada and northern United States. In 1983, a workshop was held in Cranbrook, British Columbia to determine the cause of these die-offs. The ultimate consensus seemed to be that stress is a dominant influence on the dynamics of bighorn sheep herds and on initiation and continuation of disease outbreaks. Factors thought to be significant contributors to stress were compared and they made a list of stressors in this category. I'd like to read them all to you: density, interspecific competition, adverse weather, human harassment, trace minerals, habitat loss, construction, parasites, nutritional plane, hunting regulations, and predation, i.e., everything short of the kitchen sink it seems. Let's look back at what Bronson said about subjective definitions, i.e., " any perturbation in an animal's environment that is deemed noxious bv an experimenter will evoke a condition of stress in that animal, at least in the mind of the experimenter, regardless of what happens to the secretion of ACTH in the adrenal steroids." I think that is exactly the circumstance you had there. They had no evidence at all about adrenal steroids or ACTH at the time.

I'd like to say a couple of things about problems of using concepts in science that are ill-defined like that. Scientifically, if we are going to talk about cause and effect relationships in the world, we need to go through a process known as hypothetico-deducto science. We start with observations, we make some hypotheses, we deduce some predictions from them, and then we go back and compare those predictions with further observations. We go through this so-called triangle of science. There are certain critical aspects of it that separate science from something we might call non-science or mysticism. Karl Popper refers to falsifiability that he calls his principle of demarcation. If we can not produce hypotheses that are falsifiable we basically can not do science. He calls it the principle of demarcation because he's demarcating science from non-science. So, we've got this problem: what do we do scientifically with a subjectively defined concept? I wand to read you another quick quote from an epistemologist who deals with questions of science and biology, Arthur Caplan. He says: "the empirical falsifiability or predictive value of biological theories derives, not from its logical connectedness, but from the sorts of terms or predicates one uses in formulating the premises and conclusions of the theory" (Caplan 1977). I would emphasize terms, if you're dealing with terms that are subjectively defined, what can you make in the way of predictions that you can objectively falsify? You basically can not go anywhere.

I want to ask some questions. Because the whole purpose of this panel is discussion, I am purposely going off 1 end here to try and raise some hackles as much as possible. First, does the concept of stress enhance our understanding of a situation? Is it a necessary concept? If not, I would say it is just extra terminological baggage we should get rid of. In the case of the example from the Cranbrook workshop, I wonder if we couldn't just replace the word stress with the concept of predisposing factors. Do we need the word stress at all in that circumstance? They had no data relative to the classical definition of stress. Secondly, is stress just some ill-defined entity, a boogie man if you want, some demon that is constructed as a pseudo explanation of something we really don't understand? I would like to show you 1 such example from the Cranbrook workshop. It is out of Colorado and attributed to Terry Spraker. It states that stress induced lamb mortality often occurs during the summer following an all age die-off. What we know now, thanks largely to Bill Foreyt, is that, for a year or 2 following all age die-offs, the surviving adults continue to shed pathogenic strains of bacteria. The lambs get them and die; and yet at the time Spraker was attributing this to stress. So, it was simply an ill-defined term used to explain something we didn't understand. I think this is a great danger. Finally, I'll go all the way off the end here. I propose a god and goddess of stress. In this day of affirmative action we need a god *and* a goddess. We'll name them Cortisol and Adrena. That has a nice Greek ring to it. Occasionally they get mad and cause a bunch of wild sheep to get pneumonia. Would that give us any worse understanding of those die-offs that the Cranbrook workshop dealt with than their use of the term stress? I am not convinced. I'll turn this over to somebody else.

Jim DeForge.—John asked if stress is a necessary concept. The problem we seem to be faced with is that everybody has a different opinion of what stress is. If it's just a matter of creating movement response in an animal, then at what level is stress defined as being something that is have an impact on that herd? When John was talking about disease, he referred to it as stress. Well disease is a stressor of great concern and has a negative impact on reproductive success. There are all levels of stress and we define it in many different ways, but if it is having an impact on a herd or on a population, that is when it usually comes to the forefront and we start addressing it as a concern. Stress is often defined too broadly.

Dave *Jessup.*—I think the real challenge is to quantify stress. I'm not concerned at all about the acute stress response because, as John read, it's a natural phenomenon. In fact, in many ways it is an adaptive phenomenon, a constructive activity within the animal. It is when stressors are either repeated or chronic and cause suppression of the immune response, cause changes in metabolism, or cause gastric ulcers in those species that are prone to gastric ulcers, like people and rodents. I would define stress, for my own personal definition, as being over-stressed or excessive stress. I don't even really consider what was called eustress to be stress. I think the other problem we've got is in definition. If every behavior that causes an animal to pace twice is to be called stress, and we're willing to accept that as stress and immediately bad, then we are really in trouble. If every time we have a die-off, when we have no measures of stress on the animals, we say "well lets see, it got below 30° last month so that's a stress, and the wind was blowing 2 weeks ago, and that's a stress, it must be stress that caused the die-off". We have no way of quantifying that. How do you know that the stresses resulted in some chronic depression of the immune response, decrease in immunity, increase in proliferation of *Pasteurella* on the tonsils, for example, which caused the animals to die of pneumonia? Without any measures, without any way to quantify this, we might as well consider that it is an act of the gods, and the gods must be crazy.

Tom Bunch.—I have a question to ask Dave. As we think in terms of managing bighorn populations, managers must want to be able to put something down that is definable. What can we identify as stressors that will affect biological responses, potentially leading to a pre-pathological condition and, as an end result, a die-off? Can we identify what stressors we need to be concerned with? And if so, can we minimize the effect of those stressors?

Dave Jessup.—I think we are getting to the point where we can do that. The answer is right now, maybe not. We are getting close. I think an important contribution to this question resulted from the Ph.D. work done by Mike Miller. I've had copies of the abstract for several years and use it fairly extensively. Mike has probably done more work on defining what stress is in bighorn sheep than anybody that I know of.

He took captive sheep and injected them with ACTH to induce a measurable chemical level of stress and then looked at their fecal cortisol response. He also measured it in animals coming down with pneumonia, so he had a real life example of how disease effects the adrenal cortex. In fact fecal cortisol (not only urinary cortisol, but a variety of other measures, perhaps less useful) can monitor levels of stress that are pathogenic to the animal, that have a negative influence. I think it is when we can measure those kinds of changes in the body that are either in the process of leading to pathological mechanisms within the body that the manager can define when stresses have gone to a point where they are going to cause damage.

Walter Boyce.—I implore caution concerning the implication of cause and effect. Just to play devil's advocate here, you talked about pathogenic levels of stress. I do not think that is what Mike Miller showed and I do not think that is what anyone else has demonstrated. What they showed is a relationship: elevated levels of cortisol in association with disease. We have to be very careful about cause and effect. I think there is ample evidence that cortisol is elevated when an animal is under a stress and animals with elevated cortisol do indeed show clinical manifestations of disease, but the link between the 2 is not direct.

John Wehausen.—You're turning the correlation into cause and effect, which is a great danger. As soon as we want to talk about cause and effect, that is exactly when we have to go through this triangle of science of making hypotheses with testable predictions, I think that is what is lacking. People have not been laying this out in a rigorous scientific context, looking at alternative hypotheses and clearly falsifiable ones. Again, we need to have a very precise definition of stress to even begin to do that. We can not make meaningful hypotheses and predictions without having it defined extremely well. It seems right that stress, at least the stress we are concerned about, is defined as cortisol level. That's it. There are 2 questions we need to deal with. First is the question, what are all the factors that lead to cortisol levels, because there are numerous factors that can . . .

Dave *Jessup.*—And not just cortisol levels, but chronic elevation in cortisol levels because acute elevation in cortisol levels is again an adaptive phenomenon.

John Wehausen.—I agree entirely.

Amy Fisher.—Good point John, about devising experiments that can implicate cause and effect, but how can we do that when we could have populations subjected to numerous stressors and other confounding effects?

John Wehausen.—That is the dilemma we're in. And that is what I was starting to get at. We have the problem that cortisol is potentially affected by numerous factors. For instance, there is good work in deer that shows that declining body condition and poor nutrition through the winter cause elevations of cortisol levels. Whereas there is some very good evidence, also from deer, that shows that density per se has no influence. There is that first question, what are the factors that lead to cortisol levels? And the second question, what effect does cortisol have on parameters relative to demography? That is the question that Paul Krausman brought up yesterday. That is one of our fundamental concerns in wildlife management. We ultimately care about demography and need to partition out what factors drive it. We like to think in terms of a rather simple concept of limiting factors. The problem with this whole concept of stress is that we are talking about an additive effect of numerous different factors and it does not fit in very well with our way of thinking. I think that is one of the frustrations of the whole thing.

Walter Boyce.—Paul Krausman, can you comment perhaps on how you would go about designing an experiment to investigate the effects of stress?

Paul Krausman.—The real problem is that you're going to have to look at the productivity and recruitment of the animal that you are dealing with. We are dealing with animals that are reproducing at 13 years of age and we have a lamb mortality rate that is 70–80% throughout the Southwest. We don't know what all those lambs are dying from to begin with. If we're trying to determine causes of mortality to correlate with stress, it is going to be very difficult. To answer your question, it would be very nice to have a controlled population, or have 3 controlled populations that you are exposing to the stressor, whatever it happens to be (off-road vehicles, aircraft over flight, human development), and then you would have the experiment that John is talking about. You would need to factor out all of the other factors that are influencing productivity and recruitment. It's a very difficult and expensive question to answer. It is not impossible. We can answer it, but the dollars and the resources available are going to be a burden. Maybe we should work with mice. Much of that work has been done with *Peromyscus.*

Dave Jessup.—I think Paul brought up a really good point. We can't afford it. We were talking about this yesterday. The way that you answer a lot of these questions, whether they are questions in stress physiology or in pharmacology, is you have 10,000 experimental mice and you subject them to every permutation of combinations of parameters and you section them up into little pieces and we just can't do that with bighorn sheep. So the question has to be: Can we really answer those questions? Perhaps we have to take information derived from species we really know something about, laboratory animals, and do the best we can using that information. We may not be able to do the experiment in the species that we are talking about.

Vern Bleich.—For just about as long as I have been associated with mountain sheep, I have at least had the perception that there is an agreement or a dogma that mountain sheep are for some reason more susceptible to the effects of chronic stress than are other species of wildlife. Mountain sheep, somehow, do not cope as well. Mountain sheep are different in some way and I would like each member of the panel to comment on that concept. Is that my perception of what the dogma is or do we really think that is the case?

John Wehausen.—I think 1 thing we probably all accept is that bighorn sheep seem to be particularly susceptible to pneumonia. I think the hypothesis is that cortisol decreases the immune response and leads to disease. It is probably more their susceptibility to pneumonia than that they are more susceptible to stress necessarily. Maybe that's part of the same thing.

Stan *Cunningham.*—Getting away from cortisol levels. I think Vern's question is that there seems to be a holy Ovis phenomenon where people perceive "We flew the jet too close to the sheep and they are about to die." There are those who think that is true. There are those who think "No, sheep can adapt to everything a deer can." A point of confusion for me (and I do not want to get into pink tongue-black tongue theories) is that there seems to be a myriad of responses to human stresses. I can take you to a population where you could almost pet bighorn sheep, or I can take to a population where you can not approach to within a half of a mile of them. I do not understand why. I have worked with twelve populations now. The first was a very skittish one. The one I'm studying now consists of 50 sheep that go daily to a park in Boulder City, Nevada. The last time I counted the bighorn sheep in the park there were 20 ewes, 20 lambs, and 19 yearlings. I don't know what their cortisol level is, but they are reproducing well. If you're going to manage a population, can we start to explain why there are differences in reactions. I think Vern's question was: "Are some sheep really that skittish or is that just the holy Ovis effect?"

Dave *Jessup.*—I think that, in fact, some bighorn sheep are extremely skittish and some bighorn sheep, either for behavioral reasons or possibly for genetic reasons, are adapted to human activity in their environment. Go to Gardner, Montana and you see sheep downtown walking around, or Boulder City and they are obviously sheep that are not disturbed by people. But all of us have been in situations where you get within 2 miles and they are over the hill and gone. To get back to Vern's question, I think there is a perception that bighorn sheep are more susceptible to stress than other species. I don't know whether that perception is true. I know that in terms of laboratory animals, for example, there are species of rodents that have an accelerated or excessive stress response to the same measured stimulus compared to other species. But on John's point, is pneumonia the result of stress? I think we have to look at some other things that obviously are involved in pneumonia in bighorn sheep, that may or may not work through the stress response, that may not be the result of increased cortisol levels. Ron Silflow has shown that the macrophages of the upper respiratory tract of bighorn sheep are not as capable of processing *Pasteurella* spp., not *Pasteurella* specifically, but bacteria generally, as are macrophages from domestic sheep. There's a functional difference in the ability of bighorn sheep to clear bacteria from their upper respiratory tract that has nothing to do with cortisol levels. There are vital chemical differences. One of the things that Rob and I have been playing with in our genetic study of proteins in bighorn sheep is comparing them to domestic sheep. There are differences in transfenins between bighorn sheep and domestic sheep. There are differences in superoxide dismutase. Both of those have a function. Transferrins in particular have a function. *Pasteurella* spp. are iron scavengers, and the form of iron bound by transfemn that is available to the *Pasteurella* may determine how fast it can reproduce in the rapid growth phase when it become systemic in the animal. Transfemn type may have an effect on whether *Pasteurella* spp. can become systemic, and overwhelm the animal. Superoxide dismutase is an enzyme that deals with peroxide radicals that come from exercise stress and there's a different form of superoxide dismutase in domestic sheep vs. bighorn sheep. They may have a functional role. The point is that there are things other than the glucocorticoid pathway that determine whether animals will get pneumonia or not. I think that if we are saying all pneumonias are the result of stress, thus bighorn sheep must be more susceptible to stress, I guess that could be a perception. I do not think that all pneumonias are the result of stress. I think when you get a workshop together and they have no measures of stress and they say, "well, it's the hunting season," and "it was a cold winter," and "it was this and it was that," "it was all these stressors, that must be what killed it." You might as well say it was the gods, Cortisol and Adrena, or whatever John called them, because you really don't know. It may be and it may not be.

John Wehausen.—And that, perhaps, comes down to the fact that there are more parsimonious explanations. That is Occam's razor, in terms of scientific methodology. The explanation/hypothesis that makes the fewest assumptions and explains the most observations is the one most likely to be correct. I think that is what we should be leaning toward.

Paul Krausman.—There is 1 other serious consideration when we are dealing with stress in large animals, especially when you're considering welfare and/or animal rights advocates. In trying to get approval to use animals in university or agency research you are required to go through 3 or 4 different organizations that approve these types of research. Sometimes just a blast of noise that may be 113–115 decibels raises enough eyebrows to cause concern. It was a real problem obtaining authorization from the University of Arizona to expose an animal to that level of noise. We have also had problems trying to test the hearing of sheep and deer. Just getting the approval to do that has been quite difficult. Also, we have had armed guards 24 hours a day for 9 months on our sheep facility. That cost the university $45,000. That is 1 of the criteria that we had to have to pacify some of the groups that were concerned about safety of the animals. Another concern with large animals such as the mountain sheep is the stock. Maintaining these animals in captivity is not an easy task and when you're going to put them in captivity and expose them to stress you can expect all kinds of problems. Replications are going to be somewhat limited because you just do not have the stock that you can constantly fall back on. I think Tom knows that. I am running into some of those same problems. These are going to be very difficult questions to address. John suggested something very important. How valuable are these data to sheep management and efforts to perpetuate the species? It is ultimately a question that is going to have to be answered if we plan to invest resources to get the answers that we need.

Walter Boyce.—Are there any questions?

Jim DeForge.—We have found with the Institute's captive herd (and we have varied the herd tremendously, changing herd leaders and such), that there is tremendous individuality among all the animals. You get some animals out of the same herd that show different excitement levels, at least in terms of immediate response, compared to others. What we have found, or feel, is that the animals are extremely intelligent and you can pretty much get a behavioral response out of them based upon what you put in. So they are pretty much a product of their environment. If they are being stressed to a level where environment is totally unpredictable, that may have more of a traumatic effect on the animals than if they are being stressed from an occasional capture and sampling. You can end up with a herd that is very adaptable to the situation of being in a captive state. We at times see animals that just do not appear to get to any level like that. As a result, we usually try to release those animals into the wild at an early stage because they can have a tremendous influence on the rest of the herd.

Walter Boyce.—Could you comment a little bit on what your specific concerns are with the encroaching development at the Bighorn Institute. How is that going to affect your animals?

Jim DeForge.—The property around the Institute's pen facilities has grown tremendously in value and there is pressure to develop fairly close to those pens. It is our concern that the stress on the captive herd is not necessarily the animal's immediate reaction to a new stimuli (grading and construction sounds and equipment nearby), but having to cope with prolonged exposure to foreign sights and sounds from which they cannot escape. What we are looking at is the overall success of the herd's ability to produce viable offspring. We know the zoos have good success at producing lambs in their captive herds. But the key to our success, and the way we are trying to measure the impacts of stress, is whether captive born lambs can adapt to a wild state and deal with the social makeup of the wild herd. There is very limited data that shows this type of facility working, but the Institute has had good success. There have been a few bighorn released from a zoo facility that all died within a few months. If I were to go to a zoo facility and look at the behavioral response of those animals versus the response of the animals at the Bighorn Institute, I would say that Institute animals appear to be a little bit "wilder." The animals at the Institute at times can seem to appear to be quite docile and, as Stan brought up, our biologists can approach them at a close distance usually, but that is partly because of our calm and routine behavior towards those animals. We are not there harming them, and as I said, I think the bighorn in general can be extremely intelligent and react accordingly. When they are released to the wild, we see in maybe the first 24–36 hour period that these animals' behavior changes to conform to that of the bighorn in the wild. The dominant ewe of the wild band who comes in contact with these newly released animals may get very aggressive with them in order for the released bighorn to conform to the behavior of the wild herd. We see a change or conformation in the animal's behavior that has been released to mimicking those in the wild and within a short period of time we cannot approach those animals closely. They respond like the wild sheep. If they do not the dominant animal again gets aggressive. What we'll find is the released animal may separate out. There has only been 1 case where we have had to bring a released bighorn back to the Institute for a while longer and release it again later. Again, it is a tough thing to get data on. I can not get all exited about cortisol levels all the time either. In some instances, yes, it's a gauge or something for you to look at, but in the case of the Institute, we're going to have to look at successful reproduction and survival. That is, the animals actually going into the wild and making it.

Walter *Boyce.*—Do you want to respond to Vern's question?

