DESERT BIGHORN COUNCIL TRANSACTIONS

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Editor's Note – How Far Do Our Words Travel?

How far do our words travel? This thought occurred to me after being asked to review a manuscript for a journal other than the *Desert Bighorn Council Transactions*. The manuscript had been written by a biologist in Texas, sent to a journal based in Oklahoma, forwarded to an associate editor in Kansas, and then sent to me for review in Arizona. I was on a flight to another meeting in Montana as I reviewed his work. And the manuscript would undoubtedly make several more trips among another reviewer, associate editor, editor in chief, copy editor, and author before it was finally accepted and printed. The journal would subsequently be sent to several thousand subscribers and libraries once printed. The number of miles that this author's work would travel was a more than a little surprising when I considered it.

But more than the distance, the value of our words can be of great impact. Research that has been published in prior volumes of the *Desert Bighorn Council Transactions* is routinely referenced and built upon as we learn and do more with the ecological relationships among bighorn sheep and their habitat, competitors, predators, and agency policy and management. As you read the technical reports, status reports, and abstracts of presented papers contained within this volume, I think you will agree that we are still learning important information that is essential to the management of bighorn sheep. The *Transactions* benefit from the quality of the research and management information provided in these pages, and managers routinely look to these volumes when formulating management strategies for bighorn sheep. I hope you find the information contained within this volume as useful as I have. I believe the author's words will travel far.

– Brian Wakeling

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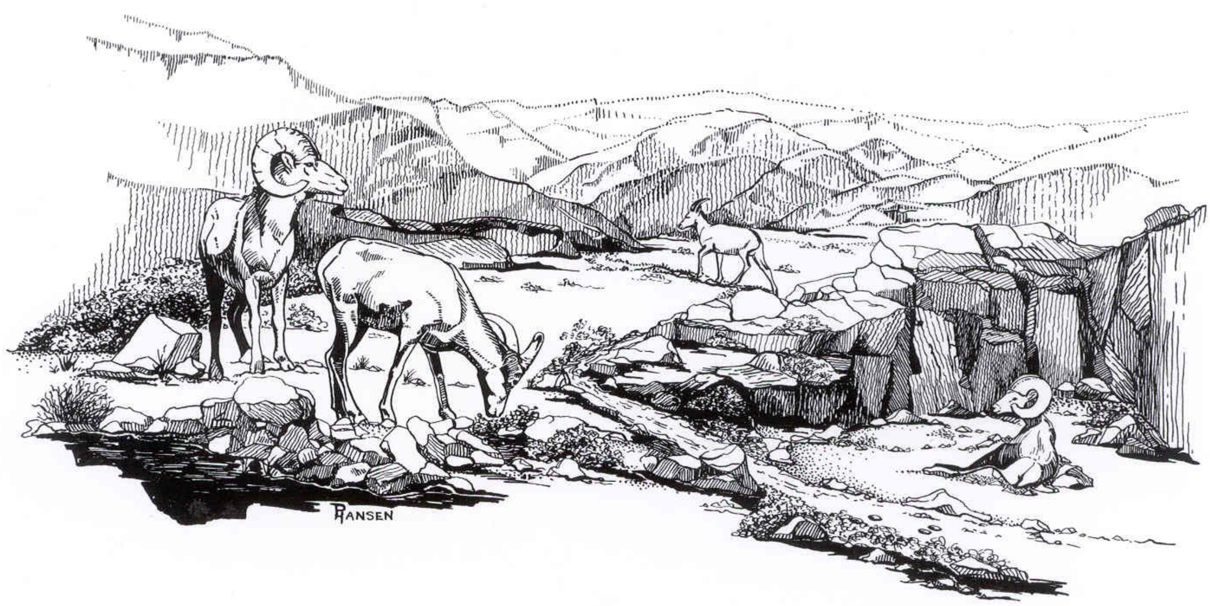

Habitat use and movements of bighorn sheep in west Texas

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Abstract We studied annual range size, movements, and habitat use of bighorn sheep (*Ovis canadensis*) at Elephant Mountain Wildlife Management Area in Brewster County, Texas to better understand bighorn sheep habitat selection at multiple spatial scales and improve translocation success. Between February 2001 and March 2002, we collected 790 (663 F, 127 M) radiolocations for 7 ewes and 2 rams, respectively. We evaluated habitat use of physical characteristics (i.e., range size, percent slope, elevation, aspect, and distance from escape terrain and water) at multiple spatial scales using habitat selection ratios. Ram annual range size ($\bar{x}$ = 1,471 ha, *SE* = 10, *n* = 2) was larger than ewe annual range size ($\bar{x}$ = 1,071 ha, *SE* = 4, *n* = 7). Ram daily movements were also larger ($\bar{x}$ = 1,080 m, *SE* = 124, *n* = 26) than ewe daily movements ($\bar{x}$ = 811 m, *SE* = 49, *n* = 182). Bighorn sheep selected steep slope classes (40–80%) in high elevation with predominately southern aspects. Areas in proximity to permanent water sources (about 1 km) and escape terrain (≤280 m) were also selected. Translocations of bighorn sheep are difficult in many respects and occasionally fail to establish self-sustaining populations. Knowledge of habitat preferences at multiple spatial scales will help biologists identify potential translocation sites using quantitative methods and improve the likelihood of establishing self-sustaining populations.

Key words bighorn sheep, habitat use, movements, *Ovis canadensis*, range size, spatial scale, Texas

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Bighorn sheep (*Ovis canadensis*) within the mountainous terrain of west Texas numbered 1,500 during the mid-1880s; however, only 500 bighorn sheep remained by the early 1900s (Cook 1994). Bighorn sheep populations continued to decline until they were extirpated in Texas by 1960 (Cook 1994). Disease, interspecific competition (i.e., domestic sheep and goats), unregulated hunting, and predation have all been postulated to cause bighorn sheep declines (Davis and Taylor 1939, Cook 1994).

Efforts to restore bighorn sheep populations began in the late 1950s by Texas Parks and Wildlife Department (TPWD), and included land acquisition, captive propagation, and translocations using bighorn sheep from other states and Mexico (Cook 1994). Early captive propagation and translocation efforts were of limited success as a result of disease and predation; however, bighorn sheep populations began to increase by the mid-1980s with the improvement of captive propagation efforts, namely predator management and the use of vaccines to minimize disease (Cook 1994). Since the 1980s, bighorn sheep have been restored to 7 mountain ranges in west Texas with population numbers in 2006 estimated to be >800 bighorn sheep (Clay E. Brewer, TPWD, personal communication).

Currently, TPWD uses qualitative field assessments of areas to evaluate their potential as bighorn sheep habitat. More quantitative methods for evaluating bighorn sheep habitat exist (McKinney et al. 2003, Locke et al. 2005) and should be employed. A greater understanding of habitat use by successful (i.e., viable, self-sustaining) bighorn sheep populations within the state are needed as translocation efforts in Texas continue to expand. Furthermore, evaluating habitat use at multiple spatial scales provides additional insight into range selections important in translocations (Garshelis 2000). Many studies have documented bighorn sheep habitat use within the desert southwest and northern Mexico (Krausman and Leopold 1986, Krausman et al. 1989, Bristow et al. 1996, Alvarez–Cardenas et al. 2001, Tarango et al. 2002); however, no studies have analyzed habitat use at multiple spatial scales. The objectives of our study were to (1) determine habitat use of a bighorn sheep population in west Texas at 3 spatial scales and (2) estimate annual ranges and daily movements.

Study Area

Our study was conducted at Elephant Mountain Wildlife Management Area (WMA) located about 42 km south of Alpine, Texas on State Highway 118 in Brewster County (Figure 1). The total area for Elephant Mountain WMA is 9,330 ha; however, we focused on 5,216 ha on the WMA that included Elephant Mountain, an area of high bighorn sheep use (Figure 1). Elephant Mountain WMA is in the eastern portion of the Chihuahuan Desert and is characterized as arid with temperatures ranging from -1.7–32.2°C (TPWD unpublished data). Mean annual rainfall is 36 cm with peak rainfall between June–September (TPWD unpublished data). Soils are of igneous origin and range from small gravel to large boulders. Elevation ranges between 1,256–1,898 m above sea level, and topography varies from semi-flat valleys to steep, rugged mountainous terrain in the upper elevations (Brewer 2001).

Elephant Mountain consists of a mid-grass community on the upper slopes and semi-flat top of Elephant Mountain, a deciduous woodland community in the deep canyons, and a desert scrub community on the lower slopes and valleys (TPWD unpublished data). Predominate species in the mid-grass community include grama grasses (*Bouteloua* spp.), bluestem grasses (*Andropogon* spp.), tobosa (*Hilaria* spp.), prickly pear (*Opuntia* spp.), and lechuguilla

(*Agave lechuguilla*; Gould 1962). Common species in the woodland canyons include gray oak (*Quercus grisea*), emory oak (*Quercus emoryi*), Texas persimmon (*Diospyros texana*), and Texas nightshade (*Solanum triquetrum*). The desert scrub community consists of creosotebush (*Larrea tridentata*), *Yucca* spp., sotol (*Dasylirion* spp.), and honey mesquite (*Prosopis glandulosa*). Other ungulates present include desert mule deer (*Odocoileus hemionus crooki*), collared peccary (*Pecari tajacu*), and pronghorn (*Antilocapra americana*). Predators of bighorn sheep include mountain lions (*Felis concolor*), coyotes (*Canis latrans*), and bobcats (*Lynx rufus*).

Methods

Capture and Telemetry.—In December 2000, 20 (10 M, 10 F) bighorn sheep were captured from Elephant Mountain using a net gun fired from a helicopter (deVos et al. 1984). Bighorn sheep were fitted with a battery powered, mortality-sensitive radiotransmitter (480–490 g; Telonics Inc., Mesa, AZ) attached to a collar (4.9 x 6.7 x 7.5 cm) and released. Radiomarked bighorn sheep were monitored (February 2001–March 2002) 3–4 X/week. Triangulation was used to determine bighorn sheep locations from fixed stations (White and Garrott 1990), and location estimates were entered into a GIS database (ArcView, Version 3.2a, ESRI, Redlands, CA, USA).

Range Size and Movements.—Annual range size was estimated using the Animal Movements Extension (Hooge and Eichenlaub 1997). We used a 100% minimum convex polygon (MCP; White and Garrott 1990) because it is a commonly used method and is easy to conceptualize although being sensitive to sample size (Powell 2000). Daily movement rates were also calculated using the Animal Movements Extension. Daily movement rate was defined as the straight-line distance between consecutive locations of an individual on consecutive days. Descriptive statistics were performed to range and movement estimates by sex.

Habitat Mapping.—Wilson et al. (1980) identified 5 physiographic habitat variables important to bighorn sheep: slope, elevation, aspect, distance to a permanent water source, and distance to escape terrain. We defined escape terrain as slopes ≥60% (McCarty and Bailey 1994, Andrew et al. 1999) with a contiguous 150 m buffer of 40–60% slopes (McKinney et al. 2003). A digital elevation model with 30 m resolution (Divine et al. 2000) was incorporated into ArcView. A slope image and aspect image were generated from the digital elevation model using percent slope and degrees as the output, respectively. Each bighorn sheep radiolocation was evaluated for each habitat variable. Slope measurements of each location were placed in 1 of the following classes: 0–19%, 20–39%, 40–59%, 60–79%, and ≥80%. Each bighorn sheep location was placed in 1 of the following elevation classes: 1,256–1,299 m, 1,300–1,399 m, 1,400–1,499 m, 1,500–1,599 m, 1,600–1,699 m, 1,700–1,799 m, and 1,800–1,898 m. Aspect values were placed in the following classes: north (315–44°), east (45–134°), south (135–224°), and west (225–314°).

Data Analysis.—We calculated habitat selection ratios (Manly et al. 2000) for bighorn sheep use of slope, elevation, and aspect classes. Selection ratios (S) were calculated as $S = ([U + 0.001]/[A + 0.001])$ where U was the observed use based on radiolocations and A was availability of the habitat variable class (Lopez et al. 2004). Aebischer et al. (1993) suggested adding 0.001 to use and availability to avoid 0 in the numerator or denominator. We described bighorn sheep habitat use as preferred when selection ratios were ≥1, and avoided when selection ratios were <1 (Manly et al. 2000, Lopez et al. 2004). Selection ratios were used to provide relative scale of preference-avoidance for habitat variable classes versus simply ranking the classes.

Bighorn sheep habitat selection ratios were evaluated at 3 spatial scales. First-order selection as defined by Johnson (1980) is the selection of physical or geographical range (i.e., point to study area). Next, habitat variable classes in the MCP of each bighorn sheep range were compared to the proportion of habitat variable classes within the study area (i.e., range to study area). Johnson (1980) described this as second-order selection. Third, the proportion of bighorn sheep locations in the habitat variable classes was compared to habitat variable classes available within each individual's MCP (i.e., point to range). This is similar to Johnson's (1980) third-order selection. Porter and Church (1987) suggested that analysis of habitat use at multiple scales reduces bias commonly attributed with subjectively defining study area boundaries. Comparisons of selection ratios were precluded due to small sample size.

Distance to water was calculated using the Nearest Features Extension in ArcView and measuring the straight-line distance (km) from each bighorn sheep location to the nearest permanent water source. Distance to escape terrain was calculated similarly by measuring the straight-line distance (m) to the nearest available escape terrain. Descriptive statistics were calculated for both variables; however, comparisons within and between sexes based on estimates of statistical significance levels were precluded due to small sample size.

Results

Range Size and Movements.—Between February 2001 and March 2002, we collected 790 (663 F, 127 M) locations for 7 ewes and 2 rams, respectively. Radiocollar malfunctions (e.g., radiocollars falling off) reduced our sample size from the original 20 (10 M, 10 F) bighorn sheep. Mean annual ram range size ($\bar{x}$ = 1,471 ha, *SE* = 10, *n* = 2) was slightly larger than ewe range size ($\bar{x}$ = 1,071 ha, *SE* = 4, *n* = 7; Table 1). Ewe ranges were largely overlapping (near 100%) each other. Ram ranges shared substantial overlap with that of the ewes (Figure 1). Ram movements ($\bar{x}$ = 1,080 m, *SE* = 124, *n* = 26) were also larger than ewe movements ($\bar{x}$ = 811 m, *SE* = 49, *n* = 182; Table 1).

Habitat Use.—The point to range spatial scale provided a realistic view of bighorn sheep habitat use at Elephant Mountain WMA in comparison to the other 2 spatial scales. For example, in the point to study area and range to study area scales the use of slope by ewes increases with increasing slope class but for the point to range scale it peaks at the 40-59% class and begins to decline. This was more representative of the population for each habitat variable and both sexes.

From the point to range spatial scale, bighorn sheep ewes preferred the 40–59% and 60–79% slope classes (*S* = 1.7, 1.5; respectively here after) whereas rams preferred the 20–39%, 40–59%, and 60–79% slope classes (*S* = 1.3, 1.3, 1.0). Both ewes (*S* = 1.2, 1.6) and rams (*S* = 1.7, 1.2) preferred the 1,500–1,599 and 1,600–1,699 m elevation classes. Selection ratios for the 1,300–1,399 m elevation class for both sexes bighorn sheep ewes and rams preferred to remain within 1 km of a permanent water

Table 1. Age (years), range size (ha), mean movements [m (*n*)], mean distance to permanent water source [DTW (km)], and mean distance to escape terrain [DTET (m)] of bighorn sheep at Elephant Mountain Wildlife Management Area, Texas (February 2001–March 2002).

	ID Number	Age	No. of Locations	Range Size[a]	Movements	DTW	DTET
Ewes	1	4–5	103	1,129	655 (28)	1.0	248
	2	4–5	94	1,012	769 (23)	1.1	218
	3	4–5	99	1,016	787 (29)	1.3	262
	4	5	98	1,050	890 (27)	1.1	282
	5	1	99	1,078	651 (26)	1.0	236
	6	1–2	99	1,254	1,072 (30)	1.2	243
	7	1	71	958	827 (19)	1.0	205
	Mean		95	1,071	811	1.1	242
	SE		1	4	49	0.02	10
Rams	1	9–10	34	1,322		1.2	264
	2	9	93	1,620	1,080 (26)	1.2	297
	Mean		64	1,471		1.2	280
	SE		5	10		0	3

[a] Range size was estimated using a 100% minimum convex polygon.

