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DIETS OF BIGHORN SHEEP IN THE CHIHUAHUAN DESERT, TEXAS

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ABSTRACT—Desert bighorn sheep (*Ovis canadensis*) have been extirpated from much of their historical range in the Chihuahuan Desert. Understanding their dietary preferences in the Chihuahuan Desert is integral to their successful restoration. We evaluated differences (sexual, temporal, and spatial) in the diets of desert bighorn sheep from Elephant Mountain Wildlife Management Area in the Chihuahuan Desert of western Texas by using microhistological analysis of 432 fecal pellet groups (209 rams, 209 ewes, 14 lambs) collected every 2 weeks between September 1998 and August 2000. Ninety-four plant species were identified; bighorn sheep diets consisted of 50% browse, 35% forbs, 11% grasses, and 4% succulents. Diets of rams and ewes did not differ annually. Diets differed seasonally ($P < 0.05$); forbs prevailed in diets of rams during winter. Diets of bighorn sheep from Elephant Mountain were compared to previously determined diets from the Beach, Baylor, and Sierra Diablo mountains. There were significant differences among female diets between Elephant Mountain and Beach Mountain during winter and the Sierra Diablo Mountains in fall, winter, and summer. Dietary overlap was greatest among desert bighorn sheep at Elephant Mountain and the Sierra Diablo Mountain populations (57.6%), followed by Baylor Mountain (55.7%) and Beach Mountain (52.0%). Dietary overlap among all ranges was highest in the browse component (53%), followed by forbs (23%), grasses (16%), and succulents (8%).

RESUMEN—El borrego cimarrón del desierto (*Ovis canadensis*) ha sido extirpado de gran parte de su distribución histórica en el desierto Chihuahuense. El conocimiento de sus preferencias alimenticias en el desierto Chihuahuense es integral para la restauración exitosa de esta especie. Hemos evaluado diferencias (sexuales, temporales y espaciales) en las dietas del borrego cimarrón del desierto en Elephant Mountain Wildlife Management Area en el desierto Chihuahuense del oeste de Texas utilizando el análisis microhistológico de 432 grupos de heces fecales (209 machos, 209 hembras, 14 crías), colectadas cada 2 semanas entre septiembre 1998 y agosto 2000. Noventa y cuatro especies de plantas fueron identificadas; las dietas de borrego cimarrón consistieron de 50% de arbustivas, 35% de herbáceas, 11% de gramíneas y 4% de suculentas. Las dietas de machos y hembras no se diferenciaron anualmente. Las dietas difirieron por temporada ($P < 0.05$); las hierbas prevalecieron en las dietas de machos durante el invierno. Las dietas del borrego cimarrón en Elephant Mountain fueron comparadas con las dietas que habían sido determinadas anteriormente en las sierras Beach, Baylor, y Sierra Diablo. Hubo diferencias significativas entre las dietas de las hembras de Elephant Mountain y Beach Mountain durante el invierno y el verano. La similitud de dietas fue mayor entre las poblaciones de borregos de Elephant Mountain y Sierra Diablo Mountain (57.6%) seguida por Baylor Mountain (55.7%) y Beach Mountain (52.0%). La similitud de las dietas entre todas las sierras fue más alta en los componentes arbustivos (53%), seguido por herbáceas (23%), gramíneas (16%) y suculentas (8%).

Populations of bighorn sheep (*Ovis canadensis*) in the Chihuahuan Desert have been extirpated from most of their historical range (Valdez and Krausman, 1999). By the end of the 1800s, populations of desert bighorn sheep had declined precipitously as a result of unregulated hunting, predation, and effects (disease and competition) of domestic livestock (Davis and Taylor, 1939). Population estimates in 1991 suggested that <24,000 desert bighorn sheep occurred in North America, of which <5% resided in the Chihuahuan Desert (Valdez and Krausman, 1999). In 2004, desert bighorn sheep in the Chihuahuan Desert were estimated at 500 in Texas (Texas Parks and Wildlife Department [TPWD], unpublished data), 255 in New Mexico

(E. Rominger, New Mexico Game and Fish, pers. comm.), and 100 in Mexico (B. P. McKinney, CEMEX Corp., pers. comm.).