Tom Bunch.—Yes, I'll try to respond. I don't have any real hard data suggesting that bighorn are more susceptible to stress than any other species of wildlife. I have worked with bighorn in captivity on several occasions. I have no reason to think that they are more stressed than other wild species we have worked with such as pronghorn antelope or elk. You bring a bighorn sheep into captivity and as long as they do not feel threatened, or you do not harass them, they habituate quickly. I think from what Jim mentioned they are very alert animals. One of the things that I observed with bighorn sheep is that they like routine. You can bring a bighorn sheep into captivity, put it into a pen, the sheep sees the caretaker everyday, and within just of period of weeks the animal habituates and allows the caretaker to approach within a few yards and sometimes allows hand feeding. If 2 people go into the pen or approach the habituated sheep, it's a whole different situation. But as soon as the animal recognizes that there is no threat, then 2 caretakers at 1 time becomes acceptable. We have done surgery on bighorn and it has been traumatic. Yet, the sheep come out of it without any post-surgical complications. They do as well going through surgical procedures as domestic sheep. From my experience the only thing about bighorn sheep in captivity that has been difficult to deal with is preventing pasteurellosis. Pneumonia is often stress induced. In our facilities, we were exposing bighorn sheep to exotic wild sheep for cross breeding purposes. I believe the cause of pneumonia was more the exposure to the exotic sheep than the stress of captivity. But, I can't really answer your question, except in captive conditions they don't appear to be seriously stressed. Bighorn sheep adapt extremely well to captivity. I found that if a lamb is born in captivity to a ewe that is used to being handled, then that lamb is going to respond much differently than a lamb from the wild. In fact I want to point out this personal experience. I had been conducting research on my hybrid sheep (Ovis *canadensis nelsoni* and *mexicana* × argali-mouflon [*O. ammon nigrimontana* × O. *musimon*] that I reported on a few years ago in a Desert Bighorn Council meeting. All of the hybrids were hand-raised. I could walk into their pen and the hybrids would come to within 2 or 3 feet of me. I took the desert bighorn ram that had been captured from the wild and placed it in an isolation pen for a few months. During isolation, the animal would not allow me to approach it from any more than about 30 feet. As soon as I got closer than that distance, the ram would take flight and run to the other side of the pen. When I put the ram in with the hybrid ewes his behavior changed. The ewes would walk up to me and the bighorn ram would come as close as 2 or 3 yards of me. So there are some learned things that are involved, and I do believe that bighorn sheep are extremely adaptable. If there is no indication from your presence in a bighorn's pen that your are presenting a threat, eventually the animal will adapt to your presence. It is just a matter of time. I think habituation is happening within the sheep next to the dam. It would be interesting to capture some of the sheep that ran over the hill when you approached and mix them with the more docile group that have habituated to human disturbance and see if there is any behavioral modification. My guess is there would be.

Stan *Cunningham.*—I think it's a learned behavior. I don't understand why some have seemed to learn to live with human influences and some have not. In some cases, development starts, and in 20 years there are no animals there, because they don't seem to learn to adapt to it. Those that are adjacent to Hoover Dam in Boulder City have been putting up with construction of dams, roads, and powerlines. These animals have seen all kinds of human influence and have adapted very well.

I have a question on the *Pasteurella* issue. If you have for example 100 lambs born, 70 of those are probably going to die, so you are going to have 30 to 100 lamb: ewe ratio, close to an average. I've always assumed that the majority of those lambs died of pneumonia. Is that right? Is it fair to center on *Pasteurella*?

Dave *Jessup.*—That's not the case at all.

John *Wehausen.*—I think most of the sheep I've diagnosed died in the claws of a mountain lion.

Dave *Jessup.*—I don't think that is probably the case. Unless you have evidence to the contrary, I would bet that if 70 of the 100 lambs die, that probably very few of them die of pneumonia. That most of them probably die of predation, or falls, or malnutrition, or other causes that we would consider "natural" because when you get Pasteurella spp. killing lambs you're usually seeing 90% mortality, or you are seeing an all-age die-off in which the lambs are involved. There is a lot of controversy about Pasteurella and it is somewhat confusing, but there are apparently very pathogenic, very hot strains of *Pasteurella* that will just flat kill all bighorn sheep. There are also some situations where the lambs alone seem to be the most susceptible. The adults that survive an all-age die-off that have the Pasteurella strains in their tonsils, whether they are the original ones that killed some of the adults, or whether they are other ones that they are carrying, they're hot enough to kill lambs. But I don't think that we can blame pneumonia for all mortalities in lambs, unless you have some evidence—gross pathology, microscopic pathology, something to suggest that is the cause. I don't think that pneumonias are really involved as a population regulating mechanism all of the time. I don't think it is a part of a natural population regulating mechanism. I would be willing to stand corrected if there was evidence to that, but I've never seen anybody show that *Pasteurella* pneumonias are a population regulating mechanism in killing a significant percentage of lambs in a normal situation.

Jim Bailey.—By regulation, you mean density dependent?

Dave *Jessup.*—That is the sense I am using it in, Jim. Again, the confusion is with the lungworm situation, for example, that you are so familiar with. Lungworms appear to be an organism that evolved with bighorn sheep and they do appear to act in a density dependent fashion and, to some extent, regulate populations. Then you throw hot *Pasteurella* strains in on top of that and you may lose a whole population. Is that a population regulating mechanism? Is it a natural population regulating mechanism? I don't think so. I think we might be mixing 2 organisms, which have very different evolutionary histories in their relationship to the host.

Walter Boyce.—You are suggesting that Pasteurella has not been present in bighorn sheep prior to the introduction of domestic livestock?

Dave *Jessup.*—No, I think there are strains of *Pasteurella* that evolved with European livestock, and there may be strains that evolved with bighorn sheep. A lot of us have for years found these "non-hemolytic, pasteurella-hemoliticas" and they are easy to find. We did an experiment at Old Dad where we did tonsil swabs and nasal swabs on 20 animals. We got non-hemolytic, pasteurella-hemolitica out of the tonsils of 14 or 15 animals and out of nasal swabs of 2 or 3. These are relatively, as far as we can tell, non-pathogenic strains of *Pasteurella* spp. These are the non-hemolytic ones that Onderka got out ofbighorn sheep in British Columbia that didn't appear to be associated with a pneumonia process. There are very hot hemolytic strains of Pasteurella *hemolitica* and P. *multocida.* I think there's a real difference between strains of Pastetirella, and we know that from livestock.

Rob *Ramey.*—Referring back to Tom's commentary. I want to ask the panel: could we be so bold as to say that any measurable physiological response in bighorn sheep to a particular set of disturbances, may not be comparable between populations simply due to the fact that there may be different degrees of habituation or learned response between those populations?

Torn *Bunch.*—Yes, I think that is the case. I also think there are individual responses. For example in our own lives, in our own families, we respond to stress differently. Animals respond differently to stress as well. You find different animal responses within a population, and different responses between populations. Some of that can be a learned phenomenon, some of it can have a genetic component, which then will determine, to some degree, how the animal is going to respond to a stressor or a disturbance. Whether an animal takes flight may have important evolutionary implications in terms of survival. It is important for an animal to respond for survival. But, if it takes flight to every non-threatening stimulus, there is an energy cost the animal has to pay. So you have to look at each individual situation.

Walter Boyce.—I would like to make the argument that diseases are a natural process. Several publications indicate that x number of sheep died of pneumonia, x number died of falls, and *x* number then died of natural causes.

Well, I kind of lumped this all together. Because we are specifically talking about diseases today. I'd like to suggest that much of this discussion results from the fact that we now can recognize these diseases. They have been out there all this time. I'm not disagreeing strictly with what Dave said, but I think in the past there have been epizootics that did completely wipe out a given population. That, in the past, when you had traditional migratory routes open, areas were repopulated by animals from other populations that had a genetic basis of resistance.

I worked on genetic resistance to diseases in domestic breeds of sheep in the southeast. If you take a sheep that has been reared anywhere else in the country, other than in the face of heavy onslaught of parasites, then parasites can regulate their hosts in a density dependent manner. The only animals that can survive well in the face of that sort of pressure are those that have been there over a long period of time. The offspring of those animals that were most resistant survived, reproduced, and their offspring survived. In the situation of bighorn sheep right now, I would suggest that we are looking at isolated pockets of genetic material that have different relative degrees of resistance to these diseases. We will see diseases having significant impacts in some populations and not in others. The stresses may be common across all these different populations. It is going to be very difficult for us to differentiate between a genetic basis in the host or a stress imposed upon a particular animal. A question I would like to throw out, implicit in all this, is that stress can enhance the ability of a disease to appear in a given population. Has anyone worked with a population of bighorn where a stress has been removed and you've seen some sort of predictable or observable effect in terms of that population having greater lamb survival and recruitment?

Dick Weave,: —Water deficiency.

Walter Boyce.—What about some of the man induced stresses? That seems to be the one that we focus on these days. Does anyone have examples where development has either been stopped or removed (say a road going through an area) and the population appeared to respond to that?

Jim Bailey.—Just the opposite, in Waterton Canyon, correlative evidence however. The population had low lamb : ewe, yearling : ewe ratios at the start of construction activity, which increased with human harassment, at least human activity, in the canyon where there were habituated sheep. The lamb production and survival in the yearling class increased, it doubled, more than doubled, for 2 years with increased human activity. Then there was the die-off.

Walter Boyce.—Paul Krausman, what about the enclosure up in the Virgin Mountains? Did that population do especially well, compared to free-ranging populations?

Paul Krausman.—The information that we have on that population suggests that, while they were in the enclosure they did extremely well. We documented the youngest desert bighorn sheep breeding in that population. The population increased from 12 animals to 26 animals over a 2 year period. The information we have following their release indicated increased mountain lion predation, disease problems, and conflict with livestock. A good portion of the captive animals that we were watching were removed from the area. To answer your question of stressors being removed we have other situations. We have monitored 1 population since 1979, in which water was not in the range for 5 years and then water was added. We monitored them for 3 more years and there has not been any response in productivity or recruitment. One other example, we had, in this same mountain range, an area where all of the animals that we were monitoring dropped their lambs. During the construction of the Central Arizona Project, a road was built that cut off that part of the mountain range. About 15 trucks/hour went through there for about a 2 month period. That terminated the use of that portion of the range for 3 years. After 3 years the ewes started going back there and now all the ewes are dropping their lambs in that area again.

Dick Weaver:—I would just like to jar some memories here. Back in the mid-1960s Dr. Hansen reported to use some of his observations from the Desert Game Range and from the captive sheep at Corn Creek. He noticed that all bighorn did not behave the same. Some were more wild and some were less wild and could be more adaptable. In the course of helping the Nevada Department of Wildlife, he looked at sheep that were taken by hunters. He then observed the sheep at Corn Creek. He noticed that they had pink tongues and black tongues, remember? The pink tongues and black tongues brought a lot of laughs from all of us back then, but the point is that he believed that there was a genetic difference that affected sheep behavior and that indeed the harvest was favoring black tongues and that in time it might change the composition of the wild, free-ranging sheep in the Desert Game Range. It evoked a lot of thought and some chuckles back at the time, but some sheep do adapt easily and some do not adapt at all, apparently.

John *Wehausen.*—One point of curiosity to me over the years has been, why are there so many populations of northern sheep that are habituated and so few southern populations of sheep that have habituated? Is it just a matter of fewer impacts and people in the desert, or is it a different genetic predisposition?

Stan *Cunningham.*—To answer that, how many people want to buy a house in some of our desert mountain ranges? Very few where it's 130°F and no water. But some of the sheep in mountain ranges close to cities seem to be doing well. Maybe with *cremnobates* that's a problem and maybe they're different, I don't know.

I was very interested in Rob Ramey's talk this morning because there are some mountain ranges very close to Phoenix, and there has been opposition to putting transplants there because the sheep would not handle all the housing developments at the base of the mountain range. If *nelsoni* and *mexicana* aren't different, we could take some *nelsoni* from where I am working now and we could put them right in the middle of Phoenix and they would do well. They don't care.

Dave Jesszip.—I'm not sure that follows what Rob said, but Rob is going to respond.

Stan Cunningham.—No, I didn't say that Rob said that would be a good idea. All I am saying is that it enables us to consider taking *nelsoni* and putting them in a range that we have thought of as *mexicana.*

Rob *Ramey.*—The lack of measurable differences in genetic markers that I have found does not mean that there are no genetic differences between ranges. I find it more likely that if there are differences between regions, it's clinal variation, not simply something discrete that you can draw a line around.

Stan Cunningham.—Right.

Rob *Ramey.*—And so that's why I advocate sort of a nearest neighbor strategy for translocations. If you have reasonably decent stock that are doing well, you may want to use them because they may have locally adaptive traits.

Walter *Boyce.*—Rob, when you were looking at differences and similarities in the genome of these animals, what proportion of the animals' genome were you actually looking at?

Rob *Ramey.*—Really good question. Two different kinds of DNA, mitochondrial and nuclear DNA. When you are looking at nuclear DNA for protein variation, you are looking at 15,000 something proteins and you are taking a subset of that, which is a very small portion of the genome.

Walter Boyce.—What proportion if you can say?

Rob Rarney.—The original pilot study had 36 loci out of 15,000.

Walter *Boyce.*—Thirty-six out of 15,000?

Rob *Ramey.*—Correct. But hopefully you're not just surveying for differences between particular genes, but also differences in the sequence of those genes. You are actually looking at 36 out of 15,000, but it is also dependent upon the length of the genes. It's a small fraction, a spit in the bucket basically, but it's an index and that's all we have to work with. With respect to mitochondrial DNA, I'm looking at about 45%, but I can say with a certain confidence that these different groups are similar, based on my sample size.

Walter *Boyce.*—What relationship is there between adaptive survival of these animals and the proportions of their genome you're looking at? Do you have any sort of connection at all?

Rob *Ramey.*—No! This is a good question. We have different traits in organisms. Some that are controlled by single genes, simple mendelian traits, like eye color, like you know the pea plants with wrinkled versus smooth seeds. They are all controlled by 1 gene with different variants. A lot of the characteristics we see in the organisms are controlled by many genes. We call these polygenic traits. Numerous genes, 2 to perhaps 50, control 1 particular trait. Trying to find differences between those using single gene loci, as Jessup and I did, is difficult. What you need to do in that sort of situation is look at the morphology and you actually have to do some breeding experiments. Quantitative genetics, as it is called, is very impractical.

Walter Boyce.—I want to point out 1 thing in terms of the immune system. The immune response genes are on a specific portion of the genome and as far as I know, no one has looked at variation among these animals with respect to their ability to respond immunologically. So we can have very marked differences that are going to directly affect the ability of these populations to survive that are not reflected in this sort of study (mtDNA). I would argue strongly that we need to look at more than just 1 data set before we decide to mix subspecies together.

Rob *Ramey.*—That's why I say that the nearest neighbor strategy is a more conservative strategy.

Dave *Jessup.*—Resistance to disease is a classic polygenic trait. I mean, there are many levels at which an organism has to pass the body's defenses to colonize the animal and either cause disease or kill the animal. If you want to look at the respiratory tract, there are a whole variety of different mechanisms including the macrophage response, the integrity of the epithelium, the ability of the organism to replicate with the bloodstream, the levels of specific antibodies or IGG, there are whole series of things; those are classic polygenic traits, everyone of them. There are many levels, so it is not simply mendelian genetics like smooth versus wrinkled, red versus white; there are probably out of your 15,000 loci, hundreds that are involved in some aspect or another of disease resistance.

Rob *Ramey.*—But the thing that is important, including the sort of genetic data that Dave and I have put together, is that it is an index of relatedness between groups and it shows that groups, those subspecies boundaries in the southwest, do not mean anything. The original data does not even support it. But is does not mean that there are not some differences between regions. It is likely those differences don't match what somebody thought back in 1940. If you do find stock which show some disease resistance . . .

Dave *Jessup.*—I think it would be a tragedy if that was taken as carte blanche to move any animal anywhere . . .

Rob *Ramey.*—Exactly!

Dave *Jessup.*— . . . a tragedy if managers said forget "the species definitions, throw out everything as far as subspecies are concerned, we can do anything we want". I think that would be a tragedy because I think that it is much more complicated than that.

Rob *Ramey.*—Right, so what we need to do is take a more mature view and to say that we do have some variation. Wehausen found it in some horn characteristics, you seem to have found it in some disease susceptibility. We have to recognize that, sure we can erase some subspecies boundaries, but we may still have genetic differences between regions. But if we call them something, then we start drawing lines around them.

Stan *Cunningham.*—I do want to point out again, however, that response to human influences is something I think all of us should consider in a transplant. Transplants that have come from the Black Canyon population have also been very adapted to humans. The Virgin River is an excellent example. Those sheep will bed right next to Interstate 15. It really stunned me to see that, until I realized they came from Black Canyon, where their mom crossed the road, their grandmother crossed the road, and they are very used to it. Because of that, they move freely across Interstate 15 which has bad some mortality effect, but it's actually been better for the population because they have dispersed and grown faster.

Jim DeForge.—Bighorn in the Santa Rosas can get rather friendly with people. We have a small tight closed-in cove community that developed near the base of the northern Santa Rosas where the homes are anywhere from a million to several million dollars. During the summer months when the sheep are down eating on lawns and looking for water in this area, most of the people are not living there. These are, in many cases, just second homes and as a result of that the bighorn feel a real security with coming into these places because there's steep escape terrain all the way around the development. It's also a guarded community, so there's really no free play inside this small and quiet developed area. I believe these animals habituate to those surroundings, over time, because they do not feel threatened.

Even when we feed the sheep at the institute, we have to follow a routine. When we first arrive to put out the supplemental feed, the sheep will be observing us from above the feed area. We train our people to do everything the exact same way. The alfalfa is given first, the water second, and the pellets last. By the time the alfalfa pellets are hitting the bowls (a discernable sound that they hear and respond to), the sheep start moving down toward the feed area while the gate is being opened. It often results in aggressive behavior toward each other if there is a change in the feeding routine. So again, I think these animals are a little bit smarter than we give them credit for. Then we have situations where they come in close contact with people. I think over a prolonged period of time the sheep have learned to adapt to some situations of human activity and then after that it's hard to change that behavior to some degree.

Walter. Boyce.—Does anyone consider reducing mountain lion populations as an effective means of reducing stress on bighorn sheep?

Dave Jessup.—In a word, no, but we have gone in and killed mountain lions in areas where we have transplanted small population because the mountain lions were killing an inordinate number of sheep that we had spent a lot of time and money transplanting. Now, obviously from a quick fix management point of view, we wanted to salvage that transplant and mountain lions obviously kill a fair number of bighorn sheep, but are they a stressor? At least in my definition of something abnormal, I don't think they are. I think they are part of the environment. They are one of those things that I wouldn't call a stressor. I wouldn't call it something that likely repeatedly or chronically increases the cortisol response and increases the susceptibility to disease, based on my definition of stress.