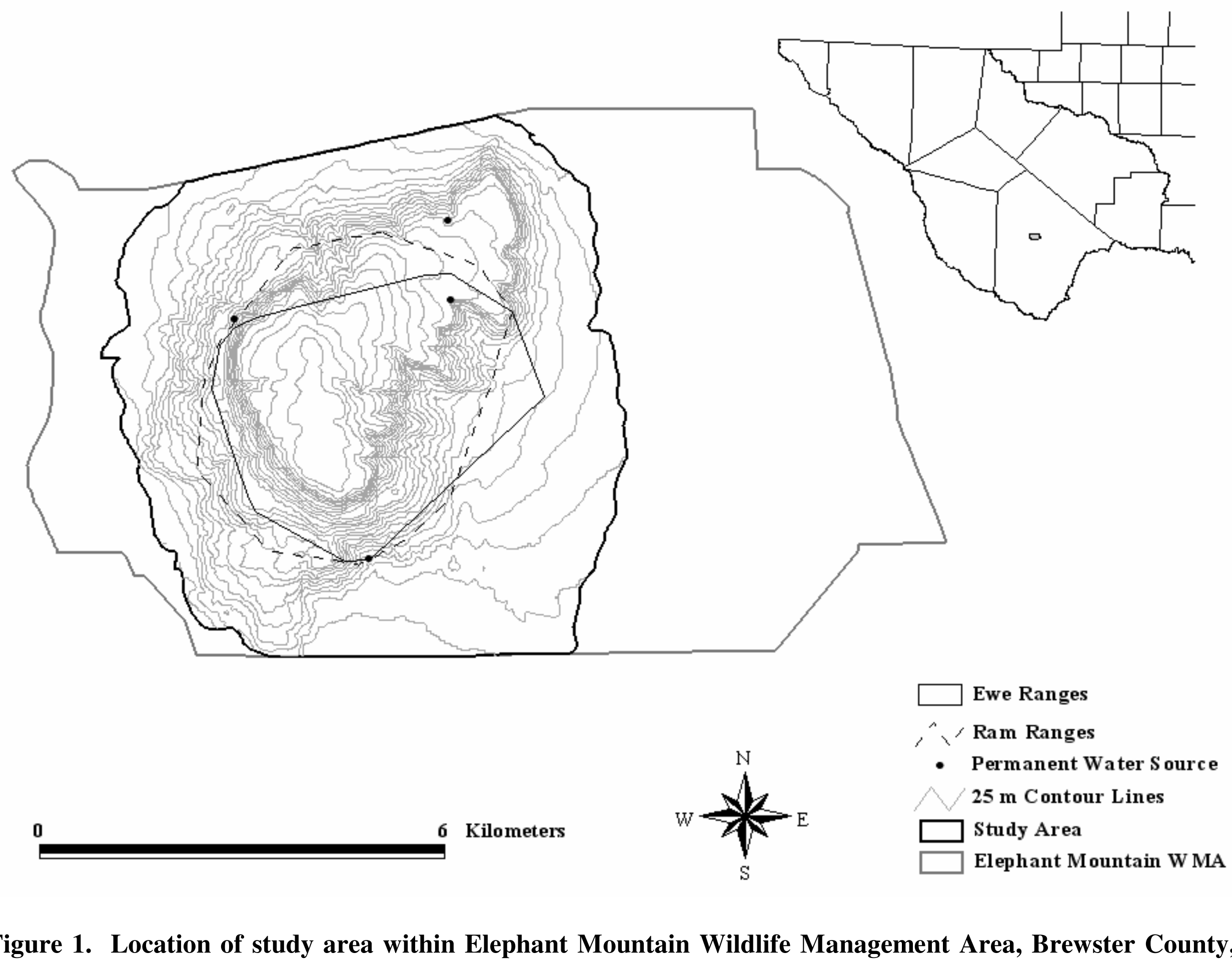

Figure 1. Location of study area within Elephant Mountain Wildlife Management Area, Brewster County, Texas. Ewe and ram ranges were determined using a 100% minimum convex polygons based on pooled locations of ewes and rams.

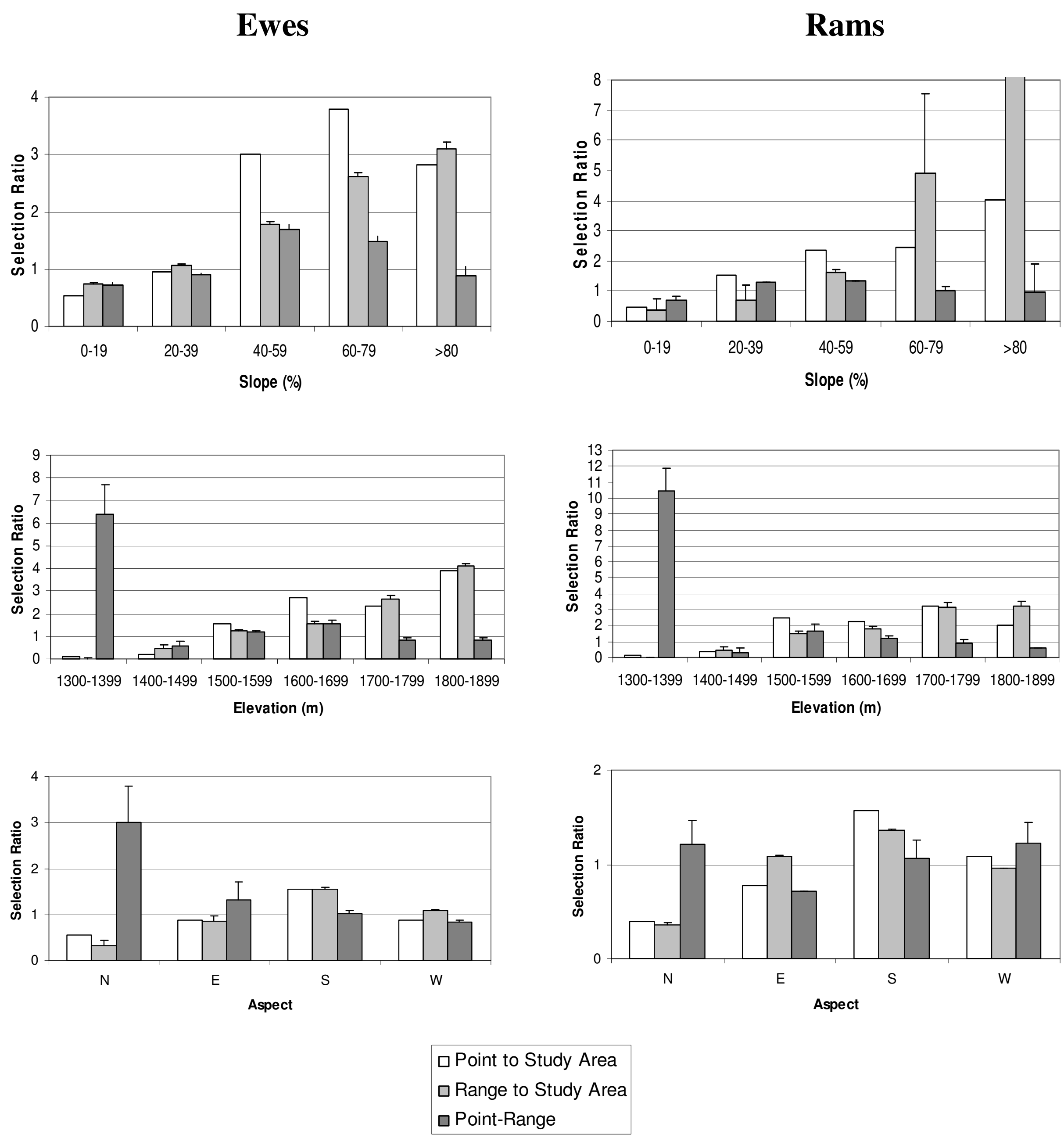

Figure 2. Bighorn sheep habitat selection ratios of habitat use at Elephant Mountain Wildlife Management Area, Brewster County, Texas. A selection ratio >1 was defined as a preferred habitat and a selection ratio <1 was defined as an avoided habitat. Whiskers represent standard error.

are high (S = 6.4 ewes, S = 10.5 rams), however this is likely an anomaly due to our analytic technique where a couple of locations were within a small proportion of available habitat, therefore inflating the selection ratio. Ewes preferred eastern and southern aspects (S = 1.3, 1.0) and rams preferred western and southern aspects (S = 1.1, 1.2). Selection ratios for northern aspects were inflated, again because of a couple of locations within a small proportion of available habitat (Figure 2). Desert source (Table 1). Ewes used areas closer in proximity to escape terrain ($\bar{x}$ = 242 m, *SE* = 10, *n* = 663) than did rams ($\bar{x}$ = 280 m, *SE* = 3, *n* = 127; Table 1).

Discussion

Range Size and Movements.—Bighorn sheep ranges are the result of many factors such as age, sex, heredity, topography, season, forage, water availability, cover, and reproductive activities (Krausman et al. 1999). Ewe ranges and movement rates at Elephant Mountain were small, although similar in size to other documented bighorn sheep ewe populations in New Mexico and Arizona (Elenowitz 1984, Bristow et al. 1996). Often small range sizes and movement rates are associated with high habitat quality such that less movement is necessary to meet daily physiological requirements (Bristow et al. 1996). Conversely, Risenhoover et al. (1988) suggested small, isolated herds of transplanted bighorn sheep may have small ranges as a result of poor habitat quality. Transplanting bighorn sheep into historic range sites may be unsuccessful because of changes in the habitat (i.e., succession, different management strategies) since their extirpation (Risenhoover and Bailey 1985, Wakelyn 1987), inadequate escape terrain (McKinney et al. 2003), and increased predation by mountain lions due to declining mule deer numbers (Kamler et al. 2002). Elephant Mountain does represent a relatively small (≤160) and isolated bighorn sheep population. Annual helicopter surveys however, indicate the population has steadily increased since the 1987 translocation (Clay E. Brewer, TPWD, unpublished data); therefore we believe habitat quality is sufficient to support an increasing population that allows for recruitment.

Ewe ranges were largely overlapping. This is likely because bighorn sheep are gregarious and young ewes and rams follow more mature ewes and rams, respectively (Geist 1971). Our locations of individuals are not independent and were therefore influenced by the habitat use and movements of dominant individuals within the population.

Habitat Use.—The point to range spatial scale provided a realistic view of bighorn sheep habitat use from a population perspective. Population habitat use would be more important than individual habitat use particularly when attempting to evaluate potential landscapes for translocation. Our selection ratios suggested bighorn sheep prefer steep slopes which is well documented (Welch 1969, Merritt 1974, Leslie and Douglas 1979, DeForge 1980, Etchberger et al. 1989, Krausman et al. 1999). Ewes seemed to be narrower in their selection of slope, preferring the 40–59% and 60–79% classes while rams preferred the 20–39%, 40–59%, and 60–79% classes from the point to range scale. Bleich et al. (1997) found that ewes due to smaller body size used areas that minimized risk of predation to offspring, whereas rams exploited areas outside that of the ewes, potentially encountering higher predation risks. This may explain the difference in use of slope classes at Elephant Mountain. Ewes and rams had similar preferences for the 1,500–1,599, and 1,600–1,699 elevation classes. One caveat is elevation and slope are not independent variables and steeper slopes are located in the upper elevations of Elephant Mountain. Therefore, whether bighorn sheep exhibit a preference for steep slope over high elevation or vice versa is difficult to conclude from out data. The highest elevation on Elephant Mountain is semi-flat grassland, which contained few bighorn sheep locations. The majority of the locations were concentrated in and around the steep slopes. Tarango et al. (2002) noted that bighorn sheep avoided flat areas in Sonora, Mexico and selected steep terrain.

Elephant Mountain contained 10.6 km^2 of escape terrain, which is less than the 15 km^2 that McKinney et al. (2003) suggested. However, the perimeter-to-area ratio (4.5) was considerably lower than the study areas McKinney et al. (2003) evaluated in Arizona. This suggests that Elephant Mountain consists of large contiguous areas of escape terrain rather than many small patches.

Desert bighorn sheep ewes selected eastern and southern aspects and rams selected western and southern aspects. Alverez-Cardenas et al. (2001) suggested that bighorn sheep used opposing slopes throughout the day to avoid high heat stress. Changing slopes and/or aspect may alleviate other environmental factors (e.g., wind, rain). Southern and western slopes at Elephant Mountain were generally more devoid of vegetation than northern or eastern facing slopes due to prevailing winds and precipitation patterns. Bighorn sheep may have preferred southern slopes because of the reduced cover resulting in high visibility allowing for predator detection. Long fields of view are important to bighorn sheep and they will avoid densely vegetated areas that limit visibility (Wakeling 1989).

Most bighorn sheep locations were about 1 km from a permanent water source. The selection of areas in proximity to permanent water sources may have been a result of below average rainfall during the study period. Use of permanent water sources may also be a function of location, structure around watering area, and proximity of the source to other habitat variables (e.g., slope, elevation, aspect). Bristow et al. (1996) found a majority of permanent water sources were in proximity to bighorn sheep high use areas and speculated whether bighorn sheep selected areas with regard to distance to water or whether water sources were in proximity of high use areas. Our results tend to suggest the latter. The majority (60%) of all bighorn sheep locations were concentrated near the southern permanent water source, which coincides with steep slopes and high elevations and was an area of high bighorn sheep use. The northern-most permanent water source seemed to be avoided completely with few locations within 0.5 km. Permanent water sources within 300 m of escape terrain have increased value (Cunningham 1989) and Turner et al. (2004) found decreasing bighorn sheep activity with increasing distance from permanent water sources.

Escape terrain is considered important in evading predators (Krausman et al. 1999). Bighorn sheep often avoid predators by seeking steep slopes and placing obstacles (e.g., steep, sharply dissected cliffs) between themselves and the predator (Geist 1999). Our results suggest ewes preferred areas closer to escape terrain than did rams. Tarango et al. (2002) and Mooring et al. (2004) both reported finding ewes in more rugged and steeper slope classes in comparison to rams. Distance to escape terrain may fluctuate seasonally due to group size, reproductive activity, lambing, sexual segregation, and other variables.

Conclusions

Our findings support other research showing bighorn sheep prefer steep slopes in proximity to permanent water sources. We also found that the bighorn sheep population at Elephant Mountain has persisted despite the lower than suggested amount of escape terrain. This could be a factor of many reasons such as the large contiguous amount of escape terrain, high habitat quality, or predator management practices. Trans-locations of large ungulates like bighorn sheep are expensive, time and effort consuming, and politically challenging (Beck et al. 1994, Biggins and Thorne 1994, Wolf et al. 1996, Dunham 1997, Fritts et al. 1997), and many restoration efforts are deemed unsuccessful (Risenhoover et al. 1988). Knowledge of bighorn sheep habitat use from a population perspective is critical because populations are typically what are managed rather than individuals. An understanding of habitat use and movements will assist biologists in predicting future reintroduction locations using quantitative methods (McKinney et al. 2003, Locke et al. 2005).

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Use of guzzlers by bighorn sheep in the Chihuahuan Desert

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Abstract Water developments are often used to improve habitat to benefit desert bighorn sheep (*Ovis canadensis*) populations. However, there is dispute among researchers and managers with regard to the benefits of water developments for enhancing desert bighorn sheep habitat. We investigated guzzler use by desert bighorn sheep in the Chihuahuan Desert with 35-mm remote cameras. Desert bighorn sheep (% composition of photographs) ranked third among 13 species documented at guzzlers and accounted for 15% of all photographs. Precipitation and temperature directly influenced guzzler use by desert bighorn sheep with 56% of photographs occurring in the summer. As predicted, guzzler use by desert bighorn sheep increased ($P < 0.05$) with remoteness to other water and decreased ($P < 0.05$) with increasing canopy cover. Aoudads (*Ammotragus lervia*) negatively influenced ($P = 0.07$) desert bighorn sheep use of guzzlers. Our results suggest that desert bighorn sheep use guzzlers during critical periods of high temperatures and low rainfall. Strategically choosing guzzler sites, improving guzzler design, and controlling exotics should enhance guzzler use by desert bighorn sheep in the Chihuahuan Desert.

Key words *Ammotragus lervia*, aoudad, bighorn sheep, Chihuahuan Desert, drinking, guzzler, *Ovis canadensis*, Texas, water development

Desert Bighorn Council Transactions 48:12–22

Controversy arises over the requirements and use of water by desert bighorn sheep. McCarty and Bailey (1994) suggested that water is not a limiting factor in cold and semi-arid deserts. Further, Broyles (1995), Broyles and Cutler (1999), and Rosenstock et al. (1999) have all stressed the need for controlled studies evaluating the effects of guzzlers on desert bighorn sheep populations (e.g., survival or productivity). Desert bighorn sheep were thought to obtain enough water from succulent vegetation (Leopold 1933) and used habitats with no (Watts 1979, Warrick and Krausman 1989) to little (Krausman and Leopold 1986) water availability. Conversely, proponents of water developments (for review, see Broyles 1995, Rosenstock et al. 1999) believe water is one of the major factors limiting survival and dispersal of desert bighorn sheep (Nichol 1937, Hansen 1965) and that large areas of habitat have gone unused due to scarcity or lack of water (Barclay 1947). Halloran and Deming (1958) suggested that water developments in desert bighorn sheep habitat provided a practical method of increasing their numbers. Additionally, water availability was determined to be extremely important during high temperatures (>43°C; Welles and Welles 1961, Blong and Pollard 1968) associated with breeding season (Koplin 1960, Wilson et al. 1980).

Despite the controversy on water requirements of and use by desert bighorn sheep, water development has become standard in management efforts focused on improving desert bighorn sheep habitat (Rosenstock et al. 1999). One method of developing water for wildlife is the guzzler (Glading 1947). Guzzler design varies considerably (Rosenstock et al. 1999). Historically, guzzlers consisted of a metal, plastic, or concrete apron for catching rainfall or runoff; a pipe or gutter to direct water; a storage tank; and a drinking trough with a float valve. Site selection is important when installing a guzzler (Kie et al. 1996). Unfortunately, many guzzlers have been installed without consideration of other critical habitat components (McCarty and Bailey 1994). However, helicopters have allowed resource managers greater flexibility for placing guzzlers in more appropriate habitats to benefit bighorn sheep. Visibility is a key habitat variable influencing use by desert bighorn sheep and should be considered in any habitat rating systems (McCarty and Bailey 1994). Further, desert bighorn sheep preferred to water in areas with high visibility ratings (e.g., low screening cover; Hansen 1980, Turner and Weaver 1980). Understanding relationships between guzzler use and surrounding habitat characteristics may enhance restoration of desert bighorn sheep in the Chihuahuan Desert.

One of the points of contention in using water developments is that it may intensify competitive interactions between species. However, Rosenstock et al. (1999) noted that competition between native and exotic wildlife has not been studied in relation to water developments. In recent years, aoudad populations have increased in west Texas (Texas Parks and Wildlife Department, unpublished data) but their effects on and interactions with desert bighorn sheep are unknown. Aoudads have similar life history strategies as do desert bighorn sheep and would likely outcompete bighorn sheep (Seegmiller and Simpson 1979, Krausman et al. 1999). Additionally, aoudad host a variety of diseases that may be detrimental to restoration efforts for desert bighorn sheep (Mungall and Sheffield 1994).

Our objectives were to (1) determine guzzler use by desert bighorn sheep, (2) assess relationships between microhabitat characteristics (vegetative and topographical) at guzzler sites and use by desert bighorn sheep, and (3) evaluate relationships in guzzler use by desert bighorn sheep and aoudad. More specifically, we predicted that guzzler use by desert bighorn sheep will: (1) increase during summer, (2) decrease with increasing screening cover, and (3) increase with distance to other permanent water sources.