In Texas, concerted efforts have been made to restore desert bighorn sheep to their former range (Brewer and Hobson, 2000). Desert bighorn sheep currently occupy 7 mountain ranges throughout the Trans-Pecos region, including the Beach, Baylor, Sierra Diablo, Van Horn, and Sierra Vieja mountains and Black Gap and Elephant Mountain Wildlife Management Areas (Brewer and Hobson, 2000). Despite the apparent successful reintroduction of desert bighorn sheep in Texas, few ecological data are available to resource managers. Baseline data (e.g., habitat use, population characteristics, and diet) are essential to the successful reintroduction of desert bighorn sheep and have been identified as priorities in the desert bighorn sheep management plan for Texas (TPWD, unpublished report).

Krausman et al. (1999) reviewed dietary information available for desert bighorn sheep. However, few studies have been conducted in the Chihuahuan Desert (Sandoval, 1979; DeYoung et al., 2000; Fulbright et al., 2001). Sandoval (1979) described the diets of a native population in the San Andres Mountains of New Mexico, and DeYoung et al. (2000) and Fulbright et al. (2001) described diets of sheep from the Beach, Baylor, and Sierra Diablo mountains of Texas. No one has evaluated diets of desert bighorn sheep in the eastern portion of the Chihuahuan Desert.

The evaluation of potential release sites for desert bighorn sheep in Texas is limited to broad-scale vegetation associations and does not include evaluation of species composition of local floras (Cook, 1994). Understanding the foraging habits of *O. canadensis* throughout its range in the Chihuahuan Desert is essential for evaluating future release sites. Knowledge of dietary preferences will assist biologists in monitoring populations and habitats of these sheep and in formulating scientifically based decisions regarding management. Our goal was to evaluate the diet of a successfully reintroduced population, providing information that might be used to refine current habitat evaluation techniques for future release sites. Our specific objectives were to determine sexual, temporal (seasonal and annual), and spatial (mountain range) differences among diets.

METHODS—*Study Area*—The study was conducted on the TPWD Elephant Mountain Wildlife Management Area (WMA), located 41.8 km south of Alpine, Texas, on State Highway 118 in Brewster County. Elephant Mountain WMA encompasses approximately 93.1 km^2 within the northeastern portion of the Chihuahuan Desert and the Trans-Pecos ecological region of western Texas. Twenty desert bighorn sheep were introduced to Elephant Mountain WMA in 1987 (Cook, 1994) and increased to approximately 160 animals by 2000 (Brewer, 2001). Elephant Mountain WMA functions as a wildlife management, research, and demonstration area for the Trans-Pecos region and as a propagation facility for free-ranging desert bighorn sheep in Texas. Cattle grazing was restricted to lower elevations. Mule deer (*Odocoileus heminous*), white-tailed deer (*O. virgininaus*), and javelina (*Tayassu tajacu*) are potential competitors found on the area.

Suitable habitat for *O. canadensis* is restricted to Elephant Mountain proper, the most prominent feature of the study area. The mountain encompasses 32.4 km^2 and is of igneous origin. Elevations on the study site range from 1,280 to 1,896 m above sea level. Mean annual rainfall on the study area is approximately 33 cm, with peak rainfall occurring July–August (Lerich, 2002). Mean rainfall during the study was slightly less than normal (31 cm), with yearly means of 26 cm in 1998, 35 cm in 1999, and 33 cm in 2000. The area is drained by Calamity Creek to the west and Chalk Draw to the east of Elephant Mountain. Temperatures ranged from −1.7°C (average daily minimum) in January to 32.2°C (average daily maximum) in June. Growing season averages approximately 225 d (U. S. Department of Commerce, 2000).