Walter Boyce.—Lets go back to John's comment about Occam's razor. Is the lion causing stress that is then reducing the recruitment rate of that population or is the lion eating the recruited portion of that population? I have problems with that.

John Wehausen.—You're right, there is a more parsimonious explanation of what's going on. I'd just like to comment, that I've actually documented a population in the Sierra that completely abandoned their winter range under very heavy mountain lion hunting. It just got to the point 1 winter where they all left and disappeared for 3 weeks. They went up in the high country and just let things cool off and then came back.

Walter. *Boyce.*—I like to get the opinions of the panel participants here. Should we try to do everything we can to reduce stressors where they occur? Exactly what is the management answer at this point?

Stan *Cunningham.*—No, I don't think we should try. We could get in a long argument of what's normal, what's abnormal. Something like stress from a mountain lion obviously is normal. They have evolved together. There's 3 excellent papers that show that if you try and control mountain lions you may have more. In other words, you may go into a mountain range, remove 3 adults and have 7 transient young move in.

John Wehausen.—I don't think we have a sufficiently precise definition of stress to talk about reducing it.

Jim DeForge.—I would see it as a concern for management when you find a herd, such as *cremnobates,* at such low population levels. I think you have to look at all the potential stressors out there and try to eliminate some if it's possible. Again, you're looking at effects on reproduction and stability of a herd and what management can do to help.

Jim Bailey.—I'd like to make a comment. First of all to defend Mike Miller, he did not simply correlate the levels of ACTH in his experiment with shedding of *Pasteurella.* He also correlated it with measurable declines in immune capacity and he did it in a switchback design so it was repeatable.

Where do we go from here? Maybe Dave could answer this as well as anybody, where are we with respect to interpretation of cortisol levels? You and I have a friend who tells me what a high or a critical level of cortisol is, but I'm not so sure he knows that. Has anybody really done a review of what levels are associated with what kinds of problems in sheep herds or have we got a long way to go on that?

Dave *Jessup.*—I agree, we've got a long way to go on it, but I think we've finally got a tool. This goes back to Tom's original question to me. I think we've finally got a tool that might get us there. I think Mike's research, Mike's dissertation is the closest thing to a controlled experiment. We have a response variable, fecal cortisol level, that is correlatable with the potential performance of bighorn sheep. Paul was saying in a discussion that came up yesterday "How are you going to measure the response of a herd?" We may not have the time and the money (in the Afton Canyon situation) to show that there is a response in terms of reproduction or survival, but you may be able to show that there is a response in terms of cortisol levels that are known to be comparable with increased susceptibility to pneumonia, with changes in metabolic function, that correlate to high levels of chronic ACTH injection. You may not have the time and money to follow it out for 15 years and show that indeed this does result in a 15% reduction in lamb survival on average over 15 years. This drops you from 30 lambs/100 ewes to 15.2 which means that your population over a 40 year period will then decline from 300 to 120. We're talking millions of dollars, but we may be able to use that tool, which we now have available that is a valid measure of the function of the adrenal gland and the sum total of stressors on the animal. There is a lot of work that needs to be done on it. Mike just opened Pandora's box. He just started us thinking about something that is going to take a lot of work to verify.

Mike *Hansen.*—On that lion predation versus stress issue. I just moved down from Alaska and the presence of grizzly bears definitely elevated my adrenalin level. I think the presence of any predator can stimulate the whole system, whether or not the predator is visible. The other comment was relative to John's talk about terminology and what we've been talking about so far are terms that all imply a negative impact. But then we've been talking about habituation and the fact that they can learn from those same stimuli, and I'm using the word "stimuli" for a purpose, to not have negative impact.

Dave *Jessup.*—I'd like to bring us back the controversy over what is or is not stress—a matter of definitions. Jim voiced his concerns about the ability of bighorn sheep at the Institute to have lambs, rear lambs successfully, and for those animals to be reintroduced to the wild. I would like to take the point of view that it is not a matter of stress, it is a matter of behavior. It is a matter of learned behavior and not one involving the adrenal gland and the outpouring of glucocorticoids, but one of really adaptive and learned behavior. I think that some of the confusion and disputes that we had in our discussions today, and some of the disputes that we have had in our personal discussions have been from perhaps using the term "stress" as a generalized concept—more like a behaviorist would use it—as opposed to using stress as defined by the hormonal response of the animal.

Dick Weaver.—Relative to your response to Jim's situation and stress and how much stress is too much stress, and how close is too close . . .

Dave *Jessup.*—Or is it stress?

Dick Weaver.—I think that one of Jim's problems is that manipulations at the Institute have a greater effect than the factors which he is trying to measure. It may also be difficult to determine the factors having an effect. And that may be more of a problem for Jim than whether they can be adapted, that is, tolerate proximity.

Mike *Hansen.*—Let's get back to terminology. The stimulus is the presence of people and that causes the stress response. I think we really need to work on what John was talking about. We know that there are many stimuli that cause that response.

Dave *Jessup.*—It's when that stimulus is prolonged, repeated or chronic and results in such a change in physiology that the animals can no longer survive, that we are really talking about a detriment to the population—otherwise it may be a positive advantage.

Mike *Hansen.*—It can be a positive advantage. Stan suggested that animals occumng where they are no coyotes are adapted. But when there are coyotes present their reaction to this presence, which produces stress, is to leave that area, and that is a very adaptive thing.

Jim DeForge.—A predictable stimulus may be something that develops good behavioral response and the animal does well. We are concerned with creating a good enough buffer around our pen facilities to provide some degree of predictability and stability within that area. When you all of the sudden have a house alarm going off and fire trucks coming within close range of these animals, you're going to get a different response. I'll guarantee you an elevation in cortisol.

Vern Bleich.—Fire trucks and other things that would occur at unpredictable frequency—probably not very frequent—would stress me out, too. How do you feel that helicopter landings might affect the behavior of penned animals?

Jim DeForge.—It can be a problem. Obviously, in our situation we control the direction that the ship comes in and prevent them from flying over the pens. That makes a world of difference. There is no doubt that keeping a helicopter as far away as possible is best. Again, you are talking about a very infrequent occurrence. The noise is a separate issue. Also, if the animal feels harmed in some way, then you might get more of a prolonged reaction from it. I think bighorn in a closed environment, like a pen enclosure, can be more harmed than those out in the wild. Those in the wild can choose to leave a scene and reappear 3 months later.

Dave Jessup.—Aren't both of those things—fire trucks and helicopters—basically going to cause an acute alarm response and, again, we are talking about many, many things that happen to an animal or person that cause an acute alarm response aren't detrimental—ifit doesn't scare you so bad you run into the wall and break your neck.

Vern Bleich.—I was just trying to make a point that there are unpredictable things that occur that would be desirable because they provide some benefit and there are things that occur that are undesirable because they don't.

Jim DeForge.—One of the things we have learned here today is that there is a lot that we don't understand. I think when you have a closed-in populations, such as a penned-facilities situation, you should treat it in a more sensitive manner than in a free-range situation where the animal can choose to leave and choose to come back when it is emotionally, psychologically, or however ready to do so. For us to sit here and try to evaluate, or put numbers on, how bighorn would respond to the noise of a fire truck or helicopter would be very difficult. Again, we even look at individuality as we've discussed. Some animals may respond differently within the same herd. We have gotten rid of (released), at times, the herd leader because she would respond to certain things differently and the whole herd would respond in the same manner. So again, there is somewhat of a calming stability within the social structure of the herd. You have to worry about those things and monitor them in a herd situation, at least on a daily basis.

Dick Weaver:—I do not know if you can call our activities in the Old Dad, Vern, frequent or not. We have repeated helicopter efforts, both capturing and collaring, more frequently than probably anywhere in the Southwest, and sheep take flight. You gave us information in your paper yesterday, but the herd is doing well.

John Wehausen.—I want to ask the question, has anybody actually followed fecal cortisol levels over time in wild populations vs. captive ones? I think it is possible that captive populations might actually have a lower fecal cortisol levels, if deer research has any parallel here. Animals that go through substantial nutritional stress and lose condition during a portion of the year have considerably elevated cortisol levels. In captive animals such as Jim had, provided you don't have mountain lion ingress, those who are fed good diets all year round may actually have lower cortisol levels than animals in the wild.

Amy Fisher:—John, actually they do, if you remember the slide that Dave Jessup showed yesterday. Mike Miller analyzed fecal samples from Red Rock, Alamo Hueco, San Andres, and Bighorn Institute herds. The lowest fecal cortisol levels were in the Red Rock sheep, a captive herd, whereas the highest fecal cortisol were in the scabies-infested San Andres herd.

Jim Bailey.—On the other hand, you can overwhelm good nutrition with serious stress. Does captured pregnant and brought into the pens at Fort Collins, on at least 2 occasions, always produced nonviable fawns with imperceptible thymi, no matter what we did with them. Those does were fed very well. Those same does in subsequent years, always produced viable fawns after they habituated to the pens.

Dave *Jessup.*—The lack of thymus tissue that Jim refers to is a classic effect of high maternal cortisol levels on the development of the immune response of the fetus. When you see that in a fetal bovine or a fetal lamb when you are doing a postmortem, it is usually the result of a severely compromised immune response and it can result from high maternal cortisol levels.

John Wehausen.—Selye identified the thymus and the lymphatics as 2 organs that shrink under chronic stress.

Sandy Schemnitz.—I have a question for Jim DeForge. A number of captive populations are potentially going to be available for release into the wild. What kinds of husbandry practices can be employed to enhance survival in the wild?

Jim DeForge.—We try to minimize contact with the animals. We never allow our people to get into a petting mode. For instance, when I'm in the pen, I am often treated as a dominant animal and this is best because otherwise you can have a ram getting aggressive with you. Also, we release sheep in sight of other bighorn because they need to be picked up by the wild sheep and then, you might say, be reprogrammed to learn the ways of the wild herd in a very short time. I am always leery of releasing bighorn in an area where there are no existing bighorn, as I feel that it would be very difficult for those animals to make it.

Mark Jorgensen.—It seems we have more questions than answers again. Being in the land management business, it is really dangerous to leave things just completely up in the air. We get bombarded by off-roaders, mountain bikers, hang gliders, 4-wheel drivers (we don't have any skateboarders yet in the desert). When we have no definition, we have no agreement—that leaves land managers vulnerable. We have opened a lot of doors here today for situations. I feel most sorry for Don Armentrout who is trying to manage things and trying to answer a specific user group that is very powerful and makes in-roads into bighorn habitat. I do not think any of us think that off-roaders, mountain bikers, or hang gliders in bighorn habitat are good for bighorn sheep. We need to come to some agreements about the lowest common denominators. What are good things occurring in or near bighorn habitat and what can we consider detrimental? Science is extremely important, but my superintendent wants some answers today, not 50 years from now. He has to answer to these constant bombardments. We need some agreement within the Desert Bighorn Council as to what activities are detrimental to bighorn sheep, especially in declining populations. And then when they talk about the Santa Rosa population it's OK because they feed on the grass at the Ritz Carlton. Everybody in the country knows about the park at Boulder City. These things are anomalies. I don't think that we can generalize about sheep being totally habituated and, in general, I would think that probably the opposite is true. Look at it from our standpoint as land managers, not lab people, not scientists working with the triangle, but the people who have to give the answers to these use groups. We need some group like the Bighorn Council behind us to say "Yea, he's right when he says that throwing 30 cattle into that bighorn watering area is not good for bighorn." Their answer is—prove it!

Dave *Jessup.*—We're up against a real problem here because if we say something is bad and it turns out we are wrong, then our credibility is shot. If we say we don't know the answer, the park superintendent might say if you don't know the answer that means I am going to do whatever is politically popular, then we aren't helping the resource. I don't think any of us have an answer for this other than to try to measure things, to try to come up with verifiable data but also to state honestly that we may not have an absolute answer. It is really the crux of the problem of managing wildlife.

John Wehausen.—I think we need to be very careful of our terminology because that's where we get into trouble. I would say that since this panel is about stress, we should be very conservative in the use of the term "stress." I think in Don Armentrout's case, there was a mistake made by BLM initially. They said they were going to close down these roads because they were going to minimize stress on bighorn sheep. If they instead had said they would like to close down these roads because we want to minimize displacement of sheep and behavior modification, they would have avoided this question of stress. We would still have something quantifiable because you can go out there and quantify the behavior, the displacement distance at which they run and so on. We should just be very careful in when we use "stress" and basically we should avoid it when we can.

Don *Armentrout.*—I want to confirm what Mark's saying here, and I can use another animal that occurs in the southwestern desert. For years scientists debated over terminology and adequate research for the desert tortoise. They met and debated. They told managers we do not have the answers and managers continued on the road to popular and political expediency. The drought in Southern California and the Southwest was probably the best thing that ever happened to the tortoise and the worst thing that ever happened to wildlife management because now they pay attention to the desert tortoise. All it took was a listing. Now 80% of the budget in my district goes to desert tortoise management. So, I would caution people when they discuss stress and say we can not define it or you can not measure it, or you can not get it into perfectly statistical sound analysis; then you are not talking management, you are talking lab, and let's get out of the lab and walk on the ground.

Jim Bailey.—When you oversimplify it, it really does seem that our problems boil down to 2 things: how do we measure stress and how much is too much? We've got some new tools that may measure stress and then we've got to start correlating levels of stress with population performance. However, there may or may not be a threshold. There may a totally linear relationship. Probability of problems goes up with fecal cortisol levels continuously and it will be a predictive kind of model. I think that's where we need to go.

Walter.Boyce.—I agree with that, and I think experiments need to be done in a variety of different areas. We can't choose a single test case and then try to extrapolate.

Many of you work with vastly different populations with different stressors, if I can use that term, and I think it is very appropriate to start using these tools, especially in populations that are currently under stable stress. Do it in as many different situations as you possibly can. Do not sit still. Go forward with trying to collect results and correlate those with what's actually happening in terms of lamb survival and recruitment.

Rob *Ramey.*—So, if we are going to go ahead with research, we should make sure that we are all using the same tools basically, and that we are using them in the correct and best way, so that we get the best sample sizes, and we can compare at least some results. So, we need to make sure we are collaborating on this.

Stan Cunningham.—I'd like to say (and this goes back to what Mark said) that even if they write the outline and everyone knows how to collect the data, and we all go out and do excellent research on stress, you are still going to find so much variation between populations. There is still going to be those populations, Mark, that respond better to certain human, unnatural stresses, than sheep at Anza-Borrego. I hear what you're saying and it is an excellent point, but I don't know any way around reporting that sheep can cross a highway at will, or inhabit a park, and are not afraid of it.

Vern Bleich.—I deal with BLM managers and bureaucrats also, but I think we do ourselves great disservice if we attempt to compromise excellence in science in order to facilitate a bureaucrat's desires. I do not think we can afford to do that as wildlife managers and biologists to give somebody else an excuse to make a decision. I think we have to strive for excellence. To get out of the lab and out on the ground and seeing what's going on is great. But we just do not want to see what's going on, we want to do it in a context where we can evaluate what's going on.

Walter. *Boyce.*—Any other comments?

Mark *Jorgensen.*—Just one. If the bureaucrat's wheels are moving, I fully support all the scientific research. I just say that we should leave here today with a consensus, like Rob says. When somebody calls and asks me if vehicles are beneficial to bighorn and I say I don't believe so and they call John and he gives them a different answer and Dave gives them a different answer, then these people have a lots of cracks in the wall. I agree we shouldn't compromise science at all, but those big bureaucrat wheels just keep moving along.

Dave *Jessup.*—Yes they do. In a number of court cases, experts don't agree, so we'll do "X" and that usually means we'll do whatever is politically or financially most beneficial.

Walter Boyce.—And we don't agree because we don't understand the phenomenon adequately.

Rob *Ramey.*—We can not extrapolate from 1 population to others due to genetics or habituation, but potentially what we could do is take some measurements within a population, which would allow us to predict future responses to that population. Then when land managers are faced with use in an area, we could say, well, in another population we do have response. We can't do a direct comparison, so let's study the problem here.

Walter. Boyce.—Mark, if I can ask you a question. What would you like to come away from this meeting with? You seem to want a consensus. Would you like a statement from the DBC, perhaps from the technical group, that gives you something that you can go to your administrators with?

Mark Jorgensen.—I do not want to have to re-invent the wheel in each subgroup or subpopulation. We had to re-invent the wheel for every burro versus bighorn population. I think we wasted a lot of time and a lot of money. Maybe we got some good science out of those areas. But when I say there are 800 burros causing problems with bighorn sheep and they say "prove it," I would love to be able to say "Death Valley" or "China Lake" or wherever. I don't need to prove it all over again. We just need to understand that it is not something we can all put our finger on, but we do agree whether we use the word "stress." Like John said, we know that this displaces sheep, we all agree with that, and that's what we say when the public calls us on the phone and asks our opinion. We should go out of here and say we don't agree on the terminology of stress, or maybe even the concept and where it leads, but is it beneficial to bighorn sheep in general, or is it not beneficial.

Mike Hamen.—Just quickly, I think that we can all agree that any stimulus that a sheep recognizes as being predatory, i.e., a vehicle, person, airplane, or anything that it recognizes as being predatory, could have a negative impact. So, as a manager you look at a potential disturbance or stimulus and think about how the sheep recognizes that, realizing that if that stimulus occurs regularly, they can habituate to it in almost every case.

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WHAT IS MINIMUM VIABLE POPULATION SIZE?

Moderator: Paul R. Krausman, University of Arizona, Tucson, Arizona
Panel: James Bailey, Colorado State University; Vernon Bleich, California Department of Fish and Game; Don Armentrout, Bureau of Land Management; Rob Ramey, Cornell University

Paul Krausman.—I will begin this discussion with a few introductory comments, and then each of the speakers will give a short presentation. At the end of each presentation, questions can be addressed.

The concept of minimum viable population size (MVP) is becoming more important to management agencies and biologists as they are charged with dealing with more species; especially those with small populations. What is a MVP? Land managers are asking the question and the information that is needed to determine MVP has very serious implications from a theoretical standpoint and from a management standpoint. J. Berger (1990) provided a service to biologists interested in large mammals by presenting information on the persistence of different size populations of mountain sheep and left us with some guidelines based on empirical data that can at least be used as a starting point to discuss the idea of MVP for desert races of mountain sheep. There are various definitions of MVP; a definition I would like to use as a starting point for discussion is this: for a population to be viable it should be able to maintain itself without significant manipulation over an agreed upon time frame with a certain degree of certitude. This definition is somewhat loose. but it is a definition that can be used bv managers and can be agreed upon for different populations. To determine what a viable population is for any given population, we are going to need to be able to calculate a probability of extinction. When we start looking at the data that are necessary to calculate that probability of extinction, we find that we are going to need, at a minimum, information on distribution of the species. Many of the species that agencies are working with now are of concern because even simple distribution information is not available. Census data are also needed to determine a MVP. But censusing techniques, even in 1991, are very subjective. We also need a tremendous amount of information on the demography of the population that we are working with: productivities, recruitment, generation times, survival values. Again, those data are difficult to obtain. We also need information on the importance of the stochastic events. Trying to get information on events that we can control is difficult enough; trying to get information on random events is almost impossible, yet those are data we need to establish MVP.