Study Area

Research was conducted for 1 year from April 2000 to March 2001 on Texas

Parks and Wildlife Department's Black Gap Wildlife Management Area (WMA) located 88 km south of Marathon, Brewster County, Texas. The 43,368-ha management area lies in the Chihuahuan Desert Biotic Province and the Trans-Pecos ecological region (Hatch et al. 1990). Elevations ranged from 548–1,402 m (Brownlee 1981) and precipitation averaged 28.4 cm annually, with 69% falling during May–September (Brownlee 1981). Surface water available at Black Gap WMA included the Rio Grande, 2 large earthen tanks that hold seasonal water, seasonal tinajas or water holes, and 38 guzzlers. Available permanent water (including guzzlers) in the area was $\leq$1 waterer/279 ha. Vegetation at Black Gap WMA was classified into 8 broad categories (Rogers 1964) including persimmon (*Diospyros texana*)-walnut (*Juglans* sp.), mesquite (*Prosopis glandulosa*)-whitethorn (*Acacia constricta*), rocky canyon cliff, whitethorn-creosote bush (*Larrea tridentata*), sotol (*Dasylirion leiophyllum*)-lechuguilla (*Agave lechuguilla*), grama (*Bouteloua* spp.)-prickly pear (*Opuntia* spp.), riparian, and yucca (*Yucca* spp.)-oak (*Quercus* spp.). Approximately 70–100 desert bighorn sheep and 40–60 aoudad occurred on Black Gap WMA and surrounding private lands during the study (Texas Parks and Wildlife Department, unpublished data).

Annual and average monthly precipitation at Black Gap WMA during the study period were 35.0 and 2.9 cm, respectively. The majority of precipitation (63%) fell during October–January. Adjusted temperatures at Black Gap WMA ranged from 3.0ºC (average daily minimum) in December to 37.5ºC (average daily maximum) in July. Temperatures ranged from –3.1ºC to 49.0ºC with lows and highs occurring in January and May, respectively. Daily maximum temperatures were $\geq$38ºC from April–October.

Methods

Use of guzzlers.–We used a stratified random sampling design to select 7 guzzlers for monitoring that were within proximity to desert bighorn sheep populations (Texas Parks and Wildlife Department, unpublished data). A 35-mm remote camera (Model CTY03, CamTrakker, Watkinsville, Ga.) was mounted 6–10 m from the water trough to facilitate "camera trapping" of wildlife drinking from the guzzler. Cameras were positioned to allow for documentation of guzzler use by ungulates drinking or standing near the trough. Cameras were pre-programmed to obtain $\leq$1 picture/10 minutes to prevent multiple exposures of extended visits by 1 animal (Campbell and Remington 1979). All photographs were inspected for the presence and number of animals. Sheep were classified as ram, ewe, lamb, or unknown. When possible, individuals were identified by unique characteristics (e.g., pelage, horns, radiocollars). Cameras were programmed to print the time and date of the photo event to evaluate extended stays by animals. Series of photographs of the same animal present >12 hrs were classified as loafing.

We assumed that animals photographed at guzzlers were using guzzlers (e.g., drinking). Although most photographs were taken while animals were approaching the trough, based on effective camera capture area (0.06 ha) and study area size (43,680 ha), it is highly improbable (<0.0001%) that animals photographed at guzzlers were there by chance alone. Thus, we defined guzzler use as $\geq$1 animal captured on film at or near the guzzler trough.

Location, season, date, time, species, number of individuals, gender, estimated age (when possible), and comments were recorded and entered into a database. Seasons were defined as winter (Dec–Feb), spring (Mar–May), summer (Jun–Aug), and fall (Sep–Nov). An internal clock printed time of exposure on each photograph. Days were separated into 4 time intervals: morning (dawn–0959 hr), midday (1000–1559 hr), evening (1600 hr–dusk), and night (dusk–dawn). Climatological data were obtained from the National Climatic Data Center from the Panther Junction Weather Station, Big Bend National Park, Brewster County, Texas (35 km southwest of Black Gap WMA). We adjusted temperatures at guzzler sites according to the Standard Atmosphere (Wallace and Hobbs 1977) using temperatures from the Panther Junction Weather Station.

Guzzler characteristics.—Vegetation data were collected along a 100-m transect at each guzzler trough. Transects were situated in a fashion to describe the dominant vegetation surrounding each guzzler site. Canopy cover and density of woody species were estimated using the line-intercept method (Canfield 1941) and a 1-x-100-m plot (Chambers and Brown 1983), respectively. Herbaceous and woody plant density and canopy cover were visually estimated by species within 10 1-m^2 quadrats/transect (Daubenmire 1959). Coverage of pebbles, rocks, boulders, cobblestones, and litter were visually estimated.

Horizontal visibility (screening cover) was estimated with a 1-m Robel pole (Robel 1970) along a 100-m transect in each cardinal direction from the trough. Obstruction (e.g., plants and topographical features) was measured at 10-m intervals along each transect and averaged. The distance from the trough to the first instance of 90% obstruction also was recorded along each cardinal direction and averaged.

Locations of guzzler sites were recorded with a global positioning system (Trimble Navigation, Ltd., Sunnyvale, Calif.), differentially corrected for accuracy, and imported into ArcView (3.2a, Environmental Systems Research Institute, Inc., Redlands, Calif.). Distance to nearest other permanent water from the guzzler sites, elevations, and slopes was generated from 7.5-minute Digital Raster Graphics and 30-m Digital Elevation Models using ArcView. The Rio Grande was excluded as permanent water because telemetry and population surveys indicated desert bighorn sheep did not use proximal habitats (Texas Parks and Wildlife Department, unpublished data). Using correlations coefficients (Zar 1999), we tested the predictions that guzzler use by desert bighorn sheep will 1) decrease with increased canopy coverage and 2) increase with increased distance to another water source.

Aoudad-bighorn sheep interactions.—No *a priori* predictions were made relative to interactions between aoudad and desert bighorn sheep use of guzzlers. However, we provide descriptive statistics regarding aoudad use of guzzlers (e.g., seasonal and diurnal use) and explore interactions between aoudad and bighorn sheep use of guzzlers (e.g., seasonal, time of day, and guzzler site) using correlation coefficients (Zar 1999). Percentage data were arcsine transformed prior to analysis.

Results

Bighorn sheep use of guzzlers.—Desert bighorn sheep (Figure 1a, b) accounted for 15.5% (n = 219) of all animal photographs (n = 1,417) and ranked third among 13 species (Foster 2002) identified at guzzlers. Desert bighorn sheep ranked second among large mammals using guzzlers. Use of guzzlers by desert bighorn sheep peaked in summer with 122 photographs and accounted for 55% of all bighorn sheep visits at guzzlers (Figure 2a). Fifty percent (n = 110) of guzzler use by desert bighorn sheep occurred during

a

b

c

d

Figure 1. Photographs of desert bighorn sheep (a, b) and aoudads (c, d) at guzzler sites at Black Gap WMA, Brewster County, Texas.

midday (Figure 2b). Morning and evening use were similar with 20 (*n* = 43) and 19% (*n* = 42), respectively, and night use accounted for 11% (*n* = 24) of all desert bighorn sheep watering events. Use of guzzlers appeared to be related to precipitation and ambient temperature (Figure 3).

Guzzler characteristics.—Guzzler sites were dominated by a gravelly mulch substrate with a variety of shrubs and herbaceous plants characteristic of Chihuahuan Desert Scrub (Foster 2002). Canopy cover of woody species ranged from 14.9–39.1% and lechuguilla, sotol, and evergreen sumac (*Rhus virens*) were dominant shrubs at guzzler sites. Chino grama (*Bouteloua ramosa*) and sideoats grama (*B. curtipendula*) were dominant grasses. Mean distance from guzzler drinker to the first instance of 90% screening cover ranged from 13.5–32.5 m and mean screening cover ranged from 56.9–89.3%. Guzzler use by desert bighorn sheep decreased with increasing woody cover (r = -0.73, P = 0.03). Elevations and slopes at guzzler sites ranged from 656–1,126 m and 10.0–66.0%, respectively. All but 1 guzzler was ≤2.9 km from another permanent water. Desert bighorn sheep use of guzzlers increased (r = 0.95, P = 0.01) as the distance to another permanent water increased.

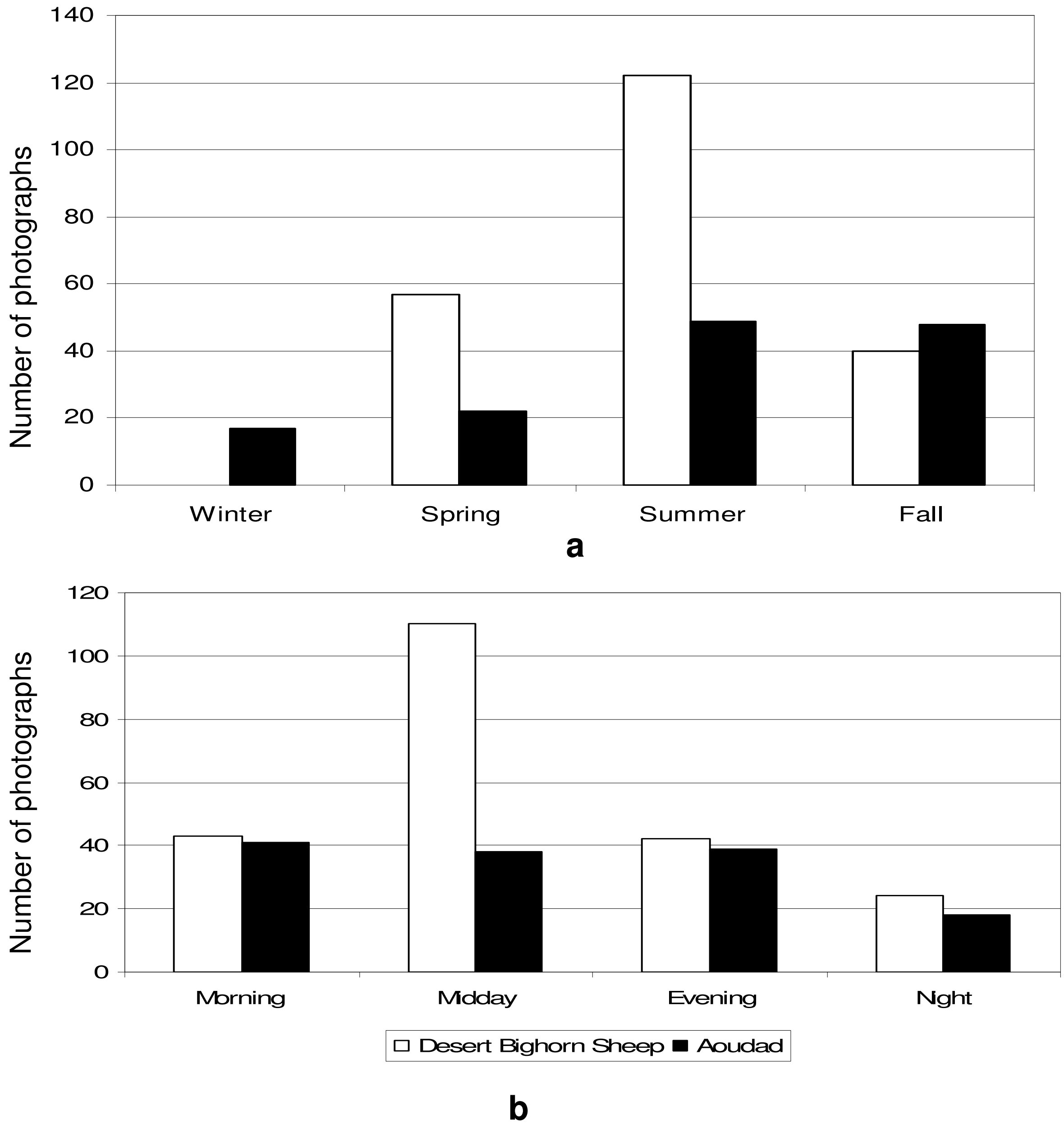

Figure 2. Seasonal (a) and diurnal (b) distributions of visits (e.g., photographs) by desert bighorn sheep and aoudads at guzzler sites at Black Gap WMA, Brewster County, Texas, 2000–2001.

Guzzler use by desert bighorn sheep was more evenly distributed in areas with water ≤2.1 km apart (Foster 2002).

Aoudad-bighorn sheep interactions.—Aoudads (Figure 1c, d) accounted for 136 photographs at guzzlers in which 12% were classified as extended stays. We identified ≥10 different aoudads from photographs. Thirty-six and 35% of aoudad use occurred during summer and fall months, respectively (Figure 2a). Aoudads used guzzlers throughout the day (Figure 2b) with 30% (n = 41) of activity occurring during morning, 28% (n = 38) during midday, 29% (n = 39) during evening, and 13% (n = 18) during night. Use of guzzlers by aoudads and desert bighorn sheep varied by location and was negatively correlated (r = –0.69, P = 0.07).

Discussion

Bighorn sheep use of guzzlers.—Our study indicates that desert bighorn sheep use guzzlers on a seasonal basis and use peaked in summer when ambient temperature was higher and the availability of pooled water from rainstorms was lower. Although precipitation during the study period was 6.6 cm higher than the long-term average, the distribution of rainfall (e.g., below average amounts during Jul–Sep) and temperature fluctuations may have influenced use of guzzlers by desert bighorn sheep (Figure 3). Specifically, the onset of temperatures ≥38ºC occurred during April which coincided with increased use of guzzlers by desert bighorn sheep. Additionally, increases in rainfall (e.g., Jun) were followed by a sharp decrease in desert bighorn sheep use of guzzlers and when rainfall amounts decreased (e.g., Jul–Sep), guzzler use subsequently increased.

Seasonal use of guzzlers by desert bighorn sheep was highest during summer which was characterized by low rainfall (4.1 cm), high daily mean (≥35.2ºC) and maximum (≥40.3ºC) temperatures, and high evapotranspiration rates. The combination of these factors likely resulted in low availability of free-standing water, low soil moisture, low plant moisture, and increasing water requirements for desert bighorn sheep. Our findings are consistent with Werner (1993) who suggested that desert bighorn sheep increase water use, concentrate within 3.2–6.4 km of water, and limit activity when temperatures exceed 38ºC. This temperature range appears to be a threshold at which water requirements increase (Campbell and Remington 1979, Turner and Weaver 1980).

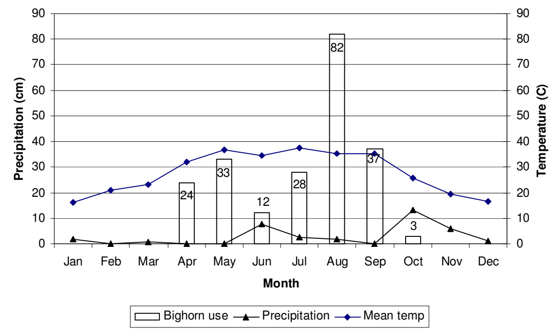

Figure 3. Monthly distribution of visits (numerals within or on top of bars) by desert bighorn sheep at guzzler sites relative to precipitation patterns and temperatures at Black Gap WMA, Brewster County, Texas, 2000–2001.

Desert bighorn sheep in our study frequented guzzlers during midday as opposed to Campbell and Remington (1979) and Turner and Weaver (1980) who suggested sheep preferred drinking during morning hours. Desert bighorn sheep may water when requirements were highest and when temperatures were beginning to rise (e.g., midday) but had not reached the intensity of those during late afternoon.

Guzzler characteristics.—Desert bighorn sheep prefer habitats that provide adequate visibility (Krausman et al. 1999). In our study, desert bighorn sheep used guzzlers that provided higher visibility and had lower canopy cover. Similarly, Hansen (1980) and Turner and Weaver (1980) found desert bighorn sheep watered in areas with minimal horizontal obstruction. Desert bighorn sheep rely on vision for predator avoidance and likely avoided guzzlers with abundant shrubs that may compromise their ability to detect predators. Other factors like slope, elevation, and juxtaposition may also affect guzzler use by bighorns, but they were not measured in our study.

Blong and Pollard (1968) recommended that water developments for desert bighorn sheep should be spaced at 3.2 km. Accordingly, water spacing in our study was adequate, however, guzzler use increased as distance to another water source increased, suggesting a more uniform distribution of water developments may better distribute desert bighorn sheep.

Aoudad-bighorn sheep interactions.—Although aoudad were general in their use of guzzlers with respect to seasons and time of day, they exhibited several behaviors at guzzlers not documented in desert bighorn sheep. Specifically, 12% of aoudad use of guzzlers was classified as extended stays which included dust and mud baths, bedding, and loafing behavior. These aoudad behaviors may result in social aversion by desert bighorn sheep or may impede desert bighorn sheep breeding behaviors. Similar behaviors have been documented by Texas Parks and Wildlife Department during ground and helicopter surveys (B. Tarrant, Texas Parks and Wildlife Department, unpublished data). Furthermore, social aversion may limit desert bighorn sheep from using preferred habitats or watering sites. Geist (1985) portrayed desert bighorn sheep as poor competitors and Krausman et al. (1999) noted that aoudad would likely prevail over desert bighorn sheep in any competitive interaction. Although competition is rarely demonstrated in field studies (Smith 1990), the negative relationship between use of guzzlers by desert bighorn sheep and aoudads suggests that aoudad may inhibit bighorn sheep use of guzzlers.

Management implications

It is not possible to determine water requirements of desert bighorn sheep from the data collected in our study. However, we did document that desert bighorn sheep increased use of guzzlers during very hot and dry periods when water requirements were highest. We concur with Hansen (1971) and Rosenstock et al. (1999) that guzzlers are beneficial to desert bighorn sheep and, based on our study, make recommendations on guzzler use, site selection, and guzzler design for desert bighorn sheep in the Chihuahuan Desert.

Use of guzzlers by desert bighorn sheep can be enhanced in the Chihuahuan Desert by choosing proper sites for guzzler construction. Guzzler sites should be chosen according to a set of guidelines and criteria using a combination of GIS models and ground evaluation. Eliminating placement of guzzlers in deficient areas will minimize costs and labor efforts. Placement of guzzlers should be in close proximity to areas with $\geq$60% slopes and numerous rock outcrops (Locke 2003). Drinkers should be located in areas where distance from the drinker to 90% screening cover is $\geq$30 m. Areas of $\geq$35% shrub canopy coverage should be avoided (Holl 1982). Dense vegetation <30 m from the drinker should be manually reduced from existing guzzler sites to reduce hiding cover for predators (e.g., mountain lions [*Puma concolor*]). Geologic obstructions to visibility should be avoided or minimized where possible. Our data also supports the findings of Blong and Pollard (1968) and indicate that guzzlers should be placed at $\leq$3.2-km intervals. Drinker units should be large enough to eliminate access problems associated with large-horned rams. Similarly, a number of photos indicated that desert bighorn sheep were waiting in line to drink at guzzlers. Surface area of drinkers can be increased or elongated and may permit watering by multiple desert bighorn sheep. This modification should not drastically affect evaporation rates. Consistent with other researchers (Schemnitz et al. 1998), all watering sites should be "wildlife friendly" with modifications to facilitate access and escape. Desert bighorn sheep should benefit from strategically located and well designed guzzlers, which may increase the amount of suitable habitat and thus carrying capacity.