Soils on the study area are comprised primarily of well-drained loams characteristic of semiarid regions (U. S. Department of Agriculture, 2001). Elephant Mountain WMA lies within the Chihuahuan Desert ecosystem, and the flora is consistent with Chihuahuan Desert vegetation (Hughes, 1993). Five major habitat types exist on the Elephant Mountain WMA, including: 1) desert-scrub plant communities that dominate the valleys surrounding Elephant Mountain proper; 2) mid-grass communities predominantly on the benches, slopes, and relatively flat top of the mountain; 3) desert riparian communities that parallel Calamity Creek; 4) juniper-pine-oak (*Juniperus-Pinus-Quercus*) woodland associations in the limestone substrate of the Del Norte Mountains, along the eastern boundary of the Elephant Mountain WMA; and 5) deciduous woodlands in the deep canyons of Elephant Mountain (Brewer, 2001). Common plant species on the study area included creosote bush (*Larrea tridentata*), tarbush (*Flourensia cernua*), honey mesquite (*Prosopis glandulosa*), ocotillo (*Fouquieria splendens*), mariola (*Parthenium incanum*), grama grasses (*Bouteloua*), muhly grasses (*Muhlenbergia*), threeawns (*Aristida*), lechuguilla (*Agave lechuguilla*), and various cacti (Cactaceae).

Fecal Collection—We determined diets from analysis of fecal material. Fresh fecal pellets were collected from the ground within 4 h of observed defecation every 2 weeks from September 1998 through August 2000. Samples were collected and segregated by sex, with equal numbers of samples collected for each sex when possible. Attempts were made to collect a minimum of

8 samples (4 ram, 4 ewe) each sample period. Only those pellet groups that could be identified positively as ram or ewe were collected. All pellets within each group were collected, and each group was analyzed separately. Lamb samples were collected without regard to sex. Fecal samples were placed in sterile plastic bags, stored on ice, and frozen within 4 h of collection to prevent destruction of plant cells through microbial action. Samples remained frozen until received by the forage analysis laboratory (D. Smith, Benson, Arizona).

Laboratory Analysis—A technician experienced in analyzing desert bighorn sheep diets determined (Bleich et al., 1997) dietary composition by genus, species, and forage class (browse, forbs, grasses, and succulents) through microhistological analyses of fecal pellet groups by using the methods of Sparks and Malechek (1968). Three slides/pellet group and the frequency of identifiable plant fragments/species within 20 randomly selected microscopic fields/slide (i.e., 60 fields/pellet group) were used to determine percent diet composition. A detailed listing of all known plant species occurring on the study area was provided to the technician. Slides of plant reference material were prepared in the same manner as fecal samples to assist in the identification, confirmation, and classification of plant fragments present in fecal samples.

Fecal samples were placed in fine-meshed nylon bags and then washed in a washing machine to remove solubles and small, unidentifiable plant fragments. Samples were then dried and ground in a Wiley Mill through an 18-mesh (1-mm opening) screen. Ground sample material was cleared with bleach to remove pigments and then thoroughly washed in hot water under a 200-mesh screen to remove additional soluble and non-diagnostic materials.

Slides were prepared by placing enough sample material on a microscope slide to provide an average of 3 identifiable plant fragments per microscope field viewed at 100×. Hertwig's clearing solution was used when samples were not cleared adequately with bleach. Samples then were mounted in Hoyer's mounting medium (1 to 2 drops), followed by placing a cover slip over the sample, and heating until bubbling evenly. Slides were placed on a wet sponge to dissipate air bubbles from under the cover slip and dried at 45 to 60°C for 24 to 48 h.

Relative proportions of plant species in each sample were quantified by examining 20 randomly selected microscopic fields at 125× magnification for each of 3 slides/ sample. Frequency of occurrence was calculated for each species by reporting the number of microscope fields that contained evidence of the species in the number of fields examined per sample. Percent occurrence was converted into relative density of identifiable fragments per microscopic field by using the conversion table of Fracker and Brischle (1944). Relative densities were then converted to percent compositions for each sample and then to aggregate percent compositions for each comparison. Plant species were identified using Correll and Johnston (1979).