We also need information on the genetics of the population. How do we get all those data available? Once obtained we have to put them all together and see how they fit into the population and see what needs to be manipulated and how the population should be manipulated. I think for the most part, we're probably not going to be able to obtain all those data, except for some species for which we have a tremendously large database. When species have been studied extensively we can at least come to grips with some of these values to establish a probability of extinction. But for the most part, I think we are going to have to look at MVP from a qualitative point of view and not a quantitative angle. This is similar to a concept that A. Leopold (1933) raised when he wrote about how to deal with population size from the standpoint of management. He wrote about using life table information that was not available at the time, just as we do not have a lot of the information needed to calculate MVP. Leopold (1933) used those data that were available and calculated a life equation. From the equation he made generalizations to come up with some decisions about the population of interest. I think we are in a very similar category today in dealing with MVP. With that, I would like to go ahead and start with Rob Ramey and have him address the issue of genetics. He has several comments that he would like to make. After his presentation feel free to ask questions.

Rob Ramey.—Thank you, Paul. The first issue I would like to address is: What is a population anyway? Considering the subject of our panel discussion today, I think that we need to seriously consider the criteria that we use to define a population. Traditionally, a population would be defined as the animals inhabiting one mountain range, isolated or semi-isolated from groups found in other mountain ranges. However, from a genetic perspective, this definition often becomes unworkable. The reason is that sheep ignore this definition all the time. It is the patterns of their movements and matings within or between mountain ranges that really define a population. Bighorns tend to ignore boundaries on maps as well as our preconceived definition of population. Our job therefore is to infer how the sheep have defined their populations, whether they be isolated subgroups within a mountain range or metapopulations, several populations that are linked by gene flow between mountain ranges.

There are several ways that we can infer the genetic structure of bighorn populations. First, direct measures of movements and migrations have come from observations and radio collar data. Vern Bleich has talked about some of the work in the Mojave Desert studying movements of bighorns between mountain ranges. The results obtained so far, suggest that groups of bighorns inhabiting these ranges are probably genetically "linked" by the mating activity of males that move between mountain ranges. Therefore, the term "metapopulation" is perhaps a better description of the genetic structure of bighorns in this region than our previous definition of population. A second, although indirect, way to infer the genetic structure of populations is through the study of patterns of genetic variation in the genes or gene products. Some of the work that Dave Jessup and I discussed yesterday on patterns of variation in proteins and mitochondria1 DNA can be used to estimate the extent of migration or gene flow between mountain ranges in the past. So, let's say that we can have a workable definition of population but that our use of the term depends upon what the sheep are doing in the wild.

Assuming that there are enough sheep in a "population" to withstand environmental fluctuations, such as a severe drought, then we can begin to concern ourselves with genetic management. From a MVPS perspective, my first genetic concern is the avoidance of inbreeding depression. Inbreeding depression can predispose individuals to disease or reduce the viability of offspring. Geneticists generally agree that this is due to the fixation of rare, deleterious alleles within a population. In large populations these deleterious alleles are kept at a low frequency due to natural selection. In a small population, there is a higher probability of two copies of these deleterious alleles coming together. Also, chance has more to do with their fates in the population than natural selection, resulting in a population of reduced fitness. Increasing population size and resorting gene flow between populations are means to control this potential problem.

My second concern is the long-term maintenance of genetic variation within populations. Variation is important in maintaining the potential for bighorns to adapt to a changing environment, for example to a new disease. For populations to persist, they must harbor sufficient genetic variation to respond to forces of natural selection. In the conservation literature there has been much discussion of how to maintain this long term potential within a population, or a metapopulation. Often times we read that the effective population size must equal 500 individuals for there to be a balance between the loss of genetic variation by genetic drift, and its replacement by mutation and recombination. An effective population size is something very different than the real population's size indicated by your census data. It is an estimate of the rate at which genetic variation is being lost in a population due to genetic drift (random changes in allele frequencies). This allows us to use population genetic models to make predictions about how populations will change genetically in the future. These mathematical models have various simplifying assumptions. In order to meet ihese assumptions with our data, we must make a conversion. Basically, we need a common denominator by which to compare our real population with the theoretical population used in the models; i.e., the effective population size. Specifically, an effective population size is the size of a theoretical population that will have a rate of inbreeding comparable to that of a wild population.

There are two different ways to estimate effective population size. First it can be estimated from the number and sex ratio of breeding individuals in a population. For example, if 1 or few males are mating with many females, then the effective population size would be greatly reduced. The second method, appropriate to populations that have undergone numerous fluctuations in size, uses long-term demographic data to calculate the harmonic mean of the population. Population bottlenecks have severe effects on the effective population size and therefore the rate of loss of genetic variation within a population. The important fact to keep in mind is that the effective population size is most often lower than the real population size. Mistakes are often made in interpreting the literature and failing to distinguish between effective population size and census size.

You may often hear that a minimum effective population size of 500 is needed to maintain long-term genetic variation in a population. This seemingly magic number is based on only 4 data sets from the study of quantitative or continuous characters in corn, maize, and *Drosophila.* It is described as the minimum effective population size under which an equilibrium could be maintained between the amount of additive genetic variance lost through genetic drift and the amount replaced by mutation. How good is that estimate? If anything, it's an underestimate but it is the only estimate that we currently have to work with.

If we suspect that there is potential deleterious inbreeding occurring in a population, or that a lack of genetic variation in a population may be leading to reduction in fitness, how can we measure that directly in the wild? We have direct measures for estimating population fitness: viability of individuals, productivity, and recruitment of offspring. These parameters however, are dependent upon both genes and environment, the effects of which are difficult to discriminate between at the population level. Unfortunately, for most species, there is no direct correlation between level of genetic variation in a population and its chances for survival.

Other potential indicators of reduced fitness are the continued low viability of offspring in a population and abnormalities in sperm morphology or mobility. These approaches have been applied to the study of inbred cheetah and lion populations. There is also another metric that I would suggest that some of us start looking at, a metric called fluctuating asymmetry. Most vertebrates have a high degree of bilateral symmetry, in other words, the right and left sides of the body are usually symmetrical. In populations that have become highly inbred, presumably due to the fixation of rare deleterious alleles, we often get deviations from this bilateral symmetry in various characters. Skull measurements are the most commonly used characters in studies of fluctuating asymmetry. It can provide us with an index of some morphological effects of inbreeding for both individuals and populations.

So, just to recap, if we have enough sheep in a population so that we do not have to worry about immediate extinction, then we have room to think about the genetic concerns. Avoidance of inbreeding depression and the long term maintenance of genetic variation within populations should be our major concerns. We also have tools that allow us to determine population structure and to measure fitness and inbreeding depression in wild populations.

Paul Krausman.—Are there any questions from the audience for Rob?

John Augsberger.—A lot of our sheep populations have resulted from transplants, starting with 25 to 50 animals. In terms of the bottlenecks, what does this do to an effective population size?

Rob Rarney.—It can greatly reduce it. Jim Bailey has some empirical data on the result of translocations and small population sizes.

Jim Bailey.—Colorado has many bighorn populations that began with 15 to 20 animals. Moreover, in many such small transplants, the sex ratio wasn't even. (This would further reduce the genetic effective population size.) One herd, in Dinosaur National Monument, began with only 3 males. I believe that one was a yearling, and two were lambs; so all 3 may not have survived to breed.

Rob *Ramey.*—Yes, it does, quite a bit. It's basically a sampling problem. Out of an original large potentially polymorphic population, where there is a lot of variation, you are sampling some subset of it. It's equivalent to reducing the population size of that original population a great deal. If you do translocations and there is potential movement between mountain ranges, then you certainly are offsetting some of those potential effects. But one point I want to caution you on, is that reduction in genetic variation within populations does not always lead to inbreeding depression. We have some organisms out there, naked mole rats for example, that are homozygous for nearly every genetic marker looked at, even very rapidly mutating loci. These animals are genetically identical, but they seem to be doing well in the wild. It is possible that they are adapted to that sort of inbreeding and that deleterious alleles are purged from the population as a result.

Jeff Jaeger.—Now on the same question. If you take a random sample of 25 animals from your original (large) population, and you put these 25 animals in a population that increases rather quickly, it is not necessarily true that your population will lose a large measure of its genetic variability. It depends on how you sample, how large your introduction is, how long that population remains in the bottleneck, and how quickly it expands.

Rob *Ramey.*—Good point, but how often do we get a chance at a totally random sample?

Jeff *Jaeger.*—That depends; i.e., if you're dropnetting on top of a group and taking 25 animals from one dropnet, I would assume that the sample would be less random than helicopter netgunning individuals from across the mountain.

Rob *Ramey.*—Good point.

Andy Sandoval.—I want to interject a comment. New Mexico's first successful transplant of mountain sheep took place in the Sandia Mountains east of Albuquerque in 1939. The founding population consisted of three sheep, one ram, and two ewes. That population was subsequently hunted for about 15 years and it served as a source of transplant materials for sheep throughout the state. So again we are talking about a founding herd of 3 individuals: 1 ram and 2 ewes.

Rob *Ramey.*—Exactly, that is why I include qualifiers in everything I say. There are always exceptions.

Jim Bailey.—Furthermore, you took only a sample of the genetic diversity in a population of Alberta sheep. While in the Sandia Mountains, some of that diversity may have been lost from the small population. And then you took another sample of the remaining genetic diversity in each subsequent transplant. I have called these subsequent transplants "dilution transplants." Each time you take a successive transplant, you are diluting the gene pool. We have double-dilution transplants in Colorado. These herds aren't doing well, but it is not clear that inbreeding is their problem.

Rob *Ramey.*—That is why I say, it doesn't always lead to inbreeding depression or loss of viability but that we should be conservative. We have some measures of viability, so perhaps some populations can be monitored for these parameters. Yes, some animals seem to do just fine, look at northern elephant seals reduced to 12 individuals but there are over 23,000 right now. Some organisms can make it through bottlenecks, but it is again the question of probability of long-term survival and potential for adaptation to a changing environment in the future.

Paul Krausman.—You mentioned that one way to measure genetic quality in a herd was with fluctuating bilateral asymmetry. Can you give us some examples?

Rob *Ramey.*—Most of this work comes from Fred Allendorf and Robert Leery of the University of Montana, working with inbred fish stocks. Also, Robert Wayne of the National Cancer Institute researched the causes of fluctuating asymmetry in cheetahs. The strength of all of these studies was that they has several measures of fitness and genetic variation. They looked at genetic variation expressed in numerous proteins, at the levels of fluctuating asymmetry. Also, in cheetahs, they looked at the production and abnormalities of spermatozoa. So by itself, fluctuating asymmetry is not a useful measure, but when you compare it to several other variables it can become useful. Nobody has used this approach with sheep, although John Wehausen and I are talking about starting it this summer.

Paul Krausman.—Our next speaker will be Don Armentrout.

Don Armentrout.—The Bureau of Land Management's (BLM) view of viable populations is expressed in our Rangewide Plan. This is a publication that we published in 1986 to evaluate and prioritize some of our work. We used as a definition of viable populations: "one that is self sustaining with minimal demographic to genetic intervention over the long term." We describe or evaluate habitat as to its ability to support a viable population in this publication by the, "historic presence of a viable population where the cause of the decline to non-viable levels was either non-habitat related, or if habitat related has been remedied." We have on the Public Lands many areas of what we feel was viable population habitat on which (primarily through grazing and subsistence hunting by miners and settlers) the populations were depleted to the point where they were almost exterminated. But, the habitat is still capable of holding a viable population. Other criteria for viable population habitat is the presence of a viable population. This means that we consider the population that is present to be viable (I'll get to that number in a minute).

Another criterion could be large areas of suitable habitat. To evaluate empty habitat we use carrying capacity calculations that indicate that the habitat would support a viable population based on habitat data analysis and an accepted habitat evaluation procedure. This is where we sometimes fall a little short. We fail to take into account, especially on forage, that there are competitors out there. Perhaps the niche that we feel will hold bighorn sheep is already filled. We are running into this in the district I work in now. We have a concern that perhaps we are looking at some competition we weren't looking at before from deer.

In California we came up with 18 areas that we consider Category II habitat. These are habitats capable of supporting viable populations, but just don't have that number in them now. We also indicated 9 areas of Category I habitat that support viable populations. This was taken, in part, from the California Desert Conservation Area Plan. We have started thinking that some of the habitats we consider viable may be fragmented habitats and mountain ranges should be joined. This is nothing new to us. In 1978 known migration routes provided by the California Department of Game and Fish, were shown to indicate what we consider to be fragmented habitats. We could basically say, if we went with the effective population point of view, that perhaps we ought to split southern California into two major population areas. In the management scheme of the world, that is not a reality. So we have to look quite hard at what fragmentation is and then pick those areas well. Vern and Paul have done a pretty good job of defining some of that.

Now we get to the part where all of us that read this book get excited. A bighorn herd of approximately 100 sheep, plus or minus 20% with normal sex and age structure (we always forget to look at that part, we focus on the 100), will be considered a viable population. Initially the Rangewide Plan came out with a flat number, which was attributed to Geist, of 125. Many of us attacked that number, but we lost sight of important criteria when we attacked: e.g., "able to sustain a population of good genetic base and demographics over a long term." This is not over the 20 years of our careers, but over a long term. We received other data, new and existing data, and personal communications from experienced people, such as Dick Weaver, who had already looked at these populations in the long-term. Using these data, we came up with the number 100 plus or minus 20% based on the experience of seeing smaller populations, which no longer existed after 30 years without intervention, reintroduction or supplemental augmentation. As data gets better that number may change.

Many feel this number is set in granite and will not change. We are already talking about changing it based on fragmentation and use the reality of habitat in the guidelines. The number in use is not based on something we pulled out of the sky. We used the data we had available at the time. I believe Joel Berger's work helped support the 100 ± 20% but we continue to review new information.

I'll leave my presentation at this point and let you ask questions.

Vern Bleich.—Don, did I interpret your statement correctly that said the Bureau's management strategies are not realistic if we look at the desert as a whole?

Don Armentrout.—No, what I said is that, in the context of multiple use management, it would be highly unreasonable to draw two lines in the desert and say that these are fragmented habitats from Ridgecrest, California down to Barstow which should be looked at as one huge fragmented habitat.

Vern Bleich.—I guess I would take the approach of an advocate for mountain sheep and argue that in the management scheme we cannot afford to take that approach. We need to look at deserts as ecosystems and be strong advocates for the long-term conservation of mountain sheep. If not, we are giving up before we even start.

Don *Armentrout.*—No, we're not giving up before starting. We are looking at the entire desert as an ecosystem. But there are certain distances between suitable habitats that may become too far for even a staunch advocate of bighorn sheep (which most of us who work with sheep at the Bureau are) to consider as fragmentation of habitat. To say: "Yea, by God they'll travel that 80 miles between mountain ranges regularly just because it's fragmented habitat." Looking at it realistically we should say: "Is there really the information to say that?"

Rob *Ramey.*—One think we could do is collaring to see if there is movement between those areas, but that would take several years to get that data set up.

Also, another thing I'd like to say is it's not just mountain sheep we are looking at here. In regions maintaining migration corridors there would be secondary benefits to other species, e.g., deer and mountain lions.

Jim Bailey.—Don, about the figure of 100 ± 20%, I once had the impression that the Bureau of Land Management was going to use a larger number for a viable population. Was that a biological compromise, or a political compromise?

Don Armentrout.—Because I'm not one of the two authors of that, I can't say it was totally political or totally biological. I will say it was a decision made based on the information they had at hand at the time. The highest number I have ever heard kicked around was 125.

When people questioned it, they talked to other people and found that what they felt was the lowest possible level, before you start loosing sheep populations, is approximately 100 ± 20%. So, if you have 120 sheep, you have a viable population within reason, or if you have 80 sheep you are right on the verge of a viable population. I don't feel it was totally political, I feel it was based on some good discussion between biologists. There wasn't a manager involved at all in the development of this plan.

Rick Wade.—I was in on some of the decisions made by Cooperider and his associates. Much of their work was based on the work of Brussard in Montana. That 100 ± 20% came out of a training session that Brussard gave in Phoenix. I would also like to pursue your idea about fragmented populations. If we consider what Rob said about metapopulations, you may have a series of metapopulations within those fragmented populations. As long as you don't disrupt the possibility of migration between these fragments, you have a set of metapopulations which would still satisfy some of our considerations.

Rob *Ramey.*—Maybe we should talk about viable regions.

Don Armentrout.—That is basically what I was trying to say. We understand and recognize that there are metapopulations, and there is fragmented habitat. However, to draw a line around a huge, huge area where there may be some question of validity of that fragmentation, would not be in the best biological interests.

Jim Bailey.—I don't have any special expertise in the area of population genetics, but I did review the historic records of Rocky Mountain bighorn sheep herds in Colorado (Colo. Div. Wildl. Spec. Rpt. 66, 1990). Among other topics, I addressed the issue of small populations in that review.

We are searching for the minimum number of bighorn sheep that will allow a population to (1) avoid inbreeding depression; (2) avoid stochastic fadeout; and (3) maintain genetic diversity to allow for continued evolution. Rob Ramey has already addressed these topics.

Regarding inbreeding depression, Franklin (1980:140) and Soulé (1980:160) somewhat arbitrarily selected 1% as the maximum level of inbreeding that we should "allow" in managed populations. We do not know how well this level applies to bighorn sheep. However, several recent assertions that 100–150 sheep are needed to avoid inbreeding depression are based upon that arbitrary assumption.

What is the minimum population necessary to avoid stochastic fadeout? We may theorize that a larger population will be necessary (1) in a relatively poor habitat; (2) in a more monotonous environment where there are few alternative habitat resources for sheep to use in responding to local impacts from weather or human disturbance; (3) in a more variable environment with frequent droughts or other severe weather; and (4) with an isolated herd for which demographic support from immigration is unlikely. Berger's (1990) analysis of extinctions in small herds did not separate effects of inbreeding depression from those of (stochastic) environmental change. He concluded that herds less than 50 are not viable, and that herds less than 100 may be non-viable.

The minimum population necessary to allow continued evolution of vertebrates has been estimated at about 1,500 (based on Franklin [1980: 147] and evidence that "effective population size" is ⅓ of actual population size in bighorn sheep, after Fitzsimmons, MSc. Thesis, 1992, U. Wyo.). However, Thomas (1990) suggests "several thousand" may be necessary.