Desert bighorn sheep use of guzzlers was negatively correlated with use by aoudad. We recommend that restoration of desert bighorn sheep may be enhanced by controlling aoudad numbers. Although controlling aoudad populations in the rugged terrain of the Chihuahuan Desert may be difficult, initial control efforts should begin at the guzzler sites, which appear to attract aoudad for extended periods.

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Desert bighorn sheep osteology

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Abstract Zooarchaeologists (i.e., science of zoology and archaeology) that understand mammalian osteology have been able to reconstruct the food gathering, zones of use, climate, butchering techniques, animal use, seasonality of use, and domestication of wild animals by humans. Although there are references available about osteology we could not find a reference that included the complete osteology of bighorn sheep (*Ovis canadensis*). We articulated the skeleton of an adult male bighorn sheep and labeled each bone to serve as a reference for anyone with an interest in the osteology of bighorn sheep.

Desert Bighorn Council Transactions 48:23–27

Key words bighorn sheep, bones, *Ovis canadensis*, skeleton, zooarcheology

Zooarchaeologists, archaeologists, osteoarechaeologists, and biologists are just a few of the disciplines interested in mammalian osteology. Scientists have used faunal analysis to increase the understanding of prehistoric peoples including their environment, seasons of occupation, social status, techniques for food gathering, zones of use, animal use, species composition and distribution, butchering techniques, and mortuary customs (Gilbert 1990). Even those without specialized training in the sciences cannot help but ask when they come across a bone in the field "what bone is that"?

Wildlife biologists, especially those interested in bighorn sheep (*Ovis canadensis*), commonly encounter skeletal remains of bighorn sheep afield. We could not find a skeleton of bighorn sheep in the literature that could be used as a reference to identify the different components of the skeleton. Our objective is to enable anyone dealing with skeletal remains of bighorn sheep to be able to identify them without total dependence on mammalogists or others.

Methods

We found an adult male bighorn sheep in Cabeza Prieta National Wildlife Refuge, Arizona that died from an unknown cause. The carcass was mostly intact. We removed the head and legs and transported the entire carcass to the University of Arizona. We removed as much material as possible from the skeleton manually and then soaked the skeleton in water for 2 weeks. We replaced the water with fresh water and clorox for an additional week. We removed the bones from the solution and removed any remaining material with a brush and scraper. We kept the skeletal remains aligned as they were removed from the solution. After the skeletal remains were cleaned, we placed a flexible copper rod through the vertebrae and attached the remaining structures to the vertebrae with wire, screws, and glue. When the skeleton was articulated, we mounted it on a frame, photographed it so most of the skeleton could be seen, and labeled each part (Lawlor 1979; Figure 1).

Some of the bones were damaged when we found the specimen (i.e., scapula) or lost during transport, or in the cleaning process (i.e., patella). These were replaced by skeletal remains from other bighorn sheep. One of the thoracic vertebrae (i.e., T-6) was broken. We "repaired" this structure with Photoshop 5.0 (Adobe Systems, San Jose, California).

Discussion

Most mammals have a similar number of bones; variation arises depending on function and age. For example, we classified the cranium as a single structure because all the bones of the cranium in this specimen were fused together. Those interested in the specific bones that make up the cranium should examine younger animals and consult most mammalogy texts.

This skeleton (Figure 1) is designed to allow those interested to be able to identify the bones that make up the skeleton of bighorn sheep. Those interested in obtaining additional information about form and function of the bones should consult Gilbert (1990) (and references cited).

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Table 1. Names of bones and labels for an adult male desert bighorn sheep (Figure 1).

Label	Bone name[a]
Cr	Cranium
D	Dentary or ramus
C 1 – 7	Cervical vertebrae
T 1 – 13	Thoracic vertebrae
L 1 – 6	Lumbar vertebrae
S 1 – 4	Sacral vertebrae (fused to form sacrum)
CA 1 – 10[b]	Caudal vertebrae
Pg	Pelvic girdle (made up of fused ilium, ischium, and pubic bones)
F	Femur
Pt	Patella
T	Tibia
Clca	Calcaneous (member of tarsal bones)
Astr	Astragalus (member of tarsal bones)
Trsl	Tarsal bones
Mt	Metatarsals (fused to form cannon bone)
Ph	Phalanges
VR	Vertebral ribs
SR	Sternal ribs
St	Sternum
Sc	Scapula
H	Humerus
U	Ulna
R	Radius
Crpl	Carpal bones
Mc	Metacarpals (fused to form cannon bone)

[a] Names based on Lawlor (1979)
[b] Lydekker (1913) lists 7 for *Ovis* spp.; Shackelton (1985) found 9 in *O. canadensis californiana*; and Anonymous (1862) lists 10 for *Caprovis canadensis*.

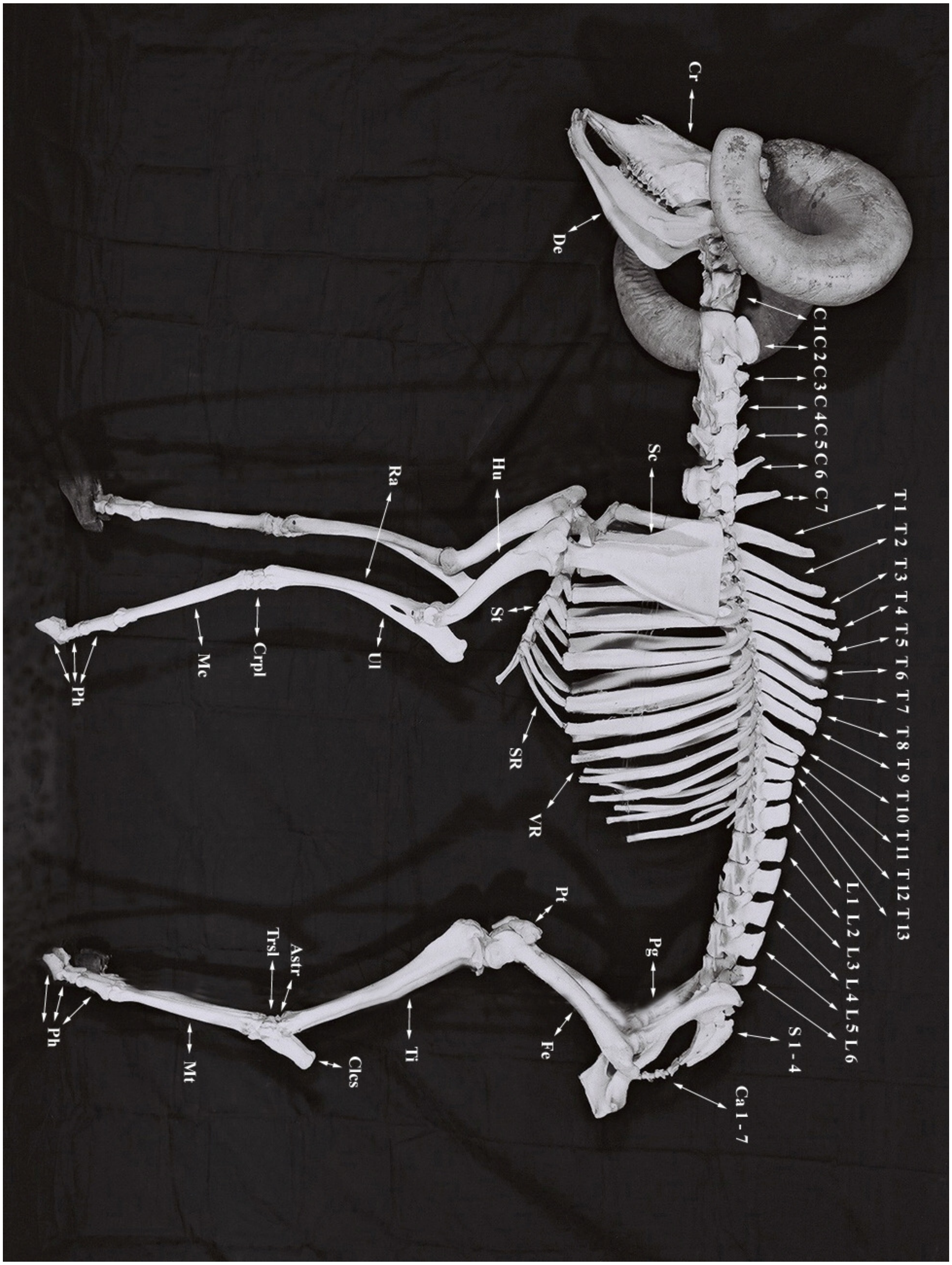

Figure 1. Articulated skeleton of an adult male desert bighorn sheep, Cabeza Prieta Mountains, Arizona, USA.

Historical occurrence and distribution of desert bighorn sheep in Chihuahua, Mexico

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Abstract Desert bighorn sheep were historically found in many rugged and arid desert mountain ranges throughout the American Southwest and northern Mexico. Their affinity for remote and rugged ranges resulted in relatively little recorded information about their status and distribution in Chihuahua, Mexico. We identified 11 areas of historical distribution comprising 23 different mountain ranges. Other mountain ranges probably supported desert bighorn sheep historically, although we were unable to find supporting evidence. Some of the sites we located probably experienced sporadic exchange of individuals as is typical in bighorn sheep metapopulations today. Desert bighorn sheep in Chihuahua were originally found in a chain of mountain ranges oriented in a northwest to southeast direction through the state. Most of these populations were extirpated and only 2 subpopulations may have persisted; 1 in the southeast along the border with Coahuila and another in the northwest adjacent to the international border with New Mexico. Desert bighorn sheep continue to move into this latter area from New Mexico following translocations to the southwestern part of that state. We [EMM, personal observation] saw sheep in the Sierra San Francisco in 1963, but there are no confirmed records of wild desert bighorn sheep in Chihuahua after the mid-1970s. The key to restoring desert bighorn sheep in Chihuahua is to identify historical distributions and evaluate the remaining suitable ranges. These ranges can be prioritized and desert bighorn sheep can be released directly into the areas that hold the highest probability for success.

Key Words Chihuahua, Desert Bighorn Sheep, petroglyphs, *Ovis canadensis*, restoration.

Desert Bighorn Council Transactions 48:28–38

Historically, desert bighorn sheep (*Ovis canadensis mexicana*) were widely distributed throughout southwestern North America (Clark 1978). Within this wide distribution, they were found in areas of arid and extremely rugged terrain (Sheldon 1925). Their reliance on these specific habitat features relegated them to isolated desert mountain ranges. This spatial discontinuity left them vulnerable to decimating factors in the last half of the 1800s. After Europeans moved into the southwestern United States and northern Mexico, desert bighorn sheep suffered from intensive overgrazing by livestock (Sandoval 1985, Holechek et al. 1998), disease (Krausman et al. 1999), drought (Bahre 1991), and unregulated hunting (Townsend 1903, Leopold 1959:528, Monson and Sumner 1980:74).

Excessive forage use and chronic overgrazing were exacerbated by regional drought (Bahre 1991). This would probably have dramatically reduced the nutritional base of desert bighorn sheep populations and contributed to submaintenence recruitment and higher mortality of adults. In addition, diseases transmitted by domestic sheep and goats would have been devastating in areas where those animals were sympatric with bighorn sheep. Desert bighorn sheep have a long history of exposure to domestic livestock (including domestic sheep) which were introduced over 460 years ago (Holechek et al. 1998:49). Despite this long coexistence, there is no evidence wild sheep have developed an immunity to the diseases of domestic sheep and goats.

Mexico passed legislation as early as 1894 restricting hunting wild game (Federal Forest Law). However, like the United States at that time, it lacked financial resources to provide enforcement of those laws (Leopold 1959). The establishment of the Departmento de Caza y Pesca (Department of Game and Fish) in 1916 mirrored similar developments north of the U. S.-Mexico border at that time and provided the infrastructure (but still not the funding) to administer wildlife conservation.

The Federal Aid in Wildlife Restoration Act of 1937 initiated funding for research and management in the USA, but these benefits did not extend south of the border. In 1940 the first game law was passed (Ley de Caza), establishing a legal foundation for wildlife administration in Mexico. Still, with inadequate enforcement of laws, desert bighorn sheep in the arid mountains of Chihuahua declined and were finally extirpated altogether (Leopold 1959).

Sheldon (1925:173) estimated at least 2,000 desert bighorn sheep occupied the state of Chihuahua in the 1920s. Davila (1960) believed desert bighorn sheep were extirpated by the 1960s, however, we [EMM, personal observation] documented desert bighorn sheep in Sierra San Francisco and Sierra el Diablo in southeastern Chihuahua and the Sierra los Borregos in the northwest in 1963–1965. Other sources suggested that by the mid-1970s, there were still about 50 desert bighorn sheep remaining in Chihuahua (Trefethen 1975, Monson and Sumner 1980). By about 1970, wild desert bighorn sheep were probably extirpated from Chihuahua. The only free-ranging desert bighorn sheep in Chihuahua in the last 20 years are those that occasionally enter the state from southwestern New Mexico.

In the absence of population surveys, presence-absence information from individuals in northern Chihuahua is available to document where desert bighorn sheep historically occurred. The first step of a reestablishment program is a consistent and comprehensive evaluation of remaining potential habitat. Historical occurrence is an important criterion to be considered when evaluating the suitability and prioritization of desert bighorn sheep habitat for population reestablishment (Brown 1983, Wakeling and Miller 1990, Cunningham 1993).

Historical bighorn information used in this summary is derived primarily from experienced hunters who spent their lives working and hunting in the mountain ranges of Chihuahua, as well as published accounts, archaeological records, rock art, and petroglyphs (Figure 1). Other mountain ranges not discussed here were inhabited by bighorn sheep, at least seasonally. The only records of occurrence included in this paper are those based on specimens collected and those confirmed personally [EMM, personal observation]. In many cases, mountain ranges were grouped together as 1 historical location if their proximity indicates they supported 1 panmictic population. There probably was some intermittent genetic exchange between some historical locations.

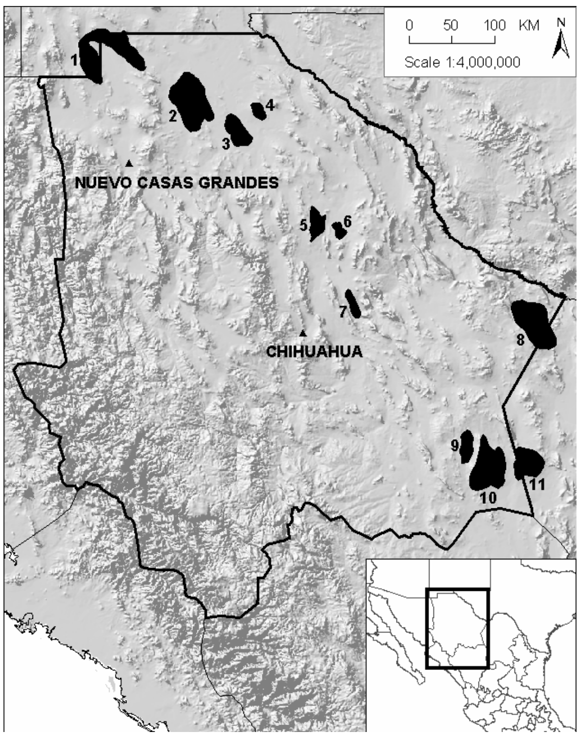

Figure 1. Historical sites where desert bighorn sheep have been documented in the state of Chihuahua.

Historical Distribution

(1) El Chino [=Cerro Chino], Sierra Boca Grande, Sierra Alta, and Sierra Rica (including interchange of desert bighorn sheep with Big Hatchet, Alamo Hueco, and Dog mountains in southern New Mexico).—This area near the U.S.-Mexico boundary has historically been a metapopulation of desert bighorn sheep moving between several interconnected mountain ranges. These movements included interchange between the Big Hatchet and Alamo Hueco mountains in the southern bootheel of New Mexico and the desert mountains in extreme northern Chihuahua.

The history of bighorn in northern Chihuahua's El Chino, Sierra Boca Grande, Sierra Alta, and Sierra Rica mountains is fairly well documented. Desert bighorn sheep occupied these mountains about 100 years ago. Townsend (1903) hunted desert bighorn sheep in the mountains near Cerro Chino in February 1902 to obtain desert bighorn sheep for museums in the East. This collecting trip came only 1 year after the desert bighorn sheep was described as a separate taxonomic entity (Merriam 1901). After about 2 weeks of hunting, Townsend and his hunting party collected at least 6 desert bighorn sheep (skull and skin of 4 males and 2 females) that were then sent to the American Museum of Natural History (AMNH #17952–17957) in New York.

Movement of desert bighorn sheep between northern Chihuahua and the Big Hatchet-Alamo Hueco mountains of New Mexico has been documented (Gross 1960). Anderson (1972:394) reported that in 1966 desert bighorn sheep were moving among these mountains across the international boundary. Mearns (1907) mentions a personal observation of 6 desert bighorn sheep and other reports of desert bighorn sheep in the Big Hatchet Mountains of New Mexico in the 1890s. They were apparently still present, but in decline when E. A. Goldman visited in 1908 (Bailey 1931:21). The desert bighorn sheep population in the Big Hatchets of New Mexico were estimated to number as high as 300 prior to the 1950s (Gordon 1957), but surveys were not systematic at that time and probably represent mere guesses. Gross (1960) reported this herd had declined to fewer than 25 desert bighorn sheep by 1960. Desert bighorn sheep were translocated from a captive New Mexico herd at Red Rock into the Big Hatchet Mountains in 1979 ($n = 14$) and 1982 ($n = 18$; Fisher 1995). Currently, fewer than 20 desert bighorn sheep inhabit the Big Hatchets and not more than 25 live in the Little Hatchets (E. Rominger, New Mexico Department of Game and Fish, personal communication).