Statistical Analysis—Two-way log-likelihood analysis was used to compare dietary differences between sexes (M, F), years (1998–1999, 1999–2000), seasons (fall, winter, spring, and summer), and mountain ranges (Elephant Mountain vs. Baylor, Beach, and Sierra Diablo mountains; Fulbright et al., 1996). Seasonal sample groupings consisted of fall (September to November), winter (December to February), spring (March to May), and summer (June to August). Proportional data were transformed using arcsine transformation prior to analysis. The Shannon-Wiener diversity index (Zar, 1999) was used to measure and compare species diversity, richness, and evenness of the dietary items used by each sex. A *t*-test was used to determine differences between diversity indices of males and females (Zar, 1999). Diet composition results from Elephant Mountain were compared to those of a similar study by Fulbright et al. (1996) in the Baylor, Beach, and Sierra Diablo mountains of Texas. Raw data from that study were obtained and reanalyzed using the same statistical procedures. Percentage overlap (Krebs, 1999) was calculated to determine dietary overlap in forage classes used by desert bighorn sheep at different mountain ranges.

RESULTS—*Diet Composition*—We collected 432 fecal pellet groups (209 rams, 209 ewes, and 14 lambs) from desert bighorn sheep at Elephant Mountain WMA from September 1998 through August 2000. Ninety-four plant species were identified in the diets, including 37 browse species, 34 forbs, 20 grasses, and 3 succulents. The dominant taxa for browse, forbs, grasses, and succulents throughout the study included wild buckwheat (*Eriogonum*), globemallow (*Sphaeralcea*), muhly grass, and prickly pear (*Opuntia*), respectively. Diets of desert bighorn sheep (rams and ewes combined) from Elephant Mountain consisted of 50% browse, 35% forbs, 11% grasses, and 4% succulents. Thirteen dominant taxa (those comprising ≥2% or more of the total diet) combined to form 73% of the total diet (Table 1). Important food items (based on percent frequency) included globemallow, wild buckwheat, fourwinged saltbush (*Atriplex canescens*), ratany (*Krameria lanceolata*), trumpet flower (*Tecoma stans*), goosefoot (*Chenopodium incanum*), ephedra (*Ephedra*), and honey mesquite.

Comparisons between Sexes—Diets of rams and ewes were similar (Table 2). The proportion of forage classes in diets did not differ ($P > 0.389$) nor did the diversity of taxa consumed by ewes ($H' = 0.4701$) and rams ($H' = 0.4660$; $P > 0.10$). Maximum possible diversity and evenness also were similar for ewes ($H'_{max} = 1.9138$ and $J' = 0.2463$) and rams ($H'_{max} = 1.9085$ and $J' = 0.2435$). The diet composition of rams and ewes throughout the study was nearly identical, as

TABLE 1—Dominant plant taxa (% composition) of desert bighorn sheep (*Ovis canadensis*) diets from Elephant Mountain Wildlife Management Area, Brewster County, Texas, September 1998 to August 2000.

Taxa	Rams and ewes combined (n = 418)	Rams (n = 209)	Ewes (n = 209)	Lambs (n = 14)
Sphaeralcea	11.22	11.78	10.66	18.34
Eriogonum	11.05	11.62	10.48	14.82
Atriplex canescens	8.88	9.51	8.26	7.78
Krameria lanceolata	7.30	7.54	7.06	3.19
Tecoma stans	5.58	6.05	5.12	4.19
Chenopodium incanum	5.41	5.98	4.83	1.96
Ephedra	4.29	4.42	4.16	1.56
Prosopis glandulosa	4.26	3.50	5.03	3.19
Borage	3.93	4.34	3.52	5.15
Janusia gracilis	3.69	3.58	3.81	3.08
Muhlenbergia	2.93	2.48	3.38	1.03
Opuntia (prickly pear)	2.56	2.65	2.46	1.64
Galium	2.24	2.35	2.14	1.12
Opuntia (not prickly pear)	1.90	1.77	2.04	3.18
Euphorbia	1.89	1.84	1.93	2.29
Total	77.15	79.41	74.89	72.53

TABLE 2—Seasonal diet composition (%) of desert bighorn (*Ovis canadensis*) rams, ewes, and lambs at Elephant Mountain Wildlife Management Area, Brewster County, Texas, 1998 through 2000.