In reviewing the Colorado data, there were no really good tests of whether or not we have genetic problems in our populations of bighorn sheep. There no experiments testing for inbreeding depression. However, comparisons of populations that *should* be more diverse genetically vs. populations that *should* be less diverse were possible. In these comparisons, there was no control over environmental factors that may also have affected bighorn herds.

Supplemented herds did not perform better than did non-supplemented herds. We had multiple-source, single-source, genetic dilution, and genetic "double dilution" transplants. The former should be most genetically diverse; the latter should be least diverse. In these herds, transplant success could not be related, statistically, to genetic diversity of transplant stock. However, there were very few herds in the extreme categories of genetic diversity; so it was a weak test of the hypothesis. Among bottlenecked herds, that got down to fewer than 50 animals: 6 went extinct. However, environmental factors causing the decline to 50 sheep could also have caused the extinctions. Five bottlenecked herds have persisted for a long time. A herd started with 15 sheep in Mesa Verde National Park, has never been estimated at more than 50 or 60, and has persisted over 45 years. Four bottlenecked herds recovered to more than 50 sheep; 3 others to >100 sheep. Many small transplants have been no more/no less successful than have transplants with larger numbers of animals.

This analysis of the historic record in Colorado suggests that inbreeding depression is not a severe, or fast-acting, problem in bighorn sheep. If it was, I should have detected more in the analysis. Despite what Sausman (1984) published on inbreeding bighorn in zoos, perhaps bighorn have a low genetic load of deleterious genes, and in fact are quite resistant to inbreeding depression. Perhaps due to the social breeding habits of bighorn, they have always been inbred. Persistent inbreeding could have exposed deleterious genes to natural selection, eliminating these genes. If this is correct, Franklin and Soulé's standard of 1% inbreeding per generation may not apply well to bighorn.

From what I have seen, stochastic fadeout of small populations of bighorn sheep womes me more than does inbreeding depression. In sheep, small populations may mean high predator-prey ratios. If predator numbers are supported by a multi-species prey base, predation could drive bighorn numbers to extinction. Small bighorn herds produce small group sizes, with reduced benefits from group vigilance and consequent greater risk of predation. Small groups are also less likely to venture far from escape terrain seeking forage. They may lose learned traditions for migrating among seasonal ranges, with consequent loss of options for responding to environmental variation or to human harassment.

Metapopulations of several interacting herds have been proposed to alleviate some of the demographic and genetic problems of small herds. However, the management of metapopulations will be complex, requiring cooperation of several, often very different, agencies and landowners. The idea of a metapopulation implies discontinuous habitat and there may be severe habitat security problems in movement corridors between herds. These must be dealt with. Also, the problems of small herds, mentioned above, persist in the small herds within a metapopulation. Our management problems do not evaporate just because we change bookkeeping methods and combine herds into metapopulations.

Another management criterion for minimum population size may be biased upon management costs and benefits from small populations. I suggest there are a lot of "fixed costs" in managing a herd. Costs for monitoring, habitat manipulation, treating disease, and habitat protection may be similar for small or large herds. So per-animal costs increase as population size declines. One may argue that small herds of bighorn are very valuable, especially if they are indigenous. However, some values decline as herd size declines. For examples, we do not hunt small herds and there are few animals for wildlife-viewing. Anyway, the cost-benefit ratio may be high for small herds. I have to ask, "How many herds can we manage well with our limited resources, and how do we set priorities for using limited resources?" In Colorado, we have about

70 bighorn herds now and we are transplanting to establish new herds every year. I suggest we have many herds that aren't managed well already. Maybe limited management resources will bring greater benefit if they are used primarily for a small number of the larger, more productive herds, rather than spread thinly over so many herds. Is there an end to Colorado's transplant program? How many herds do we ultimately want, and how many will we be able to manage? No one has asked these questions; but eventually they must be answered.

Lastly, with our focus on viable populations, we must not neglect the preservation of habitats for conserving bighorn sheep in the long term. Do we have adequately secured habitats to preserve all the ecotypes of bighorn? Seven ecotypes of bighorn might be populations in the Mojave, Sonoran, and Chihuahuan deserts, the Sierra Nevada and Rocky mountains, the Great Basin and east of the Rockies in badlands and riverbreak habitats. Biological reserves for bighorn, in order of generally decreasing security, include: (1) national parks, monuments, and preserves; (2) national wildlife refuges; (3) national recreation areas; (4) wilderness areas outside the above lands; (5) federal multiple-use areas managed by the BLM and Forest Service; (6) state parks, game ranges and forests of highly variable security; and (7) military reservations. Categories 1–3 generally provide habitats that are politically most secure from human impacts, as I judge the future. Anza-Borrego State Park in California is an exception.

We have several of these more-secured reserves with bighorn sheep in the Mojave Desert (Desert NWR, Death Valley NP, Joshua Tree NM, Lake Mead NRA, Anza-Borrego SP) and in the Sonoran Desert (Organ Pipe Cactus NM, Cabeza Prieta NWR, Kofa NWR, Havasu NWR). Likewise, bighorn ecotypes appear secure on the Colorado Plateau (Arches NP, Canyonlands NP, Capitol Reef NP, Colorado NM, Dinosaur NM, Flaming Gorge NRA, Glen Canyon NRA, Grand Canyon NP, Zion NP) and in the Rocky Mountains (Glacier NP, National Bison Range NWR, Yellowstone NP, Grand Teton NP, Rocky Mountain NP, plus an abundance of multiple-use lands).

In the Great Basin, bighorn occur in Hart Mountain NWR, they may be reintroduced into Great Basin NP; and they occur on numerous BLM lands. In the Sierra Nevada, there are bighorn in Sequoia-Kings Canyon NP, and there is a struggling transplant in Yosemite NP. The long term habitat security for two ecotypes of bighorn needs further scrutiny.

East of the Rocky Mountains, the badlands ecotype of bighorn occupies four secured habitats (Charles M. Russell NWR, Bighorn Canyon NRA, Theodore Roosevelt NP, Badlands NP). Most or all of these herds are small and deserve special attention.

In the entire Chihuahuan Desert, we have only the tiny San Andres NWR with bighorn sheep. It is a small refuge, surrounded by military lands and recent evidence suggests it is not an adequate biological reserve for the Chihuahuan ecotype of bighorn. There are a few populations of bighorn in southwest New Mexico, on BLM lands of questionable long-term security. In Texas, sheep are mostly on private land; there are no sheep in Big Bend or Guadalupe National Parks. The lack of secure biological reserves with bighorn sheep in the Chihuahuan Desert should concern us most of all.

Paul *Krausman.*—Jim, one question about the Chihuahuan Desert. Are you aware of what the historic distribution of sheep in the Chihuahuan Desert was in Texas?

Jim Bailey.—According to an old Texas Game, Fish and Oyster Commission report, there were bighorn along the Rio Grande and in the Chisos Mountains of Big Bend National Park. The last wild sheep were in the Diablo Mountains around Van Horn where Texas is trying to re-establish them. There were bighorn in the Guadalupe Mountains. How abundant these populations were is difficult to interpret from the writings of the time.

Vern Bleich.—Jim, I appreciate your recognition of the importance of parks, park lands, and recreation areas for the preservation or conservation of wild sheep habitat. I would argue, however, that parks do not necessarily provide for the conservation of mountain sheep themselves. An objective of national parks is to maintain the integrity of natural systems. Extirpations or extinctions occur under natural circumstances, but what does the recognition of viable sheep habitat with a naturally occurring extirpation do for the continued maintenance of viable mountain sheep resources?

Jim Bailey.—The Park Service policy is to retain, to the extent possible and practical, natural ecosystems including all the species and natural processes that would have occurred, had not European man altered those systems. Natural processes might include periodic fires, or local extirpations. If the park is large enough, it should maintain populations despite local extirpations. I don't know of a case of a threatened sheep herd in a park; perhaps you do.

For example, wolves in Isle Royale National Park may go extinct; but extinction is not unexpected according to island biogeography theory. Maybe the natural introduction of wolves to Isle Royale occurs once every 400 years or so; and the populations persist only 60 to 80 years. If that is the case, extinction of wolves is a natural process on Isle Royale, and the Park Service should let it happen.

Of course, fire is a natural process that should be influencing wild sheep habitat in national parks. We have found it difficult to allow natural fires in parks (and wilderness areas) and we may have to simulate natural fires with prescribed bums, especially if we have a small park in which the frequency of fires is unnaturally low. I believe the Park Service is moving in this direction. Extirpation of a park bighorn herd due to suppression of natural fires would not be a natural event.

Dave *Jessup.*—Jim, you asked for an example of a bighorn sheep herd in a national park threatened or lost due to factors, which the Park Service couldn't address. I would say that the Lava Beds National Monument is a good example. A very small national monument abutted by Forest Service Land and BLM Land, sheep were not free ranging, they were in a very large pen, nose-to-nose contact with domestic sheep—the sheep herd died off. I think it's a good example of not being able to manage a population because of the geographic size of the park and the incompatible, excuse me for saying incompatible, but the somewhat difficult land-use patterns associated with it. I think another thing that is difficult within the parks is the generally stated philosophy that diseases are a natural phenomenon—some are, some may not be. Certainly introduced viruses and bacteria that weren't existent in North America when the ecosystems evolved may not be natural phenomena. The refusal to either manage populations in the fact of that, or to recognize that all those organisms may not be part of the existing natural flora, makes it difficult to see that parks are a real stronghold, something that we have ultimate confidence in.

Jim Bailey.—I think some parks are our best strongholds, in contrast to what you say. I said that parks should be as natural "as possible and practical." Admittedly, some parks are too small. For example, Pipestone National Monument is far too small to contain a tallgrass prairie ecosystem, complete with bison and prairie chickens. All that is possible is a small patch of tallgrass prairie vegetation. That's the best we can do. Apparently Lava Beds National Monument, with its adjacent land uses, cannot have a free-ranging natural bighorn herd.

Regarding diseases—natural outbreaks should run their course in parks. This allows for evolution of both the hosts and the disease organisms; and evolution is a natural process.

Dave *Jessup.*—But evolution takes place over geologic time and man's activities don't necessarily take place over the same time course.

Jim Bailey.—I'm not sure what your point is there.

Dave *Jessup.*—Animals don't evolve relationships with organisms that they are introduced to in a relatively short period of time.

Jim Bailey.—Introduced disease organisms are not natural in the park. So if the pinkeye outbreak in Yellowstone National Park had been judged to be due to contact with domestic sheep outside the park, I'm told there would have been control of the disease. No one judged that to be the case; so the disease was allowed to run its course. What is natural, and what is not, will always be arguable, of course.

My point is that for conservation biology we would like to have large examples of all the major ecosystems of North America within a reserve system. (This becomes less and less likely as our population grows.) The Park Service is the agency that fits this model most closely. However, there are ecosystems that are missing; some parks are certainly too small; and I don't think anyone would have considered bighorn inside a pen at Lava Beds National Monument to be a natural population. Perhaps penned bighorn were the best we could do; I'm not familiar with the intention there.

Dick Weaver.—I am pleased that he brought out the point of minimum size because we tend to overlook that when we talk about minimum number. I want to address his idea of the national parks and the national wildlife refuge as good examples. I think the best examples are the military areas. They are large, and their land use is such that they have the thriftiest populations in the desert.

Jim Bailey.—I guess my position is that the military's policies and priorities can change in the long run. I known there is concern about the impacts of military activities, including low-flying aircraft, on national wildlife refuges that are surrounded by or near military reservations.

Paul Krausman.—I'd like to present our last speaker now.

Vern Bleich.—Thank you, Paul. I have some slides I'd like to use to emphasize the points I'm going to make. However, while the projector is being set up, I want to comment on Jim Bailey's use of Isle Royale National Park to illustrate natural extinctions, as predicted by island biogeographic theory. National parks effectively are islands but, in many cases. still are surrounded by similar types of habitat. Unless parks are managed, in conjunction with surrounding habitats, to perpetuate the existence of functioning ecosystems, national parks in and of themselves cannot provide for the needs of most species of large mammals. This situation dictates the need for cooperative, interagency efforts to insure that large tracts of intact ecosystems are maintained in perpetuity. No single agency can do this alone; it must be a well-planned, cooperative effort.

During the recent decade, perhaps as a result of the publication of the book Conservation Biology (Soulé and Wilcox 1980), conservation strategies have been increasingly linked to an evolutionary approach. Consequently, much thought has focused on the relatively new area that I will term conservation genetics. Certainly, most of us are familiar with the northern elephant seal and the cheetah, species with extremely low levels of genetic variation thought to be linked with historical population "bottlenecks" (Bonnell and Selander 1974, O'Brien et al. 1985). There is some speculation that low genetic variation is contributing to the decline of mountain sheep in North America.

Conservation geneticists are concerned with the short- and long-term evolutionary fitness of species. A central focus of the discipline has been inbreeding, and the subsequent loss of genetic variation. Some conservation genetics models are insular in their development, due either to (1) the biology of the species, which may exhibit low vagility, or (2) the limited preserve size which a species may inhabit. Certainly, the concept of insularity has been applied to the distribution of mountain sheep, but I would emphasize that this thinking has centered on perceptions about the biology of desert-dwelling subspecies of mountain sheep (Schwartz et al. 1986, Bleich et al. 1990).

In the past, mountain sheep managers have emphasized the perception that mountain sheep now number $<2\%$ of their historical population levels, the perception that sheep are restricted in distribution to the rugged habitats of desert mountain ranges, that only a small percentage of males breed during a particular mating season, and the perception that anthropogenic barriers now preclude any opportunity for genetic migration among insular populations. Additionally, population genetics theory suggests that an effective population size >500 is necessary for the long-term viability of populations (Franklin 1980). If that is true and we are, in fact, dealing with truly isolated populations, then I cannot be optimistic about the conservation of mountain sheep in an evolutionary sense.

When one examines the distribution of mountain sheep in California, it is quite apparent that the distribution of their primary habitat is insular. However, if one examines the juxtaposition of these insular distributions, in combination with the absence of bamers to potential movement by sheep between inhabited ranges, and the heretofore unrecognized vagility of this species, it is apparent that the potential for long-term persistence of these populations remains. Indeed, movements between mountain ranges are being documented with increasing frequency, and conservation strategies are beginning to emphasize a "metapopulation" approach to the management of mountain sheep habitat (Schwartz et al. 1986, Bleich et al. 1990).

In efforts to calculate persistence rates and viability of populations, two schools of thought predominate: one emphasizes genetic problems due, in part, to the deleterious effects of inbreeding, and the other emphasizes losses due to stochastic events, such as drought. I do not wish to dwell on population genetics theory here, except to note that an "acceptable" equilibrium inbreeding coefficient of 0.2 occurs when a population effectively is panmictic (Futuyma 1979).

Schwartz et al. (1986) recently used estimated effective population sizes for mountain sheep demes in the central Mojave Desert of California to calculate that intermountain migration rates ranging from 0.005 to 0.19 migrants per generation were necessary to maintain equilibrium inbreeding coefficients of 0.1, depending on the population size of each deme. When these values were recalculated to maintain an equilibrium inbreeding coefficient of 0.2, the projected rates decreased to 0.003 to 0.08 migrants per generation. I have no reason to believe that such rates of genetic migration are not feasible, and I conclude that it is premature to dismiss any populations (demes) of mountain sheep as nonviable, if it is not known that they are isolated from other demes of this species.

The second concern over population viability revolves around demographic (i.e., stochastic), rather than genetic-related extinctions (Lande 1988). Recently, Joel Berger (1990) analyzed a number of localized extirpations of mountain sheep, and concluded that populations of less than 50 become extinct in a relatively short time. A point I'd like to make here is that many of the forces that were operating to limit mountain sheep populations 100, or even 50, years ago are no longer important decimating factors. I've discussed this with Joel, and I am optimistic that persistence rates for these smaller populations are far greater than they were for the periods that Joel included in his analyses. Consistent with Lande's (1988) tenet that stochastic events probably are of greater immediate concern than are genetic problems (even in small populations) it is my opinion that demographic factors may well have been the primary causes of the high rates of extinctions noted by Joel. Such factors probably included disease epizootics, unregulated meat hunting, usurpation of water sources, habitat destruction, and drought, among others.

This brings us back to the original question, "What is a minimum viable population of mountain sheep?" continue to view all non-isolated populations of mountain sheep potentially as viable and argue, from the standpoint of one charged with the conservation of wildlife resources, that we cannot afford to assume otherwise. I believe there is real danger that political and economic forces will attempt to misuse the existing literature, and to argue that perceived population viability should be considered when land-use decisions, that affect mountain sheep habitat, are made. For example, if a deme numbers only 30 animals, some might question its viability, and suggest that the habitat used by those animals could be put to more "constructive" uses. However, if an argument is made that the deme is part of a larger metapopulation, its potential for long-term survival becomes more obvious, and the conservation of its habitat becomes more defensible. Moreover, the potential importance of that particular deme to the viability of the metapopulation, as a whole, suddenly can be emphasized.

Thus, I advocate an extremely conservative approach to addressing the significance of mountain sheep populations, and to assessing their potential viability. My suggestions center around the following two thoughts. First, each mountain range that is inhabited by mountain sheep should be treated as one (or, in some cases, >1; Wehausen et al. 1987) demographic unit, and their potential to be part of a larger metapopulation should be recognized. Second, all mountain sheep habitat should be managed from the standpoint of a metapopulation; that is, all demes potentially within the metapopulation, and potential movement corridors between those demes, must be considered critical to the survival of the metapopulation.

By keeping these points in mind, conservationists have the potential to maintain the long-term genetic health of existing populations, to reestablish additional subpopulations (demes) via natural recolonization of vacant habitat, and to maintain the likelihood of continued divergence and long-term evolutionary change. These three points represent the highest level of protection that can be afforded to populations (Schonewald-Cox 1983). Only by successfully maintaining all subpopulations of metapopulations, through the realization that they probably are necessary for the long-term evolutionary persistence of metapopulations, will we be successful in conserving mountain sheep as a species. Let us not assume that individual populations are nonviable, just because they are small in size; instead, let's assume that they are critical to the long-term survival of the species, and afford them the protection that is warranted.