Mearns (1907) reported that desert bighorn sheep were common in the Alamo Huecos in 1893 and that he found many horns from dead desert bighorn sheep (U.S. National Museum-National Museum of Natural History [USNM] 63161) in this mountain range, which was then referred to as the Dog Mountains. A mature male was also killed near the ranch house at Dog Spring in 1893 (USNM 36332). To bolster the population, the Alamo Hueco Mountains received a translocation of 21 desert bighorn sheep from New Mexico's Red Rock facility in 1986 (Fisher 1995). The last desert bighorn sheep was observed in the Alamo Huecos in 2000, and it is believed that this population was extirpated by 2001 (E. Rominger, New Mexico Department of Game and Fish, personal communication). There may be some rams from the Big Hatchets that travel to the Alamo Huecos, but no reports of ewes spending time there.

These historical movements across the international boundary have continued into recent years. Several desert bighorn sheep which were reestablished in the mountains in New Mexico have been harvested in Northern Chihuahua. In 1997–1998, a ram was harvested in Ascension County, Chihuahua about 24 km south of the Alamo Hueco Mountains. This ram unofficially scored 161 Boone and Crockett points and carried a Telonics radiocollar (Mesa, Arizona). This ram was originally moved from the Red Rock captive facility in New Mexico and released in the Big Hatchet Mountains in 1997 (E. Rominger, New Mexico Department of Game and Fish, personal communication). This animal (Figure 2) most likely followed the Alamo Huecos-Dog Mountains into Chihuahua before being harvested.

Figure 2. Ram killed in Ascension County, Chihuahua in 1997 after moving south from southern New Mexico.

There are also reports of 3–4 other desert bighorn sheep being harvested in the last decade just south of the international border in the same general area. One of these desert bighorn sheep was a 5-year-old ram taken on the Las Lilas Ranch. Another report was of a 4-year-old taken in 1996 just south of the Alamo Huecos that unofficially scored about 155 Boone and Crockett points. The horns of this ram are currently on a ranch in the mountains of Chihuahua where the hunter moved after killing it. One other ram was harvested south of El Berrendo (Antelope Wells) that scored 155–160 Boone and Crockett points and was reported to have had a radiocollar, but the frequency is unknown.

(2) Lago de Santa Maria, Sierra San Blas, Sierra la Nariz, Sierra Los Borregos, and Rincon de Chihuahua.—This area surrounding Lago de Santa Maria (Lake Santa Maria) has always been famous as a place to find desert bighorn sheep. It was here in 1899 that naturalists E. W. Nelson and his assistant E. A. Goldman collected 8 specimens that were deposited in the U.S. National Museum (USNM 99339–99346; Figure 3). From these specimens, Merriam (1901) selected 1 as the type specimen to

describe the Mexican desert bighorn sheep as being different from the Rocky Mountain bighorn sheep (*Ovis canadensis canadensis*).

Figure 3. One of the desert bighorn sheep (USNM 99344) shot by Nelson and Goldman in the Lago de Santa Maria Mountains in 1899.

Hornaday (1913) reported that desert bighorn sheep in the Lago de Santa Maria area had become "recently exterminated," presumably about 1910. In 1921, Charles Sheldon inquired about the status of this population from an experienced local hunter (Pedro Zorilla) who had accompanied him on earlier desert bighorn sheep hunts in the area (Sheldon 1925:178). Zorrilla reported that bighorns were probably extirpated then in the Lago de Santa Maria area. Leopold (1959) showed this area to be part of the "present" range of bighorn sheep in Mexico in the 1950s. Villa (1959) received no reports of desert bighorn sheep here in 1957–1958, but we (EMM) confirmed the presence of desert bighorn sheep in Rincon de Chihuahua in the early 1960s. The lack of formal surveys and terrain ruggedness probably accounts for Zorrilla's assumption that they had been extirpated. However, desert bighorn sheep probably did not persist much later than the mid-1960s because we were not able to locate reports of them in this area after that date.

(3) Banco de Lucero, Sierra San Miguel, El Chilicote, and Sierra Grande.— Charles Townsend (1903) also hunted the mountains north of El Carrizal and collected 3 specimens of desert bighorn sheep (adult male, adult female, and young male) on 25 April 1902. These were sent to the Chicago Academy of Sciences where Frank Woodruff made life-like dioramas of these desert bighorn sheep and other southwestern wildlife (Hendrickson and Beecher 1972). The display of 3 desert bighorn sheep collected by Townsend was later transferred to the Notebaert Nature Museum in Chicago with accession numbers 88, 89, and 90 (Figure 4).

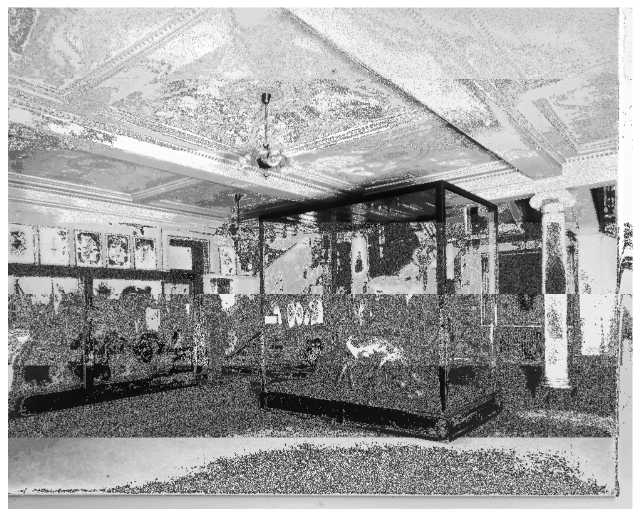

Figure 4. Desert bighorn sheep collected by Townsend (1903) in mountains north of El Carrizal in northwestern Chihuahua (Photo courtesy of Chicago Academy of Sciences).

Townsend (1903) apparently returned to these mountains because on 8 October 1902 he collected a male and female that were sent to the Smithsonian Institution (USNM 115687 and 115688).

Charles Sheldon (1925:173) reported that during the time he lived in Mexico (1898–1902) 40–50 desert bighorn sheep still occupied "a small group of mountains about 20 miles west of Villa Ahumada, including Banco de Lucero, Chilicote and

Sierra Grande, all joined together by ridges." He also believed this population of desert bighorn sheep did not interchange with those that occupied the area around Lago de Santa Maria (Sheldon 1925:173). Don Manuel Manterola Dio hunted with Charles Sheldon's old guide, Pedro Zorrilla, in 1909 and harvested the only 3 desert bighorn sheep they saw (2 rams and 1 ewe) in El Chilicote (Imaz-Baume 1949). Since 2 rams and a ewe was all that was seen in this mountain range the previous year, it was thought that these were the last remaining desert bighorn sheep. When Sheldon (1925) inquired about this population in 1921, Pedro Zorrilla told him they were extirpated.

(4) Candelaria Mountains.—This small and isolated mountain range is not mentioned in historical accounts, but the prior presence of desert bighorn sheep is suggested by the desert bighorn sheep rock art left there by much earlier inhabitants. These mountains lie about 40 km north of Banco de Lucero and 120 km south of El Paso, TX. The Candelaria Mountains contain 1 natural spring that was well known to early inhabitants and obviously served as a frequently occupied site. This area, and the nearby Sierra la Ranchería, contain some of the most remarkable petroglyphs from the Archaic Period (7,500 to 2,000 years ago). Petroglyphs in this area are so unique they are referred to as "The Candelaria Style" (Davis 1979:53, cited in Mendiola-Galván 1998).

Schaafsma (1980:57) illustrates a reconstruction of some of the Candelaria Mountain petroglyphs and rock art containing desert bighorn sheep. The rock art consists of square-bodied rams painted in light red amid a motif of hunting activity. The rams depicted are shown in a frontal view, which is uncommon in rock art in the Southwest (Schaafsma 1980, but see Murray and Espinosa 2006). The desert bighorn sheep on these panels appear to have been added later than the original Archaic artwork; just how much later is unknown, but there is a similar addition of men with bows that indicates it was within the last 1,000 years. The primary theme of the underlying artwork is that of hunters killing big game so the addition of the bighorn sheep rock art at a later date is a strong indication that desert bighorn sheep where important quarry to local inhabitants. The presence of shaman-like figures indicates there is not only utilitarian, but perhaps some religious significance to the petroglyphs as well.

Mendiola-Galván (1998:20) reproduced an illustration derived from Davis (1979:53), showing desert bighorn sheep rock art from the Candelaria Mountains and the Sierra la Ranchería. The rock art depicts what appears to be male and female desert bighorn sheep in red paint among human hunters wielding spears.

(5) Sierra las Escaramuzas and Sierra El Rayo.—Leopold (1959:525) listed this range as former habitat, but no longer occupied. However, in a book of his hunting exploits, Victor López-Gardea (1974) details his 1942 desert bighorn sheep hunt in the Sierra las Escaramuzas. He killed a ram that year in a saddle called La Vibora situated between the Sierra El Rayo and Sierra las Escaramuzas and it was given as a gift to the President of Mexico, General Manuel Avila Camacho (Figure 5, López-Gardea 1974:110). Gustavo "Michy" Schneider in the city of Chihuahua owns a mounted desert bighorn sheep head that was killed by taxidermist and well-known hunting guide, Alejandro López Escalera in Sierra las Escaramuzas in 1946 (Figure 6).

Figure 5. Victor López Gardea poses with the ram he killed in Las Escaramuzas in 1942 and presented as a gift to the president of Mexico.

Figure 6. Alejandro López Escalera killed this ram in Sierra las Escaramuzas in 1946.

(6) Sierra el Jabali.—A colored photograph from 5 February 1937 shows a pair of happy hunters and one tired horse after a hunt in El Jabali Mountains (Figure 7). The hunters are Lieutenant Colonel Romero Gallardo of the Mexican Army and local guide-taxidermist Alejandro López Escalera with 2 young rams and a desert mule deer.

A desert bighorn sheep ram skull mounted on a plaque in the city of Chihuahua is said to have been killed in the Sierra el Jabali on a later hunting trip by Alejandro López Escalera in 1944. This was possibly 1 of the last desert bighorn sheep in that mountain range; Leopold (1959:525) listed this range as former desert bighorn sheep habitat no longer occupied in the late 1950s.

Figure 7. Lieutenant Colonel Romero Gallardo of the Mexican Army and local guide-taxidermist Alejandro López Escalera with 2 young rams and a desert mule deer taken in the El Jabali Mountains in 5 February 1937.

(7) Sierra el Morrion.—This mountain range was well known as a historical population of desert bighorn sheep. Sheldon (1925:172) mentions that he "used to admire three or four fine skulls hanging on the walls of a house of an aged ranch owner then living. These sheep had been killed by his vaqueros sometime before 1860, on mountains twenty miles north of Chihuahua [City]." These mountains are the Sierra el Morrion and desert bighorn sheep persisted there up to at least 1940, but were extirpated by the time Leopold wrote his book *Wildlife of Mexico* in the late 1950s.

(8) Sierra los Hechiceros.—Baker (1956:328) reported that Juan José Zapata of the Hacienda Rincón knew of a band of desert bighorns living in these mountains in 1953. Desert bighorn sheep in the Sierra los Hechiceros may have persisted into the 1960s (Anderson 1972:394, Leopold 1959), but Villa (1959) failed to find any during a field reconnaissance in 1957–1958 despite credible local reports.

(9.) Sierra San Francisco (including El Cimarron to the north).—El Cimarron is a small, isolated peak to the north of Sierra San Francisco and was probably occupied by desert bighorn sheep periodically. There are few records associated with desert bighorn sheep in this mountain range, but it is close to Sierra del Diablo (see below) for which there are consistent records of desert bighorn sheep. We [EMM] confirmed the presence of desert bighorn sheep in this mountain range during field reconnaissance in 1963.

(10.) Sierra del Diablo.—There were reports of a "sizable band of sheep" on the Rancho La Ventura near this mountain range (possibly in the neighboring Sierra el Almagre) as late as the mid-1950s (Baker 1956:329). Anderson (1972:394) mentions field notes of a 1954 conversation with a hotel owner in Jimenez, Chihuahua who reported that desert bighorn sheep were seen in recent years in the Sierra del Diablo. Although Villa (1959) did not locate any desert bighorn sheep during his field trip in 1959, they occurred in this mountain range at the time because we [EMM, personal observation] observed them during field reconnaissance in the early 1960s. In 1960, a group of desert bighorn sheep were discovered by cowboys in that mountain range while moving cattle to a new watering site. The desert bighorn sheep were quickly pursued and a ram was shot (Figure 8). Trefethan (1975:141) states that there was "for sure" a small herd of about 50 desert bighorn sheep still inhabiting the Sierra del Diablos in the 1970s, but does not mention his sources.

Figure 8. A ram harvested in Sierra del Diablo in 1960 by a hunter in Saltillo, Coahuila. (Photo courtesy of Alejandro Espinosa).

(11.) Sierra Mojada.—Sierra Mojada is about 40 km east of Sierra del Diablo and straddles the Chihuahua-Coahuila border. This mountain range was noted as having desert bighorn sheep in the late 1950s by Villa (1959), Leopold (1959:525) and Baker (1956:329). Most of this population was in the state of Coahuila and apparently the last mountain range to hold a remnant population in either Coahuila or Chihuahua, with desert bighorn sheep persisting until about 1970 (Espinosa et al. 2006).

Discussion

The conservation of desert bighorn sheep in Mexico is hampered by the lack of protection and the frequent shifting of responsible management agencies, responsibilities, and reorganization of departments (Valdez et al. 2006). Depending on the direction of past Mexican presidents, wildlife has been administered by several different agencies over the last few decades (Tarango and Krausman 1997). Those responsible for Mexican wildlife conservation are frequently placed in a small, under-funded department within a larger agency, whose responsibilities may be very different from conservation issues (e.g., urban development, agriculture, livestock, social development).

Although there is a firm legal basis for wildlife administration in Mexico, the governmental infrastructure has lacked historical stability, continuity, and funding. In addition, there continues to be no effective state or federal wildlife law enforcement in Mexico, rendering the wildlife laws ineffective. There are many people concerned about the future of wildlife conservation in Mexico and would like to see the establishment of an effective, well-funded, and perpetual administrative system, but such changes are restrained by deep ties to economic and social issues.

Desert bighorn sheep are an important part of Chihuahua's natural heritage. In addition, properly managed desert bighorn sheep populations can make an important economic contribution to the state's economy. Interest in hunting desert bighorn sheep remains strong, which provides an incentive to manage these animals as a renewable natural resource.

The state of Chihuahua is beginning to establish a recovery program. The first step of any successful desert bighorn sheep restoration is to identify historical occurrences. The next step will be to evaluate these historical ranges and any others that appear suitable for desert bighorn sheep occupation using any of the established bighorn habitat evaluation procedures (Brown 1983, Wakeling and Miller 1990, Cunningham 1993). This has begun in the State of Chihuahua. The evaluated ranges will then be prioritized by habitat quality so translocations can occur in priority to maximize the success of restoration efforts.

The future success of desert bighorn sheep restoration in Chihuahua will hinge on the ability of those involved to avoid placing limited desert bighorn sheep in less suitable habitat for socio-political reasons. Translocation priority must be based solely on biological factors. It is preferable that bighorn sheep used for restoration be wild-caught and released without being held in captivity. If sufficient source stock are not available, very large enclosures might be a viable option for providing the necessary animals. This is currently being attempted with a 3,000 ha enclosure on La Guarida Ranch. Regardless, restoration efforts should be based on a model of wildlife and habitat management, rather than animal husbandry. This is the protocol now being used successfully by Arizona, New Mexico, and other U.S. states. The future of desert bighorn sheep in Chihuahua lies in wild animals released in the best habitat with adequate protection.

Acknowledgements.—Alejandro Espinosa and Raul Valdez thoroughly reviewed the manuscript and provided critical information on historical desert bighorn sheep occurrence in Chihuahua and in the archaeological record in Northern Mexico. Cathy Crawford (Arizona Game and Fish Department) lent her cartographic talents to depict historical distribution based on the data contained herein. Steve Sullivan (Chicago Academy of Sciences), Alfred Gardner and Craig Ludwig (National Museum of Natural History), Richard Monk, Ross MacPhee, and Teresa Pacheco (American Museum of Natural History), Jim Mead (Northern Arizona University), Ernie Lundelius (University of Texas-Austin), and Art Harris (University of Texas-El Paso) searched for and helped locate records of specimens deposited in museum collections. Anne Gondor (The Nature Conservancy-Northwest Mexico Program) provided cartographic information that made plotting these historical locations much easier. Toby Taylor helped with the geographic location of an important archaeological site. Eric Rominger (New Mexico Department of Game and Fish) shared information about recent bighorn sheep management activities north of the border. Neil Carmony provided a copy of a classic, but obscure manuscript that was very important and Dave Brown helped steer us in the right direction regarding some available museum specimens and publications.

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Survival of bighorn sheep following surgical amputation of fractured limbs

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Abstract Capturing wildlife inherently risks injury to the target wildlife regardless of capture technique. Bighorn sheep (*Ovis canadensis)* are routinely captured from helicopters using net guns because this is considered the safest and most cost-effective method. Nevertheless, injuries occur, and euthanasia is often administered to those with fractured limbs. During a 20-year period, 1985–2005, we handled 748 sheep during translocations and encountered 4 fractured limbs. We surgically amputated a fractured limb (3 rear, 1 front) from 4 bighorn sheep and subsequently monitored their survival after translocation to determine if surgical amputation was a viable alternative to euthanasia for injured animals. Bighorn sheep survived for 4 months to >5 years following amputation in new habitats as part of population translocations. At least 1 appeared to reproduce and raise offspring. Surgical amputation may be used in lieu of euthanasia when a leg fracture occurs during a capture event if appropriate materials and trained personnel are available.

Desert Bighorn Council Transactions 48:39–44

Key words amputation, bighorn sheep, surgery, survival

Wildlife are routinely captured for research and translocation, and although techniques for capturing wildlife are constantly improving, injuries still occur during these events. Net guns and helicopters have become the standard for capturing bighorn sheep because capture-related mortality and stress-related deaths have decreased with this approach (Remington and Fuller 1993). However, injuries still occur, and bighorn sheep that sustain fractures are commonly euthanized because of these debilitating injuries.