Season			
Forage class	Rams	Ewes	Lambs
Fall			
Browse	43	40	
Forbs	42	29	
Grasses	11	26	
Succulents	4	5	
Winter			
Browse	56	50	
Forbs	35	20	
Grasses	6	28	
Succulents	3	2	
Spring			
Browse	59	55	43
Forbs	27	30	43
Grasses	7	8	9
Succulents	7	7	5
Summer			
Browse	43	49	40
Forbs	41	36	44
Grasses	12	10	11
Succulents	4	5	5

were the total numbers of taxa consumed by the sexes (84 used by rams and 81 by ewes).

Temporal Comparisons—Although diets did not differ between years (P = 0.800), some seasonal differences (P = 0.030) in proportion of forage classes in ram and ewe diets occurred during winter. Forbs composed a greater portion of winter diets in rams (35%) than in ewes (20%), and grasses formed 28% of the winter diet in ewes and only 6% in rams. Diets of lambs were similar for spring and summer and were dominated by browse and forbs (Table 2).

Comparisons among Mountain Ranges—Diets of rams from Elephant Mountain differed from those of other mountain ranges as follows: Beach Mountain during fall (P = 0.047) and spring (P = 0.005), Baylor Mountain during winter ($P \leq$ 0.001), and the Sierra Diablo Mountains during spring (P = 0.004) and summer ($P \leq$ 0.001). In all comparisons, rams from Elephant Mountain consumed a greater proportion of forbs than rams at the Beach, Baylor, or Sierra Diablo mountains, which relied more heavily on browse or grasses (Table 3). Differences also were reflected among female diets between Elephant Mountain and Beach Mountain during winter (P = 0.001) and the Sierra Diablo in fall (P = 0.003), winter ($P \leq$ 0.001), and summer ($P \leq$ 0.001). In general, ewes at Elephant Mountain consumed a greater proportion of grasses, whereas ewes in the Beach, Baylor, and Sierra

TABLE 3—Diet composition (%) of desert bighorn sheep (*Ovis canadensis*) at Elephant Mountain Wildlife Management Area, Brewster County, Texas, 1998 through 2000, and Baylor, Beach, and Sierra Diablo mountains, Culberson County, Texas, 1994 to 1995 (Fulbright et al., 1996).

Forage class	Elephant Mountain	Baylor Mountain	Beach Mountain	Sierra Diablo
Browse	50	52	51	50
Forbs	35	25	20	23
Grasses	11	13	22	13
Succulents	4	10	7	8

Diablo mountains consumed a greater proportion of browse and succulents.

Percentage overlap was similar among the Baylor, Beach, Elephant, and Sierra Diablo mountains. Dietary overlap was greatest between the Elephant Mountain population and the Sierra Diablo population (58%), followed by Baylor Mountain (56%) and Beach Mountain (52%). In general, dietary overlap between mountain ranges was highest in the browse component (53%), followed by forbs (23%), grasses (16%), and succulents (8%).

DISCUSSION—Proportions of forage classes used by bighorn sheep on the study site were similar to those used by other populations throughout the Southwest (Seegmiller and Ohmart, 1981; Dodd, 1987; Krausman et al., 1989; Miller and Gaud, 1989; Holt et al., 1992). According to Krausman et al. (1999), desert bighorn sheep prefer browse despite the abundance of other forage classes. This seems to be the case in our study, in which browse was the most important forage class in the diets of desert bighorn sheep, followed by forbs, grasses, and succulents.

In contrast to adult bighorn sheep, forbs consistently dominated the forage classes used by lambs. Smith and Krausman (1987) suggested that lamb survival might be tied to abundant spring and early summer forb production. The substantial precipitation that occurred during the spring and summer seasons on the study site might explain the above-normal recruitment experienced during the study. Lamb recruitment was 53% in 1999 and 61% in 2000 (TPWD, unpublished data). Forb use was identical (44%) for spring and summer, indicating the importance of this forage class to lambs.