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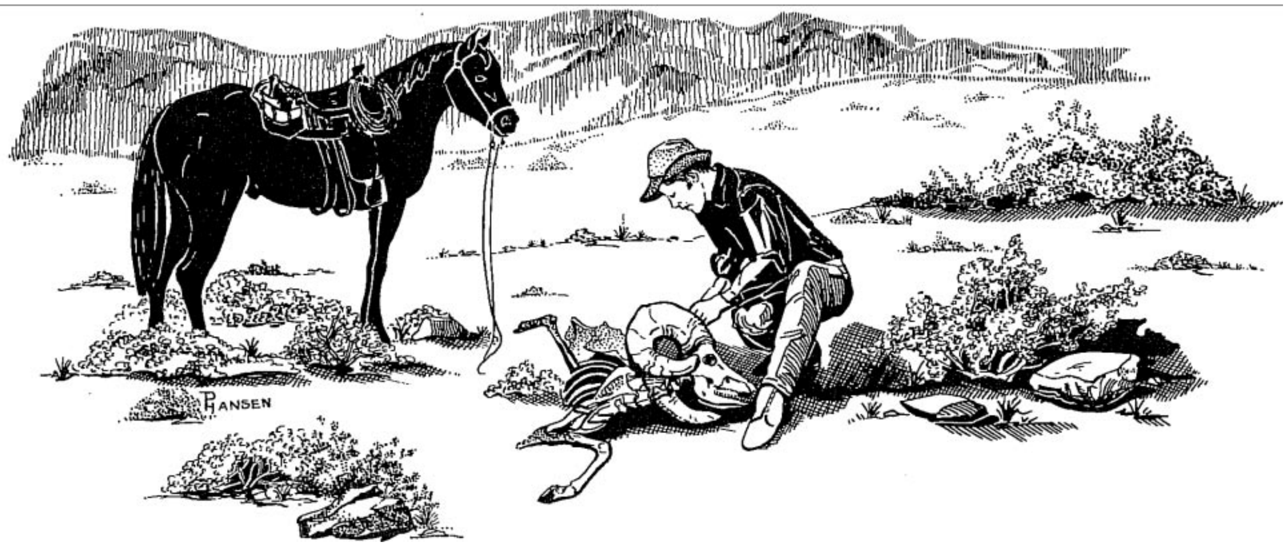

STATUS OF BIGHORN SHEEP IN ARIZONA, 1991

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CURRENT STATUS

Estimates of Arizona's desert bighorn sheep (*Ovis* canadensis *mexicana* and 0 . c. nelsoni) indicate a population of approximately 4,500 animals. During the 1991 helicopter survey biologists observed 2,125 bighorn sheep in 197 hours (10.8 sheep/hour). Survey results yield ratios of 55 rams, 31 lambs, and 19 yearlings: 100 ewes.

The Rocky Mountain bighorn sheep (Ovis c. canadensis) population, estimated at nearly 350 animals, is steadily expanding in numbers and range. Currently residing near the release sites in the San Francisco River drainage, these sheep are moving south and west into areas generally considered representative of desert bighorn sheep habitat. During 13.5 hours of winter surveys biologists observed 185 sheep (58 rams, 35 lambs, and 20 yearlings: 100 ewes).

HUNTING

Bighorn sheep permits remain the most sought after hunting permits in Arizona. There was a record of 3,734 applicants for the 83 regular season permits. This application rate represents >50 people applying for each permit, with individual unit odds varying from 5:1 to 177:1.

Due to the 1991 survey, permits for the 1992 season were decreased from 83 to 80. Two additional permits will be issued to raise funds for bighorn sheep management programs.

During the 1991 hunting season, 84 of the 85 potential hunters participated, harvesting a record 78 rams (including the 1,500th ram to be legally harvested in Arizona) for a 93% success rate. The success of past transplant efforts was illustrated with the opening of 2 new units to hunting this year. During the 1991 season 37 animals (47% of the harvest) qualified for the Arizona Trophy Book (min. score of 162 Boone and Crockett points). Of these rams, 19 (24%) scored >170 points. These scores are records for these categories.

There was a regulatory change made this year. It will no longer be required for a successful sheep hunter to "submit the entire carcass—the horns and skull intact." It will now only be necessary to bring in the head and horns intact. The Arizona Game and Fish Department (AGFD) has formalized its support for the Bighorn Hunters Clinic conducted annually by the Arizona Desert Bighorn Sheep Society (ADBSS) to better educate sheep hunters regarding hunting and ethics.

ALTERNATIVE FUNDING

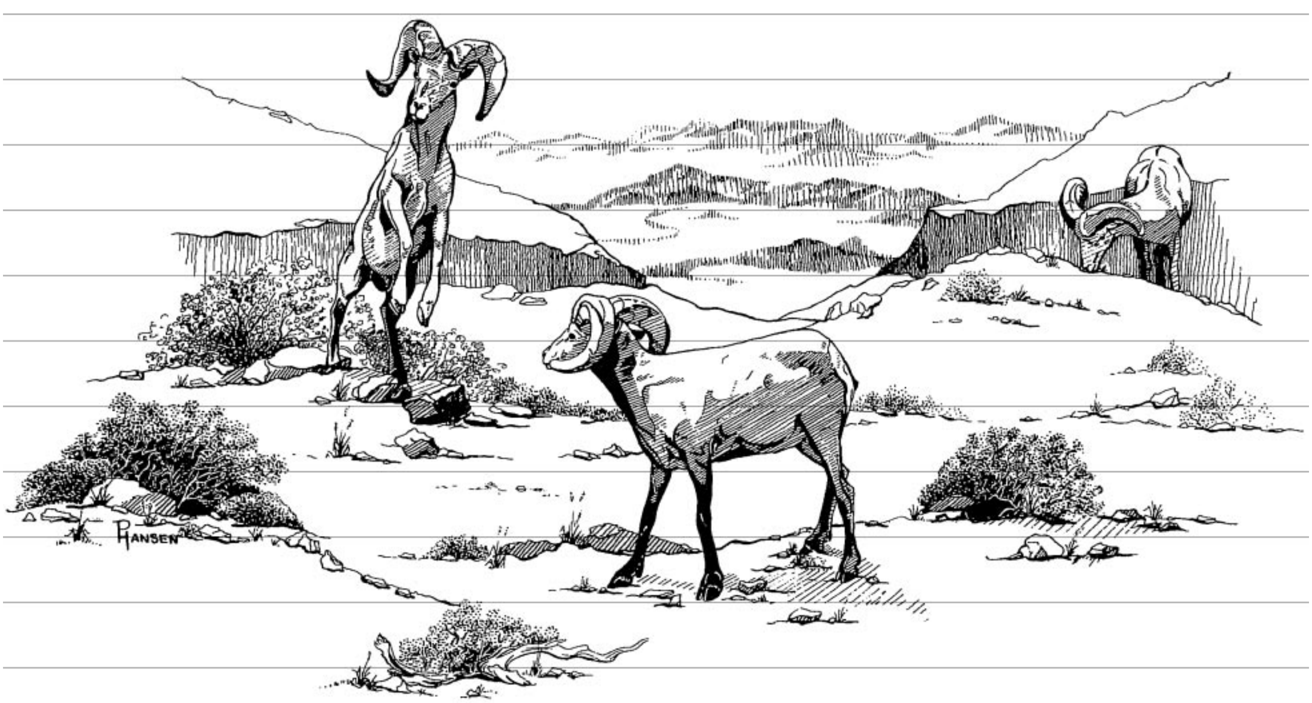
For the ninth consecutive year, the AGFD and the ADBSS have entered into an agreement whereby the ADBSS auctions 1 permit (at the Foundation for North American Wild Sheep convention) and raffles another to raise funds for bighorn sheep management in Arizona. In 1991, these permits produced >$140,000. To date, these permits have produced >$1,000,000. Arizona's bighorn sheep management program is dependent upon the funds derived from these permits.

TRANSPLANTING

Since 1980, a mean of 75 sheep have been transplanted annually, with a mean of <3 mortalities/year. In 1991, using net-guns fired from helicopters, 45 bighorn sheep (including the 1,000th caught for transplant purposes) were successfully captured and released. Colorado received 17 of the sheep for use in its transplant program. In 1991, 7 rams of ≥170 Boone and Crockett points were harvested from populations transplanted in Arizona during the 1980s.

RESEARCH

The AGFD has had several recent sheep research projects. These include survey methodology and efficiency, and movement and habitat use studies.



STATUS OF BIGHORN SHEEP IN CALIFORNIA, 1991

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POPULATION STATUS

Three subspecies of bighorn sheep recognized by Cowan (1940) occur in California: California bighorn (Ovis canadensis *californiana*; n = 325) restricted to the Sierra Nevada of eastern California; peninsular bighorn (*O.* c. cremnobates; n = 570) in the western Sonoran Desert of Riverside, Imperial, and San Diego counties; and Nelson's bighorn (*O.* c. nelsoni; n = 3,900) in the eastern Sonoran Desert, Mojave Desert, Transverse ranges, and the Great Basin Desert of Mono and Inyo counties. California and peninsular bighorn are classified as threatened by the California Fish and Game Commission. All populations of Nelson's bighorn, with the exception of those found in areas open to hunting are fully protected by state law.

LEGISLATION

Current and ongoing legislative issues certain to impact California's bighorn sheep program include state Assembly Bill 977 (Mountjoy) and the potential federal listing of peninsular bighorn. The Mountjoy bill allows the Commission to authorize sport hunting of mature Nelson's bighorn (M) in management units for which CDFG management plans have been prepared (pursuant to section 4901 of Fish and Game Code). This legislation essentially allows the Commission to authorize sport hunting of Nelson bighorn rams in several additional management units. The possibility that peninsular bighorns will be listed as threatened or endangered by the Federal government inevitably will impact future management and research on this subspecies.

HARVEST RESULTS

Since bighorn sheep hunting was authorized by the California Legislature in 1987, 5 hunting seasons have been held. To date, 38 adult rams in the 2 hunt zones (Old Dad Peak [n = 25] and Marble [n = 13] Mountains) have been harvested for an overall success rate of 93%. During the 1991–92 season, 7 of 8 hunters were successful, and 2 rams were harvested from the Marble Mountains Management Unit and 5 rams were harvested from the Old Dad/Kelso Mountains Management Unit. Unlike the previous 4 seasons, hunters did not experience any disruptions from protesters.

For the third consecutive year, the California Department of Fish and Game (CDFG) prepared and circulated an environmental document that details the anticipated environmental effects of hunting bighorn sheep. This document, through the State Resources Secretary, is intended to comply with the mandates of the California Environmental Quality Act. In the environmental document, CDFG proposes to issue 12 tags for the 1992 hunting season: 3 at the Marble Mountains (Zone 1), 5 at the Old Dad/Kelso Mountains (Zone 2), and 4 at the Clark/Kingston Mountain Ranges (Zone 3). The special fundraising tag is included in the allocations above, and the tag holder may choose any hunt zone but must designate that zone by June 1, and will be required to hunt in the designated zone. This special fundraising tag sold for $61,000 at the February 1992 Convention for the Foundation for North American Wild Sheep, an increase of $19,000 (45%) over the price paid for the 1991 auction tag.

In summary, the 1992–93 regulation changes include enlarging the boundaries of the 2 existing hunt zones (1, 2), adding a third hunt zone (3), and requiring the fundraising tag holder to choose and hunt exclusively in a single hunt zone. State law limits the number of tags issued to be ≤15% of the mature rams (≥2 years) actually counted in each hunt zone during annual CDFG surveys. For hunting purposes, legal rams are those possessing ≥¾ curl.

Animals shot during annual hunts have ranged from 5 to 13 years of age, and 11 (approx 30%) have qualified for the Boone and Crockett Records Book based on their "green" scores.

MONITORING AND RESEARCH

The CDFG continues to collaborate with several organizations in support of the Department's Bighorn Sheep Program. Detailed demographic studies continue in 9 Mojave Desert and Sierra Nevada populations, through a contract with the University of California, Los Angeles, White Mountain Research Station. The emphasis of this work has been to evaluate the demographic consequences of disease processes, harvest (from hunting and for reintroduction), predation and habitat. Additionally, a detailed demographic investigation of bighorn sheep inhabiting the Kingston, Clark, and Mesquite mountains is continuing in cooperation with the University of Nevada, Las Vegas.

The investigations of disease and demography of the peninsular bighorn sheep, in and around Anza-Borrego Desert State Park, are ongoing and an intensive population health study is being designed to supplement population estimates, distribution, survivorship, and recruitment. This augmented research will allow careful evaluation of the primary factors influencing several populations of this subspecies. This research is being conducted in collaboration with the California Department of Parks and Recreation, the Zoological Society of San Diego, and the Wildlife Health Program (WHP) at the University of California, Davis. Additionally, a morphometric analysis reexamining the taxonomic status of the 3 subspecies of bighorn sheep found in California will be conducted by collaborators from the White Mountain Research Station.

Recently completed research through the WHP includes the analysis of 10 years of disease exposure patterns in bighorn sheep from California, summarization and publication of several years of research on psoroptic scabies, evaluation of a new testing technique (kinetic ELISA) for exposure to scabies (Boyce et al. 1991), comparison of scabies mites occurring in deer (Odocoileus *hemionus*) and bighorn populations, and treatment of scabies using subcutaneous Ivermectin implants. Additionally, 2 new tick-transmitted parasites that are potentially pathogenic to bighorn sheep have been identified.

The CDFG, in collaboration with the WHP, is initiating research on the potential for transmission of infectious diseases between bighorn sheep and cattle in the Whitewater River drainage of the San Bernadino Mountains, San Bernadino and Riverside counties. This research will be conducted with the support of local livestock owners and, hopefully, the High Desert Cattleman's Association. This effort may be expanded to include a more detailed analysis of population and distribution data.

The CDFG has continued investigations on bluetongue virus (BTV), and insects that vector the disease, in cooperation with the University of California, Riverside. This work has revealed that there are many more species of blood-sucking gnats that may be capable of transmitting BTV, than originally thought. This work will continue for 1 more year with emphasis on control strategies.

Late in 1991, a collaborative effort between CDFG and the University of Rhode Island was organized. This research will be conducted in the Chocolate Mountains, Imperial County, where a graduate student will develop a detailed demographic description of that population of bighorn sheep. Those data will be used to evaluate the potential of the Chocolate Mountains population to provide stock for translocation, and to assess the potential for limited sport hunting in that population.

The CDFG Bighorn Sheep Program is also planning a cooperative study, with the Arizona Game and Fish Department, to reevaluate existing population survey methods, and to test new techniques. This research will be conducted in the Chocolate Mountains. Investigators will evaluate several survey methods under alternate scenarios of sampling, and survey method bias, consistency, and precision will be modeled. Operational costs and the use of marked animals also will be considered when evaluating the capabilities of the different methods.

The CDFG is currently preparing a proposal to monitor local bighorn populations in the Eagle Mountains, Riverside County. This monitoring effort is in response to a proposed landfill project that may impact the distribution of Nelson bighorn sheep.

A cooperative effort, between CDFG and the U.S. Army, to assess factors potentially limiting the bighorn sheep population in the Avawatz Mountains, San Bernadino County, was initiated in 1991. This population is of interest, because it appears that it remains at a low level, relative to the apparent carrying capacity of the range, and few obvious limiting factors are present. Moreover, it is necessary to understand the factors underlying the dynamics (or lack thereof) of this population prior to initiating a translocation of mountain sheep to the nearby Granite Mountains. Although the investigation has been stalled by a series of transfers of Department of Defense (DOD) biologists, telemetry data are being gathered to delineate the distribution of bighorn sheep in the Avawatz Mountains.

TRANSLOCATIONS

No translocations were conducted in 1991. However, it appears that the translocation of bighorn sheep to the Bristol Mountains will occur in November 1992, in cooperation with the Bureau of Land Management (BLM). The Bristol Mountains are within a BLM Wilderness Study Area, and it has been difficult to obtain approval to construct water developments and to proceed with the translocation (Bleich et al. 1991). Additionally, we anticipate that bighorn sheep will be translocated to the Bullion Mountains, in the Twentynine Palms Marine Corps Air Combat Gunnery Range, in a cooperative effort with the Department of Defense.

MANAGEMENT PLANS

Twenty bighorn sheep management plans have been completed through 1991. These plans were written to comply with Section 4901 of the California Fish and Game Code. These plans provide management direction for bighorn sheep occurring in the associated management units.

HABITAT IMPROVEMENTS

The CDFG, in cooperation with volunteers from the Volunteer Desert Water and Wildlife Survey (VDWWS), constructed 3 artificial catchments for bighorn sheep in 1991. In addition, inspections were made and maintenance was performed as needed on 55 other bighorn sheep catchments. Twenty-seven springs were inspected, and maintained as needed. Members of the VDWWS contributed 1,345 person-days of labor, and 132,288 vehicle-miles to CDFG while accomplishing these tasks. All development and maintenance work occurred cooperatively with the BLM.

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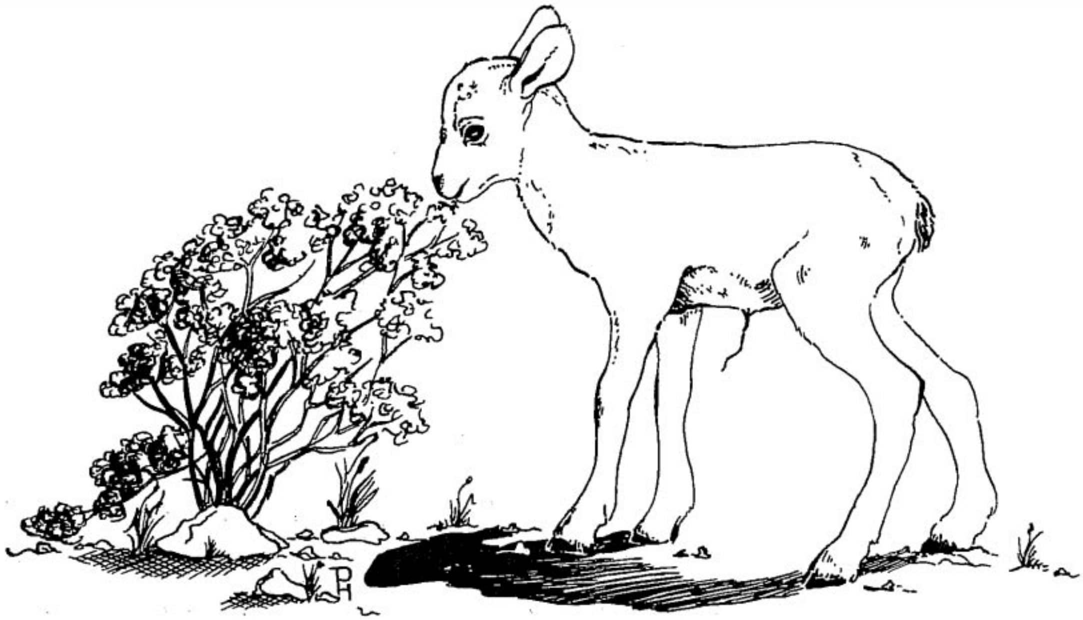

STATUS OF DESERT BIGHORN SHEEP IN TEXAS, 1991

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HELICOPTER SURVEYS

In 1991 helicopter surveys for desert bighorn sheep (Ovis *canadensis*) were conducted for the second year in the Sierra Diablo Mountains of West Texas. Flights were made in late September and early October using a Jet Ranger provided by the Texas Department of Public Safety. Eighty-seven sheep (44 rams, 28 ewes, 14 lambs, and 1 yearling ram) were observed (Table 1).