In Arizona, handling crews have been using surgical amputation of fractured limbs in lieu of euthanization to further reduce capture-induced mortality during translocations. Limb amputations of wildlife in the field have rarely been reported and post-release survival has not been determined nor documented. We report on treatment and post-release survival of 4 bighorn sheep that sustained fractures during capture and had surgical amputation of the fractured limbs.

Methods

Capture and handling.—Since the mid-1980s the Arizona Game and Fish Department has captured bighorn sheep in southwestern Arizona almost exclusively using helicopters and net guns. Netted animals are secured at the capture site with hobbles and a blindfold. They are then transported back to a central processing area either slung underneath the helicopter in a transport bag or carried inside. The transport method used was generally determined by proximity of the captured animal and a suitable landing site. Capture and handling procedures have been described by others (deVos and Remington 1981, Remington and Fuller 1993), and we routinely followed the standardized protocols they described. These techniques minimize capture injury and death.

At the processing site, prevention of injury was the primary consideration and medical-surgical procedures were secondary. All bighorn sheep were evaluated for proper restraint, injury, and vital signs. Body temperature was monitored continuously and water was poured on bodies of bighorn sheep whose temperatures exceeded 40° C. Blood samples desired for disease testing were drawn via jugular venipuncture, and about 200 cc of lactated Ringers solution was delivered intravenously to each animal. Oxygen was provided intermittently with a demand valve and facemask. Ivermectin (Ivercide, Phoenix; 0.75 cc to lambs, 1 cc to ewes, and 1.5–2 cc to rams depending on size) was injected to treat potential parasites, and tetracycline (such as Oxybiotic-200, Butler; 2 cc per 45 kg weight) was given as a broad spectrum antibiotic. Intravenous fluids and oxygen were given until all procedures such as ear tagging and radio collaring had been completed. Animals were then placed in a transport crate for later release.

When bighorn sheep were captured in rocky habitat, lacerations and injuries are common. We applied a topical antiseptic spray on abrasions and used minor surgery for lacerations. Bighorn sheep occasionally demonstrated clinical symptoms of shock. We administered 25–50 cc dexamethazone (Phoenix), increased lactated Ringers to 1000 cc or more, and provided longer administration of oxygen on these occasions.

Surgery.—Fractures occurred rarely. From 1985 to 2005, we handled 748 bighorn sheep during translocations, and encountered only 5 fractures. The first fracture we encountered was found on necropsy to be of the spine. Since then we have encountered 4 fractured legs: 2 were left hindlegs on a male and a female, the third was a right hindleg on a female, and the last was a right foreleg on a female. The first 3 were metatarsal and the last was a metacarpal fracture. Since we began using net guns in 1985, we have carried sterile surgical packs to deal with accidental injuries. We chose to amputate rather than euthanize the animals with limb fractures, and performed surgery in the field, usually working on a portable table or the tailgate of a truck. We anesthetized our first 2 fractures intravenously with 2:1 ketamine (Ketaset, Fort Dodge)-diazepam (Valium, Roche) solution to effect. We used Telazol (Fort Dodge) on the last 2. We preferred to use ketamine-diazepam because recovery was faster and the drug combination did not suppress the cardiopulmonary system in bighorn sheep (Kreeger et al. 2002). We administered oxygen and lactated Ringers throughout the procedure as well. We amputated these limbs below the stifle and elbow using standard small animal surgical procedures (Slatter 1993), leaving a muscle mass to use as a pad over the severed bone (Figure 1). We used absorbable Vicryl (Ethicon) sutures in the subcutaneous tissues and closed the skin with nonabsorbable

Vetafil (S. Jackson) sutures (Figure 2). An elasticon and gauze bandage was applied and the animals were placed in a transport crate for recovery (Figure 3). The amputees were released from the transport crates at their new locations with other sheep, typically within 24–48 hrs of surgery.

Figure 1. Desert bighorn sheep on field operating table. Front leg has been amputated above the metacarpal break and knee. Oxygen is available, body temperature is being monitored.

Figure 2. Suturing of the amputated front limb. A muscle mass has been left to pad the distal end of the cut radius bone.

Monitoring.—Before release, each of the amputees was fitted with a VHF radio collar (Telonics, Telemetry Solutions). These sheep, along with many others that were translocated with them, were relocated, usually from an aircraft, approximately once

Figure 3. The surgical procedure is complete. Bandages are in place to protect the stump, a blindfold and radiocollar have been attached and the sheep is ready to be moved to the recovery and transport crate.

a month until either the radio ceased to function or the animal died. Maximum battery life of these collars was typically 4–5 years. Locations were manually plotted on a paper map in the early years, or recorded on a GPS unit more recently. Coordinates were stored in a GIS system (ArcView GIS 3.2) for mapping and analysis. All location data was obtained by the Arizona Game and Fish Department.

Results

Our first amputation on a bighorn sheep was attempted in November 1989. Sheep were being captured by helicopter and net-gun in the Plomosa Mountains of southwestern Arizona when a 5-year-old female tripped on a rocky hillside and broke her left rear leg. After surgery, the sheep was released with 14 others near Signal Mountain in the Gila Bend Mountains about 120 km southeast of the capture site. This ewe carried a radiocollar and was relocated 16 times over the next 23 months until her radio failed. She was subsequently seen alive during a fixed-wing deer survey in January 1993, 3 years and 3 months after release. She was never found more than about 3.5 km from her release site but she apparently moved easily around her rather small home range (Figure 4). This ewe apparently reproduced successfully. In July 1991, more than 1.5 years after release, she was observed with a lamb. In January 1993 she appeared to be pregnant and had a yearling female with her.

The second fracture we encountered was on a 3-year-old ram in November 1993. Again, the fracture was to the left hind leg. This ram was captured in the Plomosa Mountains, was held an extra day in a transport crate to recover, then released with 44 other sheep into the Sauceda Mountains south of Gila Bend, about 175 km southeast of the capture site. This ram was located at least monthly (*n* = 79) until transmitter failure in April 1998, a span of 4.5 years. He moved freely throughout the Sauceda mountain range, and on one occasion moved to the Sand Tank Mountains and back, a distance of at least 35 km (Figure 5).

In November 2000, a 4-year-old female fractured her right rear leg during net gun capture in the Eagletail Mountains. As on the previous occasions, after surgical amputation she was released the following day along with 24 other sheep into the Harquahala Mountains about 30 kms to the north-northwest. This ewe was relocated monthly (*n* = 22) until she was killed by a mountain lion (*Puma concolor*) near a water hole in July 2002. She had lived for 1 year and 8 months after release and had moved freely throughout a home range that spanned at least 10 km of rugged mountain ridgeline (Figure 6).

Our most recent surgery was performed on another 4-year-old female that was captured in the Kofa Mountains in November 2005. For the first time, the fracture was of a front leg, and we believed that she would have difficulty balancing well with only 1 front leg. She was held for an extra day of recovery and observation, then released with 20 other sheep into the Big Horn Mountains 100 km east-northeast of the capture site. This sheep ran from the release trailer with no apparent handicap, and subsequently moved around the highest parts of the mountain with other sheep. She survived for only 4 months, and was killed by a mountain lion along a trail leading to a waterhole. Her final location was about 5 km from the release site (Figure 7). Three other members of this release were also preyed on by mountain lions during the first 5 months after translocation.

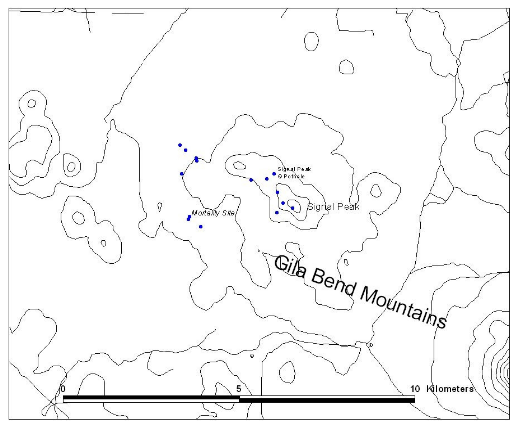

Figure 4. Radiotelemetry locations of a ewe with amputated left rear leg in the Gila Bend Mountains, Maricopa County, Arizona, November 1989 to October 1991.

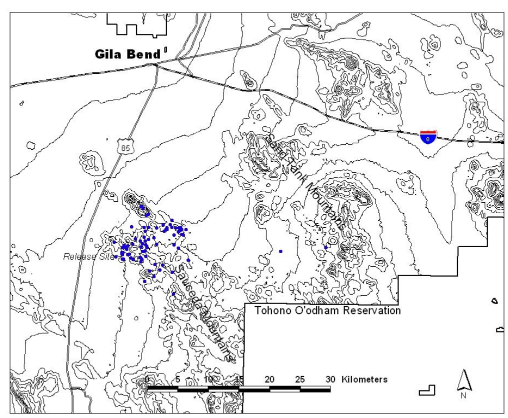

Figure 5. Release site and radiotelemetry locations of a ram with amputated left rear leg in the Sauceda Mountains, Maricopa County, Arizona, November 1993 to April 1998.

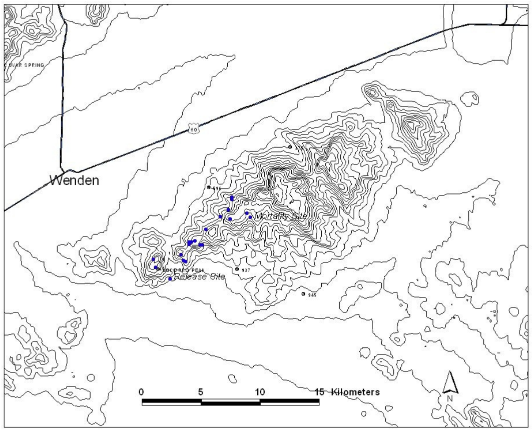

Figure 6. Release site, radiotelemetry locations, and kill site of a ewe with amputated right rear leg in the Harquahala Mountains, La Paz County, Arizona, November 2000 to July 2002.

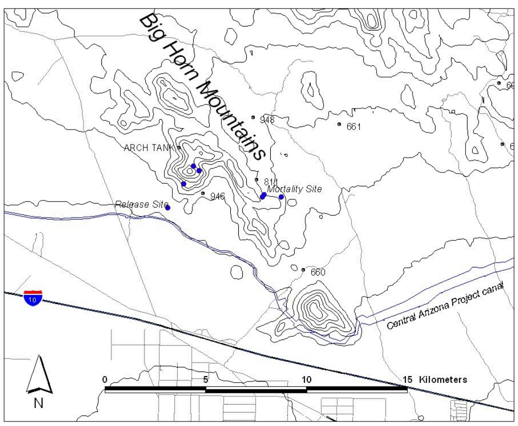

Figure 7. Release site, radiotelemetry locations, and kill site of a ewe with amputated right front leg in the Big Horn Mountains, Maricopa County, Arizona, November 2005 to March 2006.

Discussion

Bighorn sheep seem to require little recovery time after amputation of their limbs and can survive for months to years post-release even though the sheep habitat in southwestern Arizona where these amputees have been released is extremely rugged and arid. However, the amputees were rarely observed from the ground and it is not known if all were able to successfully reproduce, although at least 1 appeared to have done so. Two of the 4 sheep that have had surgical amputations outlived their radiotransmitters, and the other 2 were killed by mountain lions. Reduced mobility may have contributed to the likelihood of being killed by predators, although other sheep with no handicaps met similar fates during the same time periods. Fractures, in our experience, can be handled surgically. The animals can lead mobile, healthy lives and produce offspring. Fractures can be treated in lieu of euthanization when adequate planning allows for appropriate equipment and trained veterinarians to be available to conduct the surgery.

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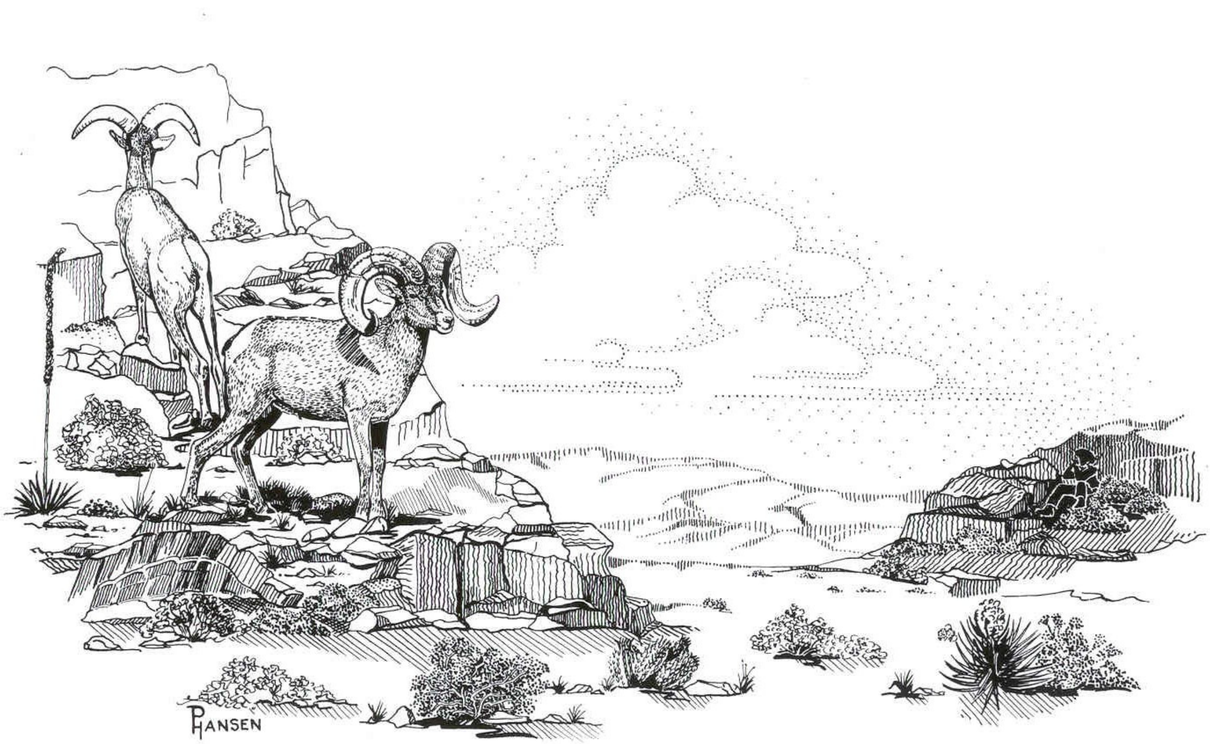
and other game species programs in the southwest quarter of Arizona. ***Clancy Gansberg*** is also a retired veterinarian and "snowbird" who spends his winters in balmy Yuma. He has partnered with Bob Kreycik for 20 years to tend to the animals during nearly all wildlife captures in southwestern Arizona and many others throughout the state.

State Status Reports



Desert bighorn sheep reintroduction in Maderas del Carmen, Coahuila, México

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Abstract Desert bighorn sheep (*Ovis canadensis mexicana)* were extirpated from the state of Coahuila during the 1940s and 1950s. In 2000, Cemex, Agrupación Sierra Madre and Unidos para la Conservación began a proactive program to reintroduce desert bighorn sheep to former historic range using wild-captured animals from Sonora, México. Cemex constructed a high-fenced, predator proof area containing 5,000 ha for a brood facility. Currently >100 desert bighorn sheep of all age classes are in the brood facility. These desert bighorn sheep will be used in reintroduction efforts in Coahuila. In addition, 2 wild releases of desert bighorn sheep were conducted in 2004 (July and November); >30 desert bighorn sheep are in the wild at El Carmen Project Area located in the Maderas del Carmen in northern Coahuila, México.

Desert Bighorn Council Transactions 48:46–49

Key Words Cemex, Coahuila, desert bighorn sheep extirpation, México, reintroduction

Historical Perspective

Substantial information in historical literature verifies the presence of desert bighorn sheep in northern Coahuila, from the Rio Grande border with western Texas south to the Sierra de la Paila (Marsh 1938 unpublished, Baker 1956, Leopold 1959). Reportedly the last desert bighorn sheep taken by hunters was in the Sierra San Lazaro during the early 1950s (R. Baker personal communication). The decline and ultimate extirpation of the desert bighorn sheep in Coahuila was attributed to loss of habitat, disease transmission from domestic goats and sheep, and unregulated hunting (Baker 1956, Leopold 1959, Monson 1980). Efforts to reintroduce desert bighorn sheep were not initiated until 2000, when CEMEX, a global cement company headquartered in Monterrey, Nuevo León, México, in collaboration with Agrupación Sierra Madre and Unidios para la Conservación; began a proactive program to return the desert bighorn sheep to historic range in the desert mountains of northern Coahuila. The objectives of the program are to: (1) provide a brood facility in natural habitat with a predator free environment for maximum production and protection of desert bighorn sheep, (2) build a herd to viable numbers, and (3) use surplus desert bighorn sheep from the brood facility for releases into the wild at Maderas del Carmen and adjacent areas in Coahuila and adjoining states that contain historical or suitable habitat.

Los Pilares Desert Bighorn Sheep Brood Facility

The Los Pilares brood facility is a 5,000 ha enclosure located in the municipality of Ocampo; 165 km northwest of Muzquiz, Coahuila and 60 km south of the Big Bend Region in western Texas. The brood facility lies on the southwest boundary of the Maderas del Carmen Protected Area and is an integral part of Proyecto El Carmen, which is a large conservation project owned by CEMEX and dedicated to the restoration of habitats and native wildlife in the Maderas del Carmen ecosystem.

The brood facility encompasses a series of igneous ridges that run in a north-south direction ≥20 km in length and ≥5 km wide. A series of smaller hills are connected to the higher ridges by valleys, arroyos, and narrow canyons. Elevation ranges from 1,100 m in the low desert to 1,300 m at the summit of the peaks. Cliffs, rockpiles, outcrops, and caves provide cover and lambing areas.

Water is supplied to a series of drinkers located on ridgetops by ≥35 km of pipeline. Lower elevation waters are modified livestock troughs. Ephemeral water is supplied by earthern stock tanks and tinajas. Water is evenly distributed throughout the facility.