Analyses of bighorn sheep forage indicated that forbs contain higher nutrient levels than browse or grasses during portions of the year (Morgart et al., 1986; Smith and Krausman, 1987). The greatest use of forbs occurred during the summer (38%), whereas grasses were used most during the fall (19%). Smith and Krausman (1987) suggested that greater use of forbs should increase bighorn sheep productivity. The population of desert bighorn sheep substantially increased during our study from 60 (1998) to 160 (2000; Brewer, 2001), despite the high use of browse.

Proportional use of forage classes was similar for both sexes. However, seasonal differences between sexes were reflected in the level of use within each forage class. Bleich et al. (1997) noted that annuals, shrubs, and succulents comprised a greater portion of the male diet than that of females, whereas females used greater portions of grasses and perennial forbs than did males during periods of segregation. Consistent with our study, rams used a greater proportion of browse than ewes, whereas use of grasses was greater by ewes than rams during segregation periods.

Bleich et al. (1997) noted distinct differences in the habitats used by males and females during sexual segregation. We found this to be true, based on observations, sample-collection locations, and the specific taxa found within bighorn sheep diets. During segregation, females consistently used the steep cliffs and rocky outcrops on the southern and western sides of Elephant Mountain. In contrast, rams used the top and lower, less steep slopes of the mountain. Levels of specific dietary items provided additional evidence of differential habitat use by the sexes. Species such as desert willow (*Chilopsis linearis*) and cottonwood (*Populus deltoides*) were present in male diets during all seasons. In contrast, female diets included cottonwood and desert willow only during the winter. On our study site, these riparian species only occurred along the Calamity Creek and Chalk Draw drainages, which indicated that rams were foraging at lower elevations throughout the year. Our findings did not concur with Fulbright et al. (2001), who did not detect differences between sexes in diet composition in any season.

Miller and Gaud (1989) noted the importance of diverse vegetation within bighorn sheep habitat to provide constant availability of suitable

forage. The diverse diet (i.e., 94 plant taxa consumed) in the Chihuahuan Desert might indicate the adaptive nature of desert bighorn sheep or the large numbers of dietary items needed to sustain viable populations on the study site. Regardless, the substantial population growth since the initial release in 1987 indicates that forage requirements have been met at Elephant Mountain.

Comparisons of diets among mountain ranges might suggest that diets vary with availability. The study sites differed considerably in temperature, soils, precipitation, vegetation, and grazing histories. Fulbright et al. (2001) considered forbs to be the preferred forage for desert bighorn sheep in the Sierra Diablo, Beach, and Baylor mountains. In our study, browse was the dominant forage class and, although diets differed by mountain range and season, composition by forage classes of diets were similar to some degree (~50%) for all mountain ranges.

Management Implications—Strategies for habitat management for desert bighorn sheep in the Chihuahuan Desert must ensure proper levels of high-quality forage. Aggressive habitat manipulations (e.g., prescribed burning) that are designed to stimulate and promote browse and forb production should be applied at the appropriate scale to ensure quality habitat throughout the naturally fragmented landscape. Prescribed burning should provide appropriate levels of browse on portions of the area during all seasons, while still maintaining open visibility. Resource managers should incorporate vegetation inventorying and monitoring techniques to monitor use, status, condition, and trends of the browse forage class and other key forage species. Additional strategies should include implementation of seasonal browse-use surveys and construction of high-fence exclosures within representative plant communities to better assess browsing by desert bighorn sheep.

Because desert bighorn sheep are still at critically low numbers throughout the Chihuahuan Desert, population levels of other ungulates (e.g., deer) should be carefully monitored and regulated as required to prevent degradation of sheep habitat. The forage component of future release sites should be evaluated and a monitoring system should be in place prior to the introduction of desert bighorn sheep. The importance of browse species documented in our study indicates that transplant sites should contain an adequate supply of browse if stocked with desert bighorn sheep.

Our results indicate that desert bighorn sheep forage at lower elevations in rolling hills, flats, and drainages, in addition to the steep cliffs and rocky outcrops. These areas must be afforded the same protection and management as habitat that is considered optimal (Schwartz et al., 1986; Bleich et al., 1990, 1997). A rotational livestock grazing system during the non-growing season, as used on our study site, should provide ample forage for desert bighorn sheep.

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