POPULATION TRENDS

Free-ranging desert bighorn sheep populations are estimated at 288 animals in 6 locations. With the exception of the Sierra Diablo Mountains in Hudspeth and Culberson counties, all populations are generally small. The Sierra Diablo population is estimated at 175 animals (Table 2).

The Sierra Diablo Wildlife Management Area brood facility continues to be highly successful and important to the overall bighorn sheep program in Texas. All 25 lambs born in the facility in 1991 have survived. From 1984 through 1991 195 lambs were born at Sierra Diablo and 147 (75.4%) survived (Table 3).

HABITAT EVALUATION AND REINTRODUCTIONS

The Texas Parks and Wildlife Department is continuing to evaluate areas suitable for future bighorn sheep transplants. Two of the primary limiting factors in many potential areas are lack of permanent water and encroachment of exotic sheep.

The Texas Bighorn Society constructed 2 water catchments in a remote section of the Black Gap Wildlife Management Area (BGWMA) on 13–14 March 1992. The BGWMA is considered the best future transplant site for desert bighorn sheep and is being prepared for a direct release of wild-trapped sheep when a source of animals is available.

HUNTING

In 1991 2 desert bighorn sheep permits were issued to private landowners as part of a cooperative agreement with the Texas Parks and Wildlife Department. Hunts were conducted on 15–30 October and 1–15 November 1991 on the Sierra Diablo Wildlife Management Area and adjoining private property in the sheep management cooperative.

A Texas Parks and Wildlife Department biologist participated in the hunts as an observer and to certify and tag the animals harvested. Both hunts were successful and resulted in rams of 8 and 11 years of age with Boone and Crockett green scores of $153\frac{7}{8}$ and $166\frac{7}{8}$, respectively. Thirty-two sheep (13 rams, 13 ewes, 6 lambs) and 49 sheep (30 rams, 15 ewes, 4 lambs) were observed on the 2 hunts.

Table 2. Summary of desert bighorn sheep numbers and locations in Texas, 1992.

	1991			1992		
Area	Rams	Ewes	Lambs	Lambs	Unk	Total
Sierra Diablo Mountains					175	175[a]
Sierra Diablo Brood Pens						
Nevada Pen	1	10	4 (F)	4		19
Arizona Pen						
Utah Pen	1	11	7 (F)	7		26
Texas Pen	1	11	4 (F)	9		25
Old Pen		1	9 (M)			10
Isolation Pen						
Elephant Mountain				4	36	40[a]
Chilicote Ranch						
Pasture					18	18[a]
Free-ranging	3	3	2			8[a]
Van Horn Mountains			2		19	21[a]
Baylor Mountains					16	16[a]
Beach Mountains	14	10	4			28
Glaze Clinic		1				1
Total						387[a]

[a]Estimated without all 1992 lambs.

Table 3. Lamb production and survival at the Sierra Diablo Wildlife Management Area brood facility, Texas.

Year	Lambs born	Lambs surviving	% survival
1984	17	10	58.8
1985	18	11	61.1
1986	29	14	48.3
1987	25	16	64.0
1988	25	25	100.0
1989	27	20	74.0
1990	29	26	89.7
1991	25	25	100.0
Totals	195	147	75.4

Table 1. Bighorn sheep observed during September and October helicopter surveys, Sierra Diablo Mountains, Texas.

	Ram class						Yearlings			
Date	I	II	III	IV	Ewes	Lambs	M	F	Total	Flight time (hr)
Aug 1990	2	13	5	3	20	7	2	0	52	35.8
Oct 1990	8	12	21	3	24	10	2	0	80	21.4
Sep–Oct 1992	1	21	16	6	28	14	1	0	87	27.6

A permit was issued to a third cooperating private landowner for the 1992 season. Prospects for another successful hunt are excellent.

RESEARCH AND THE FUTURE

A biologist has been assigned to the Van Horn area beginning 1 May 1992. The biologist will monitor free-ranging populations, delineate water development project sites, and assess research needs.

The Texas Parks and Wildlife Department continues to receive substantial support from the Texas Bighorn Society and private landowners. The outlook for the future of desert bighorn sheep in West Texas remains optimistic.

STATUS OF DESERT BIGHORN SHEEP IN NEVADA, 1991

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There are 3 subspecies of bighorn sheep in Nevada: Rocky Mountain bighorn (Ovis *canadensis canadensis*), California bighorn (*Ovis canadensis california*) and Nelson's desert bighorn (Ovis *canadensis nelsoni*). Desert bighorn are located in 47 mountain ranges in the central and southern portions of Nevada. This report summarizes Nevada's desert bighorn sheep program activities that occurred during 1991.

SURVEYS

Nevada's desert bighorn population is approximately 4,600 animals. During the 1991 fall helicopter survey biologists observed 1,564 bighorn sheep (35 lambs:100 ewes and 60 rams:100 ewes). Survey totals in 1991 are 8% below the previous 5-year average. Drought and related conditions the past several years have reduced some populations. Water developments constructed in recent years may have reduced the adverse impacts of drought.

WATER DEVELOPMENTS

In 1991, water catchments were constructed in the Spring Mountains ($n = 3$), Specter Range ($n = 2$), Mormon Mountains ($n = 2$), Las Vegas Range ($n = 1$), East Desert Range ($n = 1$) and Muddy Mountains ($n = 1$). The combined storage capacity of these new catchments is 252,490 L. These projects were funded all or in part by The Fraternity of the Desert Bighorn (Las Vegas), Nevada Bighorns Unlimited (Reno, Fallon and Elko chapters), Foundation for North American Wild Sheep, and National Fish and Wildlife Foundation. Projects were constructed in cooperation with the Bureau of Land Management (BLM), U.S. Fish and Wildlife Service and Nevada Department of Wildlife (NDOW).

[1] Deceased.

TRAPPING AND TRANSPLANTING

In 1991, 38 desert bighorn sheep were captured in the Black Mountains. They were released in the Tobin Range ($n = 18$) and the Specter Range ($n = 20$). Since 1982, 682 desert bighorn sheep have been transplanted in 22 mountain ranges in Nevada. In addition, 162 desert bighorn from Nevada have been transplanted to Colorado ($n = 75$), Texas ($n = 67$) and Utah ($n = 20$).

HARVEST

The desire to hunt desert bighorn rams remains high in Nevada. Resident applications are at all-time record highs with 2,353 applications received in 1991. There were 1,102 non-resident applications in 1991.

During the 1991 season, 128 desert bighorn sheep tags were available in Nevada. This included 114 resident, 12 non-resident, and 2 special bid tags. One new desert bighorn sheep area was opened for hunting in 1991. This new area was established by transplant. Populations established by transplant accounted for 19 tags or 15% of the desert bighorn tags available in 1991.

In 1991, 87 rams were harvested (hunter success = 68%), which was equal to the 1990 harvest, but was below the previous 5-year average (79%). The average age of rams harvested was 7 years old, comparable to the previous 5-year average. Three rams exceeded the Boone and Crockett minimum of 168 points. The largest ram was harvested in the Muddy Mountains and scored 170⅝ points.

FUTURE PLANS

The NDOW recommended to the Board of Wildlife Commissioners that 113 tags (101 resident and 12 non-resident) be issued for 29 management units for 1992. Two harvest permits were auctioned for Nevada desert bighorns: 1 at the Foundation for North American Wild Sheep Conservation in San Diego, California; the second at the Nevada Bighorns Unlimited (Reno Chapter) banquet. Funds raised from these totaled $125,000.

There are currently 8 water developments scheduled for construction in 1992, 7 in the Las Vegas area and 1 near Reno. These will be constructed by volunteers. Funds for most of the materials were also donated by volunteers. Plans for the transplanting of desert bighorn sheep into several more ranges in the state have been approved and are awaiting available animals.

Starting in summer 1992, each release of bighorn sheep on BLM administered lands will require a "release package." This release package will consist of a signed habitat management plan, an environmental analysis, an operations plan, and a public affairs plan. The release package will be prepared jointly by NDOW and BLM personnel. The release package will be signed by the BLM State Director prior to release of bighorns.

STATUS OF DESERT BIGHORN SHEEP IN NEW MEXICO, 1991

Amy S. Fisher
New Mexico Department of Game and Fish
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In 1991, 231 desert bighorn sheep (Ovis *canadensis mexicana*) occurred in New Mexico based on fall surveys (Table 1). The population trend between 1986 and 1991 indicates that the herds in the Hatchet and Peloncillo mountains are increasing, those in the Alamo Hueco Mountains are decreasing, and the other populations are stable.

POPULATION STATUS

Hatchet, Alamo Hueco and Peloncillo Mountains

High lamb survival in the Hatchet Mountains corresponded with high rainfall (Fisher 1991). Bighorn sheep in the Alamo Hueco Mountains have not been able to recover from the effects of the 1989 drought. This year marked the first increase in the bighorn sheep population in the Peloncillo Mountains since they were released in 1981.

San Andres Mountains

The San Andres population is still infested by scabies mites (Psoroptes *ovis*). Some individuals in 4 out of 5 groups exhibited behavioral and clinical signs of scabies (i.e., scratching ears, rubbing against rocks, moving lethargically, and droopy ears) (N.M. Dept. Game and Fish surveys). The Wildlife Management Institute reviewed the problem and issued a report that recommended mite research; habitat use, movement, and population studies; on-site treatment; and augmentation with Red Rock sheep based on results of studies. The New Mexico Department of Game and Fish and the U.S. Fish and Wildlife Service have not decided on the management direction for this herd.

Red Rock

Approximately 15% (z = 16) of the captive Red Rock herd died in summer 1991. Death occurred within 8 hours of ataxia and included all sex and age classes. Dissimilar results from 4 animals that were sampled precluded a conclusive diagnosis; the data are still being evaluated.

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Table 1. Status of desert bighorn sheep in New Mexico, Fall 1991.

Area	Population history	No. Estimated	No. Actual[a]	Trend
Hatchet Mountains	Indigenous, supplemented 30 in 1979, 1982	70	58	Increasing
Alamo Hueco Mountains	Transplanted 21 in 1986	15	12	Decreasing
Peloncillo Mountains	Transplanted 44 in 1981, 1982, 1991	50	44	Increasing
San Andres Mountains	Indigenous	25	22	Stable
Red Rock	Propagating facility, supplemented 21 in 1972, 1973, 1975	71	71	Stable

[a]Actual number based on aerial or ground surveys, Fall 1991.

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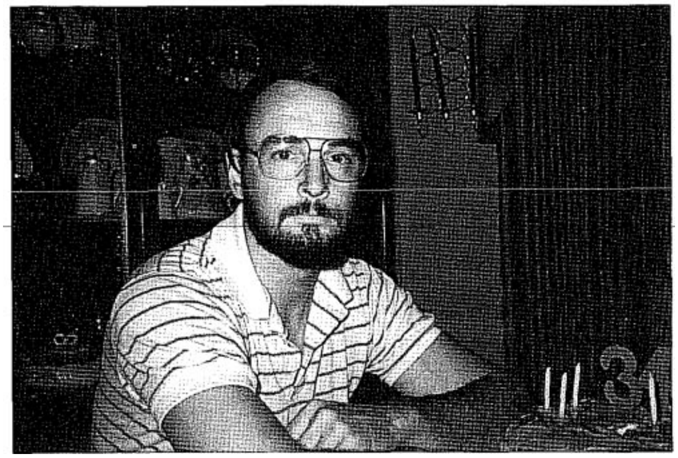

DANIEL E. DELANEY
1951–1992

Daniel E. Delaney was born on 22 October 1951 in Indianapolis, Indiana. He is survived by his parents, Ed and Jeanellyn Delaney, sister Edean Calhoon, her husband Larry, niece Kristinna, and nephew Patrick.

He enlisted in the United States Army in 1969, serving a tour of duty in Vietnam, where he was involved with helicopters and helicopter maintenance. After Vietnam, he was assigned to Fort Rucker, Alabama as an instructor in the United States Army Aviation Center. Before ending his military duties in 1972, Dan was assigned to Fort Monroe, Virginia, where he was a member of the Honor Guard of the Military Police.

Dan started his college career at George Mason University, a branch of the University of Virginia in Fairfax. He completed his formal education at the University of Nevada at Las Vegas in 1977 where he received a Bachelor of Science in Biology.

He started his career in wildlife working as a research assistant for various studies being conducted by the University of Nevada Las Vegas and the University of California Los Angeles. Work on these studies included small mammal trapping in the Mojave Desert of southern California, the Lake Mead National Recreation Area, and on the Nevada Test Site. He also worked on a radio telemetry study of Desert Kit Fox on a Bureau of Land Management funded study in southern California's Mojave Desert. The Nevada Department of Wildlife (then Fish and Game) hired Dan on 27 November 1978 where he was employed working on the Upland Game Water Development Project in southern Nevada. In August 1979 Dan moved to Elko, Nevada as a research biologist working on the Saval Project collecting data on mule deer and sage grouse. The Saval Project was temporarily funded and upon termination of the project in October 1981, Dan returned to the Upland Game Water Development Project in southern Nevada. In August 1982, he assumed the duties of 3212—a biologist position working out of the Nevada Department of Wildlife's Region III office in Las Vegas with primary responsibilities for desert bighorn sheep. Finally, he accepted the position of Supervising Biologist in Region III in July 1992.

To say Dan was enthusiastic and sincere in assuming his responsibilities as the State's premiere desert bighorn biologist is an understatement. Dan's enthusiasm was infectious and his selfless dedication to the resource was an inspiration to us all. During his years of service to the State of Nevada, Dan amassed an enviable record of accomplishments. Record counts of bighorn populations during helicopter surveys enabled Dan to assess Nevada's bighorn resource like no other biologist before him. Because of his keen understanding of bighorn population dynamics, Dan was able not only to increase recreational consumptive use of the resource, but to use his knowledge and dynamic personality to establish program objectives and direction that have significantly improved Nevada's desert bighorn resource. His work was instrumental in g that Nevada's state animal will continue to exist at health population levels on into the next century. Dan's diligence, i in that bighorn habitats will be protected and enhanced through cooperative planning for the future with land managing agencies and through big game water development programs he was instrumental in expanding, should result in increasing bighorn populations for the future. At times there weren't words to describe the intensity with which Dan worked to make the bighorn Trapping and Transplanting Program in Nevada the huge success it is today. During Dan's 10 years as the sheep biologist in Clark County, 845 desert bighorn sheep were trapped in Nevada and transplanted. If we count the sheep trapped, marked, and released on site, the number of sheep Dan caught exceeded 1,000 animals. If we recall Dan's attentiveness around the trapsite, it's probably safe to say he handled, or at least touched, each and every sheep. Needless to say, this took countless hours of dedicated hard work to complete the necessary paperwork, coordination, negotiations, and physical trapping and handling of animals. We often wondered how he managed to get it all done and still find time to assist many of us on our trapping and transplanting projects that included work with mule deer in Nevada, elk in Nevada, antelope in Nevada and Wyoming, and California bighorn in Nevada, Oregon, and British Columbia. On top of his many duties, he developed a Program and Procedure for Net Gunning that ensured the safety of personnel involved, as well as providing guidelines for professional handling of the target species that will result in successful operations with a minimum of stress to the animals.

Although Dan will be missed, he will always be right there with us as we continue the work to which he dedicated his life: i.e., to preserve, protect, and ENHANCE wildlife and its habitat in the State of Nevada, especially desert bighorn sheep. There isn't a biologist or associate in the state that doesn't have a "Dan Delaney" story that inspires, motivates, or brings a smile, guaranteeing Dan will always have a special place in the hearts of all associated with him—family, friends, associates, sportsmen and others who continue to carry on the legacy of enhancing Nevada's wildlife resources for the future.—Larry *Gilbertson*, Nevada *Department of Wildlife, 1375 Mountain* City *Highway, Elko, NV 89801.*

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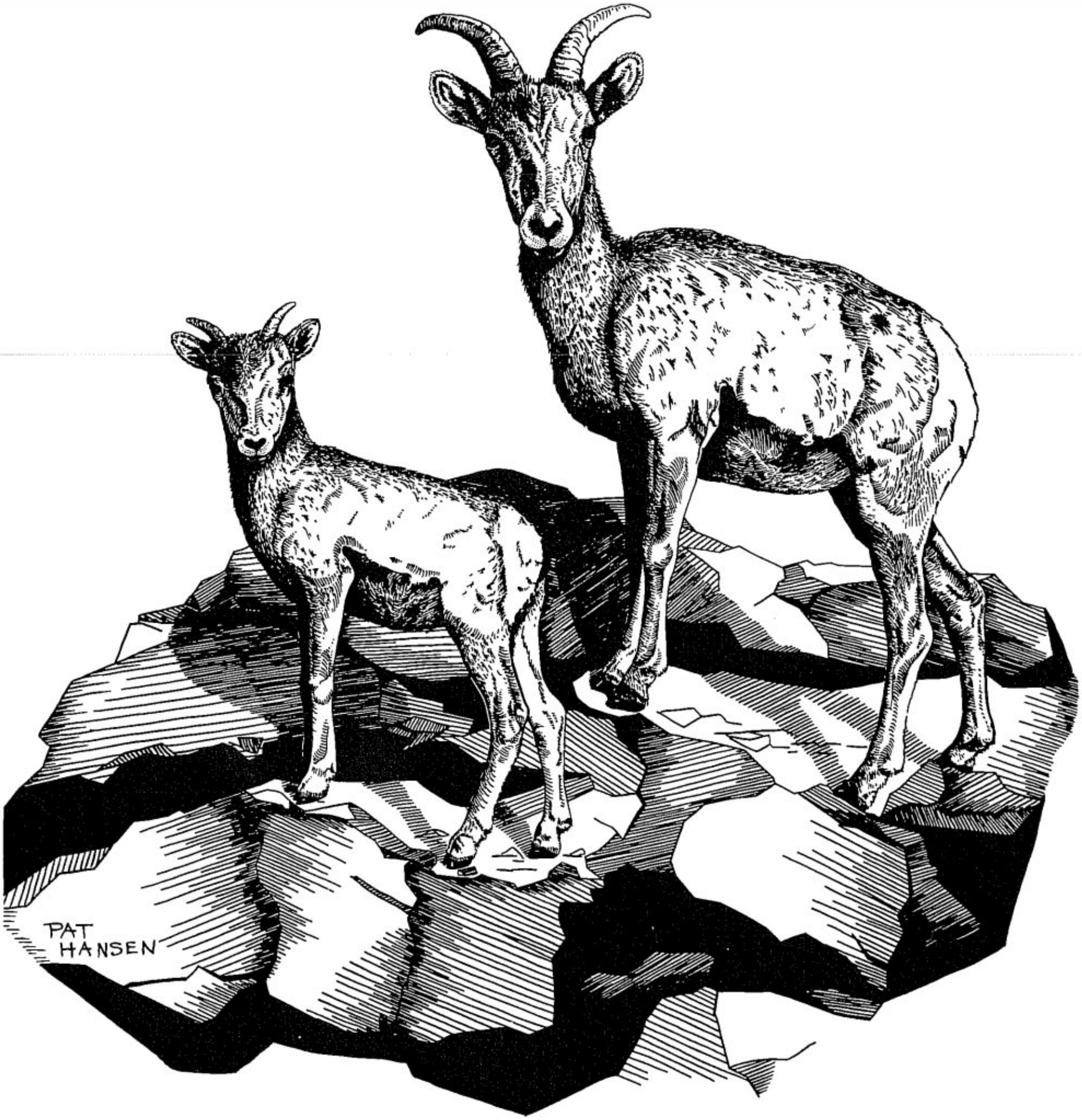


PROGRAM
THE 36TH ANNUAL
DESERT BIGHORN COUNCIL MEETING
"BIGHORN SHEEP MANAGEMENT—THEN AND NOW"
BULLHEAD CITY, ARIZONA
1992, APRIL 8–11

WEDNESDAY, APRIL 8

6:00–9:00 p.m. Registration and Icebreaker

THURSDAY, APRIL 9

8:00–9:00 a.m.