Vegetation is typical of lower Chihuahuan Desert shrub habitat. The desert flats are dominated by creosotebush (*Larrea tridentata)*, mesquite (*Prosopis glandulosa),* prickly pear cactus (*Opuntia* spp.), Spanish dagger (*Yucca torreyi*), mariola (*Parthenium incanum*), skeleton-leaf goldeneye (*Vigueria stenoloba*), and lechuguilla (*Agave lechugilla*). The slopes and ridges are dominated by ocotillo (*Fouquieria splendens*), prickly pear cactus, candelilla (*Euphorbia antisyphilitica*), mariola, false agave (*Hechtia texensis*), leatherstem (*Jatropha dioica*), sotol (*Dasylirion leiophyllum*), Mormon tea (*Ephedra aspera*), skeleton-leaf goldeneye, chino grama (*Bouteloua breviseta*), side-oats grama (*B. curtipendula*), mesa greggia (*Nerisyrenia camporum*), pitayah cactus (*Echinocereus enneacanthus*), and lechuguilla.

Twenty permanent vegetation transects were established to determine plant diversity, herbaceous cover, and changes in vegetation over a period of time using 100 m transects (Canfield 1941, Chambers and Brown 1983).

Wildlife species found inside the brood facility are desert mule deer (*Odocoileus hemionus*), several Carmen Mountain white-tailed deer (*O. virginianus carminis*), coyote (*Canis latrans*), gray fox (*Urocyon cinereoargenteus*), javelina (*Pecari tejacu*), ringtail (*Bassariscus astutus*), striped skunk (*Mephitis mephitis*), hognose skunk (*Conepatus leuconotus*), and a vast array of songbirds, scaled quail (*Callipepla squamata*), white-winged dove (*Zenaida asiatica*), and mourning dove (*Z. macroura*). Prior to transplanting desert bighorn sheep into the facility, 1 puma

(*Puma concolor*) and 2 Mexican black bear (*Ursus americanus*) were live trapped and removed from the facility. No large predators are inside the brood facility. This is evidenced by the absence of sign, scats, and tracks. The high electric fence discourages both puma and black bear from entering.

Population Dynamics

Beginning in November 2000, 3 desert bighorn sheep (1 ram, 2 ewes) were released into the Los Pilares brood facility. They were captured at CEMEX's Yaqui Desert Bighorn Sheep Reserve located 20 km southeast of Hermosillo, Sonora. During 2001 and 2002, an additional 48 desert bighorn sheep of all age classes and sexes were released into the brood facility from captures in Sonora, México at CEMEX's Yaqui Desert Bighorn Sheep Reserve, Punta Cirios, San Ramón, and Isla Tiburón. Desert bighorn sheep were radio-collared so they could be monitored in the large brood facility at Los Pilares. The first lamb (ram) was born inside the facility in January 2001. Lamb production has increased steadily; 2002-14 lambs, 2003-25 lambs, 2004-34 lambs, and currently (April 2005) 20 lambs have been born with 10 to 15 pregnant ewes that should lamb by mid to late April 2005.

Mortalities have averaged 2 / yr.; 6 desert bighorn sheep (3 rams, 3 ewes) died from toxic weed poisoning, 3 died from capture myopathy, and 1 died from old age.

The desert bighorn sheep are monitored 3-5 X weekly by telemetry and direct observation, and 21 days / month during lambing season (January – April). Fence and water maintenance checks are conducted several times each week and daily during periods of heavy rainfall or high winds. Current population estimate for the brood facility is 120-125 desert bighorn sheep. Helicopter surveys will be conducted in fall 2005 to verify this number.

The First Wild Release in Coahuila

The Maderas del Carmen ecosystem is vast and contains many large areas of desert bighorn sheep habitat. We conducted habitat surveys and developed waters in a serious of igneous mountain peaks on the west face of the Maderas del Carmen. We captured desert bighorn sheep at CEMEX's Yaqui Desert Bighorn Sheep Reserve in Sonora, México in July and November 2004. Thirty-two desert bighorn sheep were released into the wild in the Maderas del Carmen; this was the first wild release in the state of Coahuila and the first time a desert bighorn sheep had been in these mountains in >50 years. We observed the first lamb born in the wild on 17 March 2005. Desert bighorn sheep were radio-collared when captured in Sonora, and they are monitored 4 x weekly by radio telemetry and direct observation. The desert bighorn sheep settled in a rough mountain with high cliffs, peaks, deep narrow canyons, and high rolling hills. They adapted quickly to Coahuila and produced 4 lambs in 2005. Mortalities incurred were the result of puma predation (2 rams, 2 ewes) and 1 ewe died of capture myopathy. Currently the wild population estimate is 27 adults and 4 lambs. This population needs a larger number of desert bighorn sheep to achieve long term viability; this is based on Berger's (1990) analysis that a population or metapopulation of 100 animals is considered the minimum number for a long-term survival up to 70 years; and from personal experience working with desert bighorn sheep reintroduction in western Texas. Future releases from Sonora or augmenting this population from the brood facility at Los Pilares are both management options that will be explored.

The Future for Desert Bighorn Sheep in Coahuila

The desert bighorn sheep is back in historic range in northern Coahuila, Méxicio after an absence of >50 years. Continued population growth and natural expansion in the future will present a challenge to protect the ecological corridors and desert bighorn sheep habitat. Desert bighorn sheep from western Texas on the Texas Parks's and Wildlife's Black Gap Wildlife Management Area (Black Gap WMA), Big Bend National Park (Big Bend NP) and northern Coahuila are likely to eventually mingle and provide genetic diversity among populations. Desert bighorn sheep have been documented crossing the Rio Grande from Black Gap WMA into the Maderas del Carmen by radio telemetry (B. McKinney personal observations).

Continued population growth in the brood facility at Los Pilares should provide surplus desert bighorn sheep for supplementing the wild herd in Maderas del Carmen as well as providing animals for other releases in the immediate area and adjacent mountain ranges in Coahuila, including other northern states in México.

Acknowledgments.—We gratefully acknowledge CEMEX for their commitment and resources to reintroduce the desert bighorn sheep in historic range in Coahuila. Agrupación Sierra Madre and Unidos para la Conservación played a key role in collaboration with CEMEX on desert bighorn sheep reintroduction. We thank Secretaría de Medio Ambiente y Recursos Naturales (SEMARNAT), and the Seri Kon Kaak of Sonora. We also appreciate the support from Billy Pat McKinney, Gerente El Carmen Project. Alejandro Espinosa, Andy Sandoval, Martin Franco, and El Carmen staff that all help in various ways on the desert bighorn sheep project. We acknowledge the support from our international associates, Texas Parks and Wildlife Department and Texas Bighorn Society.

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Status of bighorn sheep in Arizona, 2004–2005

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Desert Bighorn Council Transactions 48:50–52

Populations

Estimates of Arizona's desert bighorn sheep (*Ovis canadensis mexicana and O. c. nelsoni*) populations have remained stable over the past 2 years. Desert sheep are estimated to number about 5,500. Ram:100 ewes:lamb ratios averaged 44:100:40 in 2004 (n = 863) and 55:100:28 in 2005 (n = 776). Despite improved precipitation, populations are somewhat reduced from previous drought years.

The bighorn sheep (*O. c. mexicana*) herd in the Silver Bell Mountains in Unit 37A was reduced from about 100 to about 75 as a result of a 2003 disease outbreak. These sheep contracted keratoconjunctivitis and contagious echthyma after exposure to domestic goats that were released without permission during fall 2003. Legal proceedings continue regarding several alleged environmental violations relating to this outbreak.

A substantial decline in bighorn sheep (*O. c. nelsoni*) in the Black Mountains near Kingman was also detected. Hunters reported >40 pick up heads during recent hunts. Mountain lion (*Puma concolor*) predation has been implicated as well as drought conditions. Recent, ongoing research has documented that 68% (29 of 43 mortalities) were a result of mountain lion predation, whereas Cunningham and deVos (1992) only determined 1 of 12 mortalities were caused by mountain lions in this area over a decade ago.

Rocky Mountain bighorn sheep (*O. c. candensis*) continue to do well in Arizona, and seem less impacted by the drought than were Arizona's desert sheep. This population is estimated at about 800 animals. Ram:100 ewes:lamb ratios averaged 54:100:38 in 2004 (n = 169) and 57:100:32 in 2005 (n = 348). For both Rocky Mountain and desert bighorn sheep, Arizona surveys about one third of the population annually.

Research

The Department completed several studies of bighorn sheep recently. Studies include bighorn sheep, habitat, and mountain lion relationships (McKinney et al. 2006), genetic relationships among subpopulations (Latch et al. 2006), and habitat analyses (McKinney et al. 2003, O'Brien et al. 2006). Ongoing research is focused primarily on highway influence on survival and movement.

Habitat

The Department works with private organizations (primarily the Arizona Desert Bighorn Sheep Society [ADBSS]) and federal agencies to achieve habitat improvements. Many of these projects are solicited each year through the Department's Habitat Partnership Committees and are funded with Special Big Game License-Tag funds generated through the sale of 2 sheep tags. In 2005, this law was amended to allow for the sale of 3 Special Big Game License-Tags.

In 2004, the Department and ADBSS coordinated on 12 individual projects for $134,586, and in 2003 we coordinated on 19 projects for $295,518. Most projects involved building or maintaining water sources, but also included prescribed fire, sheep survey, and translocations. Habitat evaluations for potential Rocky Mountain bighorn sheep translocations were funded and completed using with these funds.

Translocations

The Department conducted no translocations in 2004. However in 2005, 148 bighorn sheep were captured for translocation. Thirty-two Rocky Mountain bighorn sheep were captured in the Pecos Wilderness Area, New Mexico with drop nets and released in the Pipestem area of Unit 27 in eastern Arizona. Thirty-two desert bighorn sheep (*O. c. mexicana*) were captured in the Kofa Mountains and 30 of these were released on the San Andres National Wildlife Refuge in New Mexico. One ewe sustained a fractured limb and was treated by surgical amputation (Kreycik et al. 2005). This animal was held for 48 hrs and released with another translocation in Arizona. Another bighorn sheep had clinical symptoms of contagious echthyma and was released at the point of capture. An additional 27 desert bighorn sheep (*O. c. mexicana*) were captured in the Plomosa, Chocolate, and Trigo mountains and released in the Big Horn Mountains in Unit 42, along with the bighorn sheep that underwent amputation in the Kofa capture. Twenty-six desert bighorn sheep (*O. c. nelsoni*) were captured in the Virgin Mountains in northwestern Arizona and released in Kanab Creek in Unit 13A. Thirty-one Rocky Mountain bighorn sheep were captured in Eagle Creek and the Phelps Dodge mine near Clifton-Morenci and 29 were released to establish a new population in West Clear Creek near Camp Verde (2 died following drug capture).

The Department continues to plan for additional transplant opportunities, especially for Rocky Mountain bighorn sheep. The Chevelon Canyon area has remained a high priority for future releases, although a domestic sheep allotment in close proximity has kept this transplant from becoming a reality. Other areas under consideration include Hell's Gate, Mazatzal Wilderness, and Sycamore Canyon (north of Sedona). Domestic sheep allotments play a determining role in several potential desert and Rocky Mountain bighorn sheep sites.

Harvest

Bighorn sheep permits remain the most sought after hunting permits in Arizona. In 2004, 18,927 individuals applied for the 84 available permits, whereas in 2005, only 11,266 individuals applied for the 82 available permits. In 2005, applicants could not apply online with a credit card as they could in 2004.

During the 2004 season, 84 hunters participated, harvesting 68 rams in 663 days of hunting. Hunt success averaged 80.9%. In 2005, 81 hunters participated, harvesting 73 rams in 681 days of hunting. Hunt success averaged 90.1% in 2005.

In 2004, age of harvested rams ranged from 3.5 to 11.5 ($\bar{x}$ = 7.5), and horns green scored from 122 3/8 to 182 6/8 ($\bar{x}$ = 155 7/8 B&C). In 2005, age ranged from 3.5 to 11.5 ($\bar{x}$ = 7) on harvested rams, and green scores on horns ranged from 113 2/8 to 173 ($\bar{x}$ = 152 3/8 B&C).

Continuing a long history, the Arizona Game and Fish Commission awarded the Special Big Game License Tags for bighorn sheep (2 tags per year) to ADBSS in 2004 and 2005. Each year, ADBSS has traditionally auctioned 1 tag at the Foundation for North American Wild Sheep Annual Convention and raffles the second tag. In 2004 and 2005, ADBSS raised $174,225 and $328,225 by marketing these tags. In 2006, 3 tags will be available, 2 as an auction and 1 as part of the Arizona Big Game Super Raffle.

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Status of desert bighorn sheep in Nevada, 2004–2005

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Desert Bighorn Council Transactions 48:53–57

Populations

Over 2,700 desert bighorn sheep (*Ovis canadensis*) were classified during standard aerial (helicopter) surveys in September and October 2004. Very encouraging lamb production was again observed as in 2003, compared to the past 2 years of extreme drought conditions that severely reduced lamb numbers to a level below population maintenance levels. The statewide survey resulted in a ratio of 60 rams:100 ewes:45 lambs. In 2005, an abbreviated survey effort classified 1,665 animals. This survey documented yet another good lamb ratio of 42 lambs:100 ewes.

With more favorable habitat conditions and great lamb production in over half the herds in 2003 after 2 years of severe drought, the 2004 statewide population estimate rose to 5,100 (yearlings and older). With continued improvement in habitat conditions resulting in greater lamb production and survival in 2004, the 2005 statewide estimate increased to 5,400. Estimates for each herd are generated from deterministic spreadsheet models that reconstructs population dynamics based on known production-recruitment, known harvested ram ages, and estimated adult survival.

Nevada's desert bighorn population is distributed over two thirds of the state (Figure 1). In 2001, the statewide bighorn sheep management plan was completed, redefining the future restoration goals and delineation for the various bighorn subspecies in the state. Past management practices had identified the northern half of the state for reintroduction of Rocky Mountain and/or California bighorn sheep. The 2001 plan fully recognized for the first time that the entire state of Nevada, the heart of the Great Basin, was historically a single but diverse metapopulation of desert bighorn sheep. It also recognized the decades of successful transplants of Rocky Mountain and California bighorn sheep. The decision was made to extend the desert bighorn sheep restoration habitat area as far north as possible taking into account current distribution of subspecies, geographic separations, and manmade barriers.

Harvest

Nevada continued to provide outstanding opportunity to hunt desert bighorn sheep rams in 2004 and 2005. As

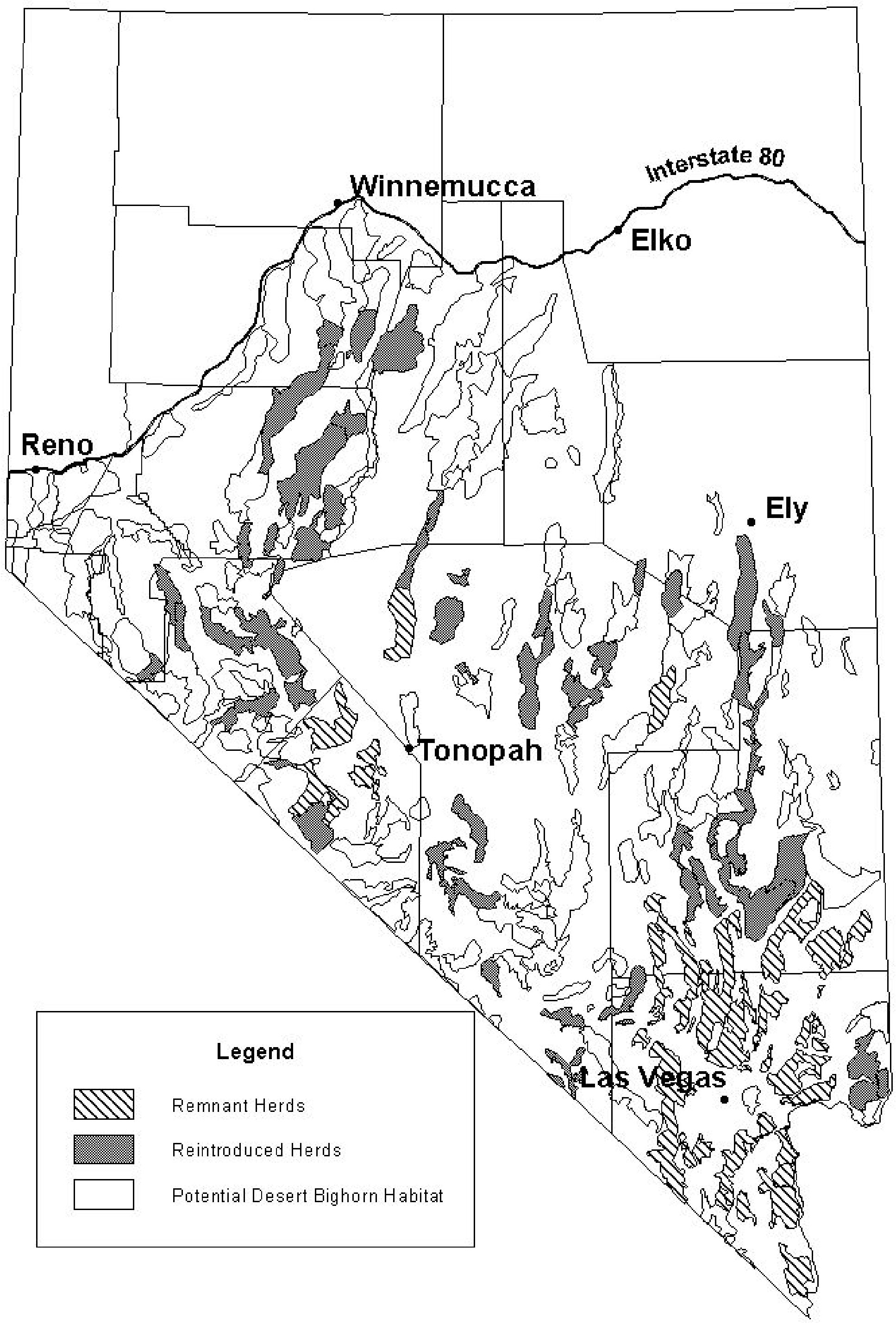

Figure 1. Distribution of desert bighorn sheep in Nevada, 2005.

reflected in the number of first-choice applicants, the desire to hunt bighorn sheep continues to be high. Resident hunters in 2004 sought 120 tags that resulted in draw odds ranging from 11 to 1 up to 141 to 1 for individual hunt units. Among nonresidents, draw odds for 13 tags ranged from 85 to 1 up to 1,578 to 1. There were also 2 Heritage tags (auction) and 3 Partnership In Wildlife (PIW) tags (statewide tags for unsuccessful first draw applicants that donate $50) for a total of 138 tags in 2004. Overall, resident hunters enjoyed a success rate of 91%. The average hunt duration was 6.1 days. Harvested rams averaged 6.1 years of age and 150 3/8 B&C points.