Registration	
Introduction	Jim deVos
Welcoming Address	Duane Shroufe
Program Chairman	Ray Lee
Keynote Address	Dick Weaver

10:00 a.m. Break

10:15 a.m.
Panel **Discussion**

Then	George Welsh
	Jim Blaisdell
	Warren Kelly
Now	Amy Fisher
	Steve Torres
	John Hervert

11:45 a.m. Lunch

1:15 p.m.
State Status Reports

Arizona
California
Colorado
Nevada
New Mexico
Utah
Texas

Poster Session

POTENTIAL VECTORS OF HEMORRHAGIC DISEASE VIRUSES TO DESERT BIGHORN SHEEP
Bradley A. Mullens and Coralie E. Dada, Department of Entomology, University of California, Riverside, Calif.

3:00 p.m.
Technical Session I

PROBLEMS ASSOCIATED WITH INSTRUMENTING MOUNTAIN SHEEP HEART RATE TELEMETRY
Mark C. Wallace and Paul R. Krausman, School of Renewable Natural Resources, Tucson, Ariz.; Donald W. DeYoung, University of Arizona Health Sciences Center, Tucson, Ariz.

PROGRESS TOWARD COOPERATIVE WILDLIFE HEALTH PROGRAMS IN THE WEST
David A. Jessup and William E. Clark, California Department of Fish and Game, Wildlife Investigations Laboratory, Rancho Cordova, Calif.

STRESS
Gerald A. Gronet, M.D., University of California, Davis, Calif.

IMPLICATIONS OF CAPTIVE BREEDING PROGRAMS FOR THE CONSERVATION OF DESERT BIGHORN SHEEP
Lee Elliott and Walter Boyce, University of California, Davis, Calif.

GEOGRAPHICAL AND SUBSPECIFIC ANALYSIS OF DISEASE EXPOSURE IN BIGHORN SHEEP IN CALIFORNIA
Walter Boyce and Lee Elliott, University of California, Davis, Calif.; David Jessup and Richard Clark, California Department of Fish and Game, Rancho Cordova, Calif.

MORTALITY RATES IN AN ENDEMIC DESERT BIGHORN POPULATION IN WESTERN ARIZONA
James C. deVos, E. Linwood Smith and Stanley C. Cunningham, Arizona Game and Fish Department, Phoenix, Ariz.

LAMBING SEASONS REVISITED
John D. Wehausen, University of California, White Mountain Research Station, Bishop, Calif.

6:00–9:00 p.m. Reception at Holiday Inn

FRIDAY, APRIL 10

8:00 a.m.
Technical Session **II**

AN ANALYSIS OF DESERT BIGHORN SHEEP HELICOPTER SURVEYS IN ARIZONA
Raymond M. Lee, Arizona Game and Fish Department, Phoenix, Ariz.; John Hervert, Arizona Game and Fish Department, Yuma, Ariz.; Mike Hawke and Ron Kearns, U.S. Fish and Wildlife Service, Kofa National Wildlife Refuge, Yuma, Ariz.

BO-PEEP REVISITED: WHAT INFLUENCES RESPONSES OF MOUNTAIN SHEEP TO HELICOPTER SURVEYS?
Vernon C. Bleich, Institute of Arctic Biology, Department of Biology and Wildlife, University of Alaska–Fairbanks, Fairbanks, Alas.; R. Terry Bowyer; Andrew M. Pauli, California Department of Fish and Game, Bishop, Calif.; Matthew C. Nicholson, Department of Biology and Wildlife, University of Alaska–Fairbanks, Fairbanks, Alas.; Richard W. Anthes, California Department of Fish and Game, Long Beach, Calif.

MEASURING VISUAL OBSTRUCTION CAUSED BY DISCRETE OBJECTS IN BIGHORN SHEEP HABITATS
Craig W. McCarty and James A. Bailey, Department of Fishery and Wildlife Biology, Colorado State University, Fort Collins, Colo.

ACTUAL COST OF BIGHORN SHEEP WATER DEVELOPMENT
Rodney J. Mouton and Raymond M. Lee, Arizona Game and Fish Department, Phoenix, Ariz.

COMPOSITION AND QUALITY OF DESERT BIGHORN SHEEP DIETS IN THE SUPERSTITION MOUNTAINS, ARIZONA
Bryon S. Holt and William H. Miller, School of Agribusiness and Environmental Resources, Arizona State University, Tempe, Ariz.; Brian F. Wakeling, Arizona Game and Fish Department, Phoenix, Ariz.

USE OF SALT STATIONS TO REDUCE BIGHORN SHEEP–HUMAN INTERACTIONS IN THE PECOS WILDERNESS, NEW MEXICO
Christine C. Hass, University of North Dakota, Grand Forks, N.D.; Amy S. Fisher, New Mexico Department of Game and Fish, Santa Fe, N.M.

10:00 a.m. Break

GIS MODELING OF BIGHORN SHEEP HABITAT IN THE BLACK MOUNTAINS, DEATH VALLEY NATIONAL MONUMENT
Kathleen Longshore and Charles L. Douglas, NPS Cooperative Park Studies Unit, University of Nevada, Las Vegas, Nev.

EVALUATION OF DESERT BIGHORN SHEEP HABITAT IN ZION NATIONAL PARK, UTAH
Tom S. Smith and Jerran R. Flinders, Department of Botany and Range Sciences, Brigham Young University, Provo, Ut.

MOUNTAIN SHEEP HABITAT EVALUATION IN MOJAVE DESERT SCRUB
Louis R. Berner and Paul R. Krausman, School of Renewable Natural Resources, University of Arizona, Tucson, Ariz.

EVALUATING MOUNTAIN SHEEP HABITAT MODELS USING GIS TECHNOLOGY
Vernon C. Bleich, Institute of Arctic Biology and Department of Biology and Wildlife, University of Alaska, Fairbanks, Alas. and California Department of Fish and Game, Bishop, Calif.; Matthew C. Nicholson, Institute of Arctic Biology and Department of Biology and Wildlife, University of Alaska, Fairbanks, Alas.; Amanda T. Lombard, Fitzpatrick Institute of African Ornithology, University of Cape Town, South Africa; Peter V. August, Environmental Data Center, University of Rhode Island, Kingston, R.I.

FROM MOUNTAIN RANGE TO META-POPULATIONS: THE DEVELOPMENT OF COMPREHENSIVE HABITAT MANAGEMENT FOR DESERT BIGHORN SHEEP IN CALIFORNIA
Don Armentrout, Bureau of Land Management, Riverside, Calif.

12:00 noon Lunch

1:00 p.m.
Technical Session III

SOCIAL BEHAVIOR AND HABITAT USE OF BIGHORN SHEEP NEAR HOOVER DAM, ARIZONA
Stanley C. Cunningham, Arizona Game and Fish Department, Phoenix, Ariz.

DESERT BIGHORN SHEEP MOVEMENTS AND HABITAT USE IN RELATION TO THE PROPOSED BLACK CANYON BRIDGE PROJECT—NEVADA
Donald W. Ebert and Charles L. Douglas, NPS Cooperative Park Studies Unit, University of Nevada, Las Vegas, Nev.

EFFECTS OF AND REACTIONS TO U.S. HIGHWAY 93 BY DESERT BIGHORN IN THE BLACK MOUNTAINS IN NORTHWEST ARIZONA
Stanley C. Cunningham, Layne S. Hanna, James C. deVos and Joseph Sacco, Arizona Game and Fish Department, Phoenix, AZ; Mike Walker, Environmental Office, Bureau of Reclamation, Boulder City, Nev.

DEVELOPMENT OF A LONG-TERM MONITORING PROGRAM FOR BIGHORN IN THE BLACK MOUNTAINS, DEATH VALLEY NATIONAL MONUMENT
Charles L. Douglas and Kathleen Longshore, NPS Cooperative Park Studies Unit, University of Nevada, Las Vegas, Nev.

2:30 p.m. Break

RESOURCE USE BY MOUNTAIN SHEEP IN A LARGE ENCLOSURE
Matthew J. Zine, Paul R. Krausman, Mark C. Wallace and Louis R. Berner, School of Renewable Natural Resources, University of Arizona, Tucson, Ariz.

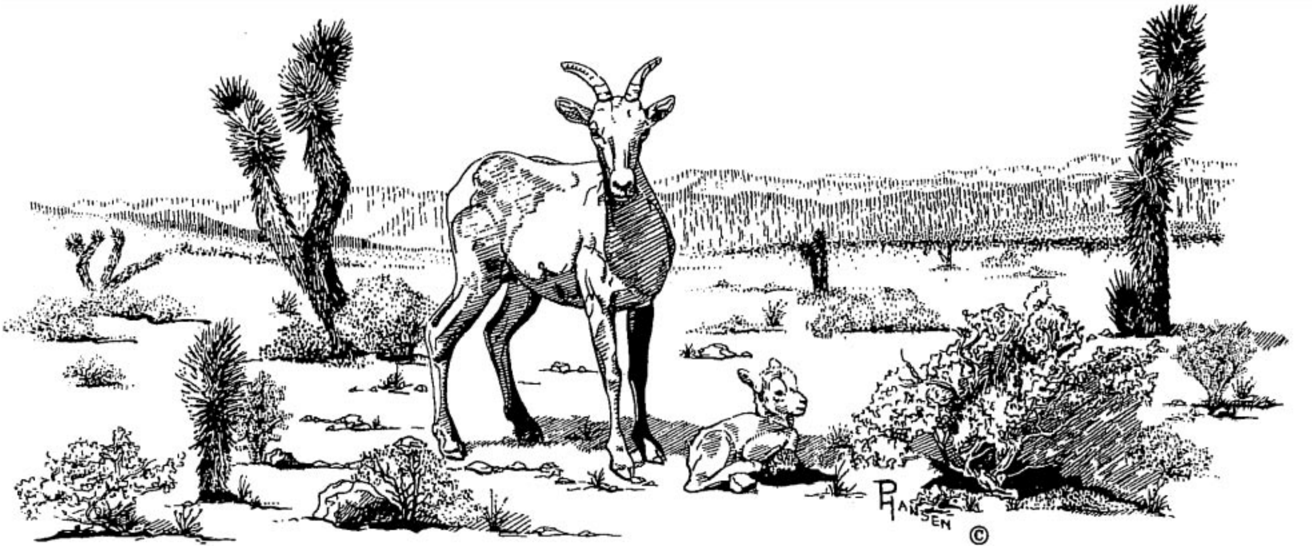
DISTINGUISHING PENINSULAR BIGHORN SHEEP FROM OTHER SUBSPECIES
Rob R. Ramey, Cornell University, Ithaca, N.Y.; David A. Jessup, California Department of Fish and Game, Wildlife Investigations Laboratory, Rancho Cordova, Calif.

4:00 p.m. Business Meeting

7:00 p.m. Steak Fry at Holiday Inn

SATURDAY, APRIL 11

8:00 a.m.–12:00 noon Field Trip to Oatman



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Vice-chairman:	Dan Delaney, Nevada Department of Wildlife
Past Chairman:	Doug Humphreys, New Mexico Department of Game and Fish
Secretary-Treasurer:	Stan Cunningham, Arizona Game and Fish Department

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Art Fuller, Mark Jorgensen,
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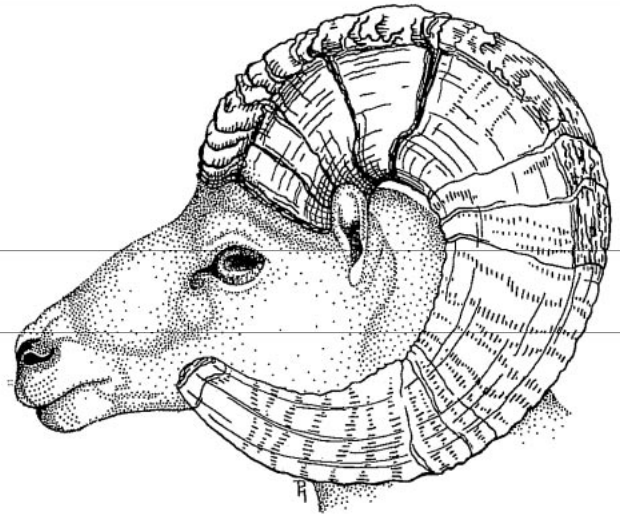

DESERT BIGHORN COUNCIL MEETINGS AND OFFICERS
1957–1992 ANNUAL MEETINGS

Year	Location	Chairman	Secretary-Treasurer
1957	Las Vegas, Nevada	M. Clair Aldous	
1958	Yuma, Arizona	Gale Monson and Warren Kelly	
1959	Death Valley, California	M. Clair Aldous	Fred Jones
1960	Las Cruces, New Mexico	Warren Kelly	Fred Jones
1961	Hermosillo, Sonora, Mexico	Jon Van Den Akker	Ralph Welles
1962	Grand Canyon, Arizona	James Blaisdell	Charles Hansen
1963	Las Vegas, Nevada	Al Ray Jonez	Charles Hansen
1964	Mexicali, Baja Calif., Mexico	Rudolfo Hernandez Corzo	Charles Hansen
1965	Redlands, California	John D. Goodman	John P. Russo
1966	Silver City, New Mexico	Cecil Kennedy	John P. Russo
1967	Kingman, Arizona	Claud Lard	John P. Russo
1968	Las Vegas, Nevada	Ray Brechbill	John P. Russo
1969	Monticello, Utah	Ralph and Buddy Welles	W. Glen Bradley
1970	Bishop, California	William Graf	W. Glen Bradley
1971	Santa Fe, New Mexico	Richard Weaver	Tillie Barling
1972	Tucson, Arizona	George W. Welsh	Doris Weaver
1973	Hawthorne, Nevada	Warren Kelly	Doris Weaver
1974	Moab, Utah	Carl Mahon	Lanny Wilson
1975	Indio, California	Bonnar Blong	Lanny Wilson
1976	Bahia Kino, Mexico	Mario Luis Cossio	Lanny Wilson
1977	Las Cruces, New Mexico	Jerry Gates	Peter Sanchez
1978	Kingman, Arizona	Kelly Neal	Peter Sanchez
1979	Boulder City, Nevada	Bob McQuivey	Peter Sanchez
1980	St. George, Utah	Carl Mahon	Peter Sanchez
1981	Kerrville, Texas	Jack Kilpatric	Peter Sanchez
1982	Borrego Springs, California	Mark Jorgensen	Rick Brigham
1983	Silver City, New Mexico	Andrew Sandoval	Rick Brigham
1984	Bullhead City, Arizona	Jim de Vos, Jr.	Rick Brigham
1985	Las Vegas, Nevada	David E. Pulliam, Jr.	Rick Brigham
1986	Page, Arizona	Jim Guymon	Bill Dunn
1987	Van Horn, Texas	Jack Kilpatric	Bill Dunn
1988	Needles, California	Vernon C. Bleich	Donald Armentrout
1989	Grand Junction, Colorado	Jerry L. Wolfe	Donald Armentrout
1990	Hermosillo, Sonora, Mexico	Raul Valdez	Donald Armentrout
1991	Las Cruces, New Mexico	Doug Humphreys	Donald Armentrout
1992	Bullhead City, Arizona	Jim deVos, Jr.	Stanley C. Cunningham

INSTRUCTIONS FOR CONTRIBUTIONS TO THE DESERT BIGHORN COUNCIL TRANSACTIONS

GENERAL POLICY: Original papers relating to desert bighorn sheep ecology and management are published in the DESERT BIGHORN COUNCIL TRANSACTIONS. All papers presented at the Council's annual meetings are eligible for publication. There are 3 types of papers published in the TRANSACTIONS: technical papers; state reports; and opinions, comments, and case histories or notes. Technical papers are peer reviewed. State reports are edited for syntax and style. Opinions, comments, case histories and notes provide for philosophical presentations and the presentation of ideas and concepts. Some of these papers are also peer reviewed. Preliminary papers will also be published if they are complete enough to provide new information. Additional papers may be published when reviewed and approved by the Editorial Board. Papers must be submitted to the Editor at or before the Council's annual meeting to be considered for the current edition of *The Transactions.*

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TITLE: The title should be concise, descriptive, and $\leq$10 words. Use vernacular names of organisms.

FOOTNOTES: Use only for an author's address if it differs from the byline address, and in tables.

ACKNOWLEDGMENTS: Include acknowledgments at the end of the introduction as an untitled paragraph.

SCIENTIFIC NAMES: Vernacular names of plants and animals should be accompanied by the appropriate scientific names (in parentheses) the first time each is mentioned.

ABSTRACT: An abstract of about 1–2 typed lines per typed page of text should accompany all articles. The abstract should be an informative digest of significant content. It should be able to stand alone as a brief statement of problems examined, the most important findings, and their utility.

KEY WORDS: Place key words below the abstract. Supply 6–12 key words for indexing: vernacular and scientific names of principal organisms, geographic area, phenomena and entities studied, and methods.

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PROOF: All papers will be reviewed for acceptability by the Editorial Board and 2 outside reviewers. Submit papers to Dr. Paul R. Krausman, Desert Bighorn Transactions, 108 Biological Sciences East Building, University of Arizona, Tucson, AZ 85721. When papers are returned to authors for revision, please return corrected manuscripts within 30 days. Galley proofs should be returned within 72 hours.

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