Nevada continued in 2005 to provide more quality desert bighorn sheep hunting opportunities than any other state. A record number of 148 tags was issued. Hunter success continued to be high at 91%. Hunters averaged only 4.7 days hunted, the lowest ever recorded hunter-day effort since desert bighorn sheep hunting began in 1952. The average age of harvested rams rose to 6.5, the highest since 1992 and the average B&C score of over 153 points was the highest since the late 1980s. Eight rams scored over 170 B&C.

Herd Restoration

Restoration of desert bighorn sheep populations into historic ranges remains an important goal in Nevada. There were 23 remnant desert bighorn sheep herds that existed in 1960. This is the year considered to be the low point of bighorn sheep numbers in Nevada at between 2,000 and 3,000 bighorn. As of 2005, Nevada Department of Wildlife in cooperation with bighorn sheep support groups like Nevada Bighorns Unlimited and the Fraternity of the Desert Bighorn have established an additional 36 herds reintroduced into historic unoccupied habitats (Figure 1). These reintroduced herds provided 66% of the total bighorn ram tags in 2005.

Two desert bighorn sheep transplants were cancelled in 2004 due to net gun contractor deficiencies. Both were completed in 2005. The first transplant involved 25 bighorns being reintroduced into the Virgin Mountains along the Arizona state line and east of Lake Mead. The second transplant occurred in the Grant Range of east central Nevada with 26 desert bighorn sheep augmenting a remnant herd that no longer sustained a viable population. This remnant herd was somewhat unique in that it was isolated from all other remnant herds for decades and survived the market hunting and disease die-offs that extirpated all surrounding herds by the 1940s. It was unfortunate that genetic and other biological samples were not collected from the last few remaining animals before it was augmented in 2005.

As 1 of the primary goals identified in the 2001 Nevada bighorn sheep management plan, a bighorn sheep habitat GIS matrix was developed in 2005. The matrix involves identified occupied and potential habitat polygons and series of ranked limiting factors that prevent reintroductions or limit growth of existing herds. The matrix will be used to prioritize management actions to prepare unoccupied bighorn habitats for future desert bighorn herd restoration efforts.

Management Challenges

McCullough Range mortality event.—On 24 July 2005, 22 bighorn sheep were found to have died in proximity to the

Roy water development in the north McCullough Range, directly south of Henderson, Nevada. An extensive investigation ensued into what caused the deaths of 11 rams, 6 ewes, and 5 lambs. Dr. Dan Crowell, a veterinarian with Nevada Department of Agriculture, coordinated the investigation. Bighorn sheep tissue and water samples were submitted to California Animal Health and Food Safety Laboratories at University of California, Davis. The considered possible causes of death included: lightning, dehydration, toxic compounds or metals, or disease.

The drinker to the Roy water development went dry between the time it was visited by game wardens on 11 June 2005 and the rain event on 24 July 2005. The drinker was severely damaged by bighorn sheep hoof activity, with the flow control valve in the open position. Of the 3 storage tanks at the site, 2 of the valves controlling flow to the drinker were closed. Those tanks were full on 24 July. A heavy rain event occurred on the morning of Sunday, 24 July (3.3 cm). The animals all died within a relatively short period of time (within days rather than weeks). Some animals had gotten entangled in Teddy Bear Cholla then moved and died in areas where no Cholla grows. Three carcasses were found over a rise in an adjacent drainage (1 with Cholla tangled in the hide); the remainder of the carcasses were in the draw with the drinker. It is estimated that >100 bighorn sheep were dependent upon and using this drinker at the time of the incident.

Diagnostic findings were inconclusive as to the cause of death of the 22 bighorn sheep. Lightning was reasoned as not a causative factor. A confounding aspect that limited the scope of testing was extreme high temperatures prior to and during the narrow timeframe within which the bighorn sheep died. The record high temperatures in late July served to hasten decomposition. The rapid decomposition of the carcasses limited the number and types of tissue samples collected. Almost all tissue samples were autolyzed and unsuitable for bacteriology tests.

The water samples from the tank that was connected to the open-value drinker and the drinker were negative for microcystin and anatoxin-a. Neither the microcystins nor anatoxin-a algal toxins were detected in any of the submitted water samples at or above the indicated method detection limits. The detected water nitrate-nitrite concentrations were within acceptable limits. Critical factors that likely hampered detection of a toxin in the drinker were the dismantled float valve at the drinker and heavy rainfall that occurred the night before and early morning of the day the sheep were discovered. The inoperable float valve resulted in an open, flow-through system through which the drinker was thoroughly flushed when it rained. Thus, if a toxin were present in the drinker it likely would have been eliminated through prolonged flushing action shortly after rainfall began the night prior to discovery.

The following are test results from a necropsy conducted on a single lamb that was the least decomposed of the carcasses:

- Samples were negative for Botulism toxin via mouse assay,
- Laboratory gross and histo-pathological examinations of a lesion on the right rear foot were consistent with an injury and did not show evidence of electrocution via lightning,
- Heavy metal screens performed on the kidney including arsenic,

cadmium, copper, iron, lead, manganese, mercury, molybdenum, and zinc were within normal ranges for domestic sheep,

- Kidney oxalate testing did not detect the presence of oxalates,
- Testing of Lamb #5 rumenal contents did not detect the presence of strychnine. Infectious Bovine Respiratory Virus (IBR), and Bovine Respiratory Syncytial Virus (BRSV) tests were negative, and
- As discussed in a conference call of NDOW employees, veterinarians, and pathologists, brain sodium levels from the single lamb were elevated above the normal expected levels for domestic sheep, however the sodium levels were not elevated to a level that would be considered diagnostic for sodium toxicity-water deprivation. Attempts at obtaining additional brain samples from the carcasses remaining at the original site were unsuccessful due to lack of brain material in the calvarium of the carcasses.

Wilderness designations.—In November 2004, 16 separate wilderness areas inhabited by desert bighorn sheep herds were designated as wilderness in Clark County, southern Nevada. Again in 2005, 6 additional areas in Lincoln County directly north of Clark County along the Utah border containing desert bighorn sheep herds were designated by Congress as wilderness. Wilderness advocates touted the wilderness bills as protecting bighorn habitat in perpetuity. Certainly the future threats of permanent development and structures were eliminated in these areas, but most are relatively small in size and did little if any to buffer core bighorn habitats and provide connectivity for the metapopulation of bighorn sheep herds still threatened by a burgeoning human population. The lack of appreciation of most publics and land management agencies to do what it takes to manage and sustain a viable bighorn sheep population has already had its impacts on desert bighorn sheep herds inhabiting these new wilderness areas. The opportunities and in many cases required management activities to maintain and enhance water availability, conduct captures and transplants, and investigate die-offs have been compromised.

Suite of issues impacting desert bighorn sheep herds.—There are many issues that continue to impact desert bighorn sheep herd health and sustainability through undetected and long-term cumulative effects. The following is an excerpt from the 2004–2005 Nevada Big Game Status Book for a desert bighorn sheep herd in southern Nevada; it shows the myriad of issues that are affecting many desert bighorn herds in southern Nevada: "...however, due to proximity to Las Vegas, recreational pursuits (e.g., OHV and mountain bike use/proliferation of roads and trails), feral horses and burros, and suburban sprawl serve to degrade the habitat. Landscape scale projects in bighorn sheep habitat include the Kern River Gas Transmission Expansion and Lone Mountain Community Pit. Future large-scale projects include upgrade of Sandy Valley Road and construction of Ivanpah Energy Center (power plant) near Goodsprings. In addition, interest remains to develop a wind energy power generation plant in the Table Mountain area."

Status of desert bighorn sheep in New Mexico, 2004 and 2005

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Desert Bighorn Council Transactions 48:58–60

The desert bighorn sheep (*Ovis candensis mexicana*) population estimate in New Mexico was 248–287 in autumn 2004. No transplants occurred during this year, and in the beginning of December there were about 62 radiocollared desert bighorn sheep statewide. In December 2005, there were 316–375 bighorn sheep in the wild with 99 radiocollars. The statewide population has been increasing since it reached its low of less than 170 bighorn sheep in 2001 (Figure 1). Much of the increase is attributed to transplants out of Red Rock and from Arizona into the wild, with smaller increases from increased lamb recruitment. We believe that transplants after 2001 have been more successful than transplants in the 1990s because of decreased mountain lion (*Puma concolor*) predation in desert bighorn sheep ranges following implementation of a mountain lion removal program in these areas.

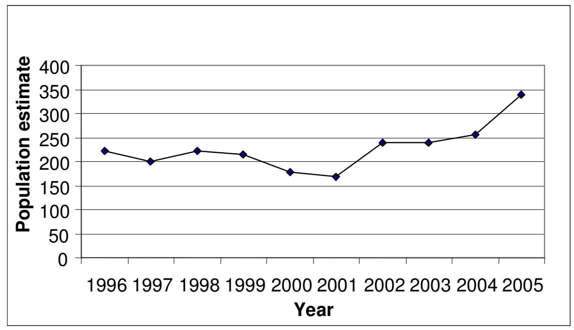

Figure 1. Autumn population estimate for desert bighorn sheep in New Mexico, 1996–2005.

Population Reports

San Andres.—In November 2002, the 9 bighorn sheep on the mountain were augmented with 51 animals from Kofa NWR in AZ, and from the Red Rock captive herd, for an initial population of 60. Fourteen bighorn sheep died between December 2002 and November 2003. Eight of these were killed by mountain lions, 5 were suspected disease related (all 5 were from Red Rock), and 1 was unknown. An additional 6 bighorn sheep died between December 2003 and November 2004. One ewe was killed by a mountain lion, and 5 bighorn sheep (3 ewes, 2 rams) died of other causes, 4 of which were suspected disease related. Mountain lion mortality ceased after December 2003, which coincides with the time we believe mountain lion control was established. From December 2004–November 2005, only 2 radiocollared bighorn sheep died. One was an old ewe who died from kidney failure, and the second ewe died from unknown causes. No mountain lions have been removed since

April 2004 and we are currently in the offending-mountain lion removal only phase of the adaptive mountain lion removal program.

In June 2005, pre-emptive mountain lion control commenced in anticipation of a November 2005 augmentation to the herd. Four mountain lions were removed from June until the release. In November 2005, New Mexico Department of Game Fish received 30 bighorn sheep (25 ewes, 5 rams) from the Arizona Game and Fish Department. They were captured on the Kofa National Wildlife Refuge, and released several miles north of the core area used by the existing herd on the San Andres National Wildlife Refuge. There has been a full time monitor tracking the bighorn sheep herd since the release. The autumn 2004 population estimate was 65–70 bighorn sheep, and the autumn 2005 estimate was 105–110.

Peloncillos.—This herd had declined to about 20–25 individuals, with only 4–6 ewes. In October 2003, we transplanted 33 bighorn sheep (20 ewes, 13 rams) to augment the herd, for a total of 50–55 bighorn sheep. In the year 2 years prior to the release, we removed 5 mountain lions, in the year prior to the release we removed 4 mountain lions, and in the year following the release we removed 5 mountain lions. Three ewes were killed by mountain lions from July–September 2004, and about half the lambs were lost during these months. One female mountain lion was removed and the sheep mortalities to mountain lion predation ceased. There have been no radiocollared mortalities since August 2004, and no additional mountain lions have been removed. There has been a full time monitor tracking the bighorn sheep herd since the release (with the exception of July-September 2004 and July-October 2005). The autumn 2004 population estimate was 65–75 bighorn sheep and the autumn 2005 estimate was 60–70. Lack of increase in 2005 was due primarily to very low lamb recruitment.

Hatchets.— This population remained stable at about 40 individuals for several years. The mountain lion removal program in this mountain range has not been very successful because the very hot, dry, rocky conditions make hunting with hounds extremely difficult. A contract with a snareman was put in place in the spring 2005 in the hopes that the mountain lion removal program would be more successful. One mountain lion was removed in anticipation of a November 2005 bighorn sheep augmentation. The augmentation consisted of 28 bighorn sheep (14 ewes, 14 rams) from Red Rock. Two additional mountain lions were removed in conjunction with the release. A juniper thinning project in the Little Hatchet Mountains was implemented in 2005 in collaboration with the BLM and the State Lands Office (SLO). It was funded jointly by Sikes Act funds and the SLO. Increased visibility as a result of juniper removal should make it more difficult for mountain lions in the area to kill bighorn sheep. The total autumn 2005 population estimate was 60–75 individuals.

Fra Cristobals.—A decline from unknown causes is occurring in the Fra Cristobals. The population increased to an estimated 75 individuals in autumn 2002, but fell to about 60 by autumn 2003 and remained stable through 2004. In 2003 and 2004, there was a full time bighorn sheep monitor, and full time mountain lion snareman. The mountain lion management plan consisted of removing female mountain lions and radiocollaring and releasing male mountain lions. This program was designed to test the hypothesis that if female mountain lions were not present, male mountain lions would move through the bighorn sheep habitat quickly and not remain long enough to make a kill. Five mountain lions were removed during 2004. No bighorn sheep were killed by mountain lions in this year, though there were 2 bighorn sheep mortalities from suspected disease and 1 mortality from old age. However, bighorn sheep hair was present in 3 independent mountain lion scats analyzed in 2004; therefore mountain lion predation was still occurring. In 2005, 2 radiocollared bighorn sheep mortalities were documented, both from mountain lion predation. One mountain lion was removed in 2005. The bighorn sheep population estimate in both autumn 2004 and 2005 was 60 animals. A small group of bighorn sheep (originally reported to be <10) has been reported in the Caballo Mountains, adjacent to the Fra Cristobal Mountains, since 2003. It is assumed that these bighorn sheep emigrated from the Fra Cristobal population.

Ladrons.—This is the most difficult population to survey because of low numbers scattered over a large area and only one functional radiocollar in 2005. This prompted a radiocollaring effort in autumn 2005 that resulted in 3 newly radiocollared bighorn sheep. In 2004, a young ram was documented traveling 50–60 miles away from the core of the habitat, and coming into contact with domestic ewes. This ram was euthanized and sent to the Veterinary Diagnostic Services laboratory (Albuquerque, NM) where he tested negative for pneumonia. In collaboration with the Bureau of Land Management, a juniper thinning project was implemented in 2005 to open a corridor to prime bighorn sheep habitat. The 2004 survey found only 16 bighorn sheep, but we believe the population was 25–30 animals.

Red Rock.—We are continuing with our supplemental feeding program in an attempt to equilibrate the male:female lamb ratio. Initially, it looked promising that the management action was helping, but the 2004 recruitment ratio of 14 males and 6 females was less promising. The 2005 recruitment ratio was 8 males and 9 females. There is a full time contractor on the premises who keeps the fence repaired, monitors bighorn sheep, and removes mountain lions. In 2004 and 2005, 3 and 2 mountain lions, respectively were removed from Red Rock. The population estimate was 70 in 2004 and 93 in 2005 prior to the transplant to the Little Hatchets.

Hunter Harvest

In 2004, only 1 public hunting license was issued in the Peloncillos herd. The hunter took a ram scoring 178 4/8 B&C. In 2005, 1 public hunting license was issued in the Peloncillos, and the harvested ram scored 174 6/8 B&C. The auction hunter hunted in the Peloncillos in 2005 and harvested the new state record ram which scored 186 2/8 B&C.

Status of desert bighorn sheep in Texas, 2004–2005

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Desert Bighorn Council Transactions 48:61–63

Populations

The Trans Pecos region of Texas currently supports 7 primary free-ranging populations of desert bighorn sheep. These occur within the Baylor, Beach, Sierra Diablo, Sierra Vieja, and Van Horn Mountains, and the Texas Parks and Wildlife Department's (TPWD) Black Gap and Elephant Mountain Wildlife Management Areas (WMA). Substantial movement of desert bighorn sheep between mountain ranges has been observed. Isolated bighorn sheep populations now exist within suitable habitat throughout the Trans Pecos region on both private and public land (Big Bend National Park), with limited production occurring.

Desert bighorn sheep numbers in Texas have exceeded the population levels of the early 1900s (500) with numbers currently estimated at over 800 animals. Helicopter surveys conducted August–September 2003 and 2004, indicated increasing bighorn sheep populations. The most substantial increases have consistently been reflected in the Baylor, Beach, and Sierra Diablo Metapopulation (2%, 21%, and 18% in 2003 and 48%, 16%, and 34% during 2004, respectively). Surveys conducted in 2003 produced 477 classifications during 54.3 hours of flight time (8.8 sheep/hour). Survey results yielded ratios of 58 rams:100 ewes:59 lambs. Survey efforts in 2004 produced a record 581 classifications during 65.3 hours of flight time (8.9 sheep/hour) with survey results yielding ratios of 50 rams:100 ewes:36 lambs.

Habitat Improvements

In March 2003, 13 water catchments were refurbished at Black Gap WMA. In 2004, the 427 acre enclosure at Black Gap WMA was refurbished for use as a soft-release facility in future transplants. These projects were accomplished through the cooperative efforts of the Texas Bighorn Society (TBS) and TPWD.

Harvest

Bighorn sheep restoration and management in Texas continues to be funded by hunters through the Federal Aid in Wildlife Restoration Program, Foundation for North American Wild Sheep (FNAWS) auction permits, the Texas Grand Slam Hunt Program, and the TBS. A total of 53 desert bighorn sheep hunting permits have been issued since the Texas Legislature reinstated hunting in 1988. These include: 28 private landowner permits, 16 public hunting permits, 8 FNAWS permits, and 1 TBS permit. Since 1989, $558,000 has been generated from 8 FNAWS permits. Additional funding for research and management has been generated from 7 Texas Grand Slam permits. Overall success for desert bighorn sheep hunting in Texas is 87%.

The 2003–2004 and 2004–2005 hunting seasons proved to be record years for Texas in several categories. Seven total bighorn hunting permits were issued for the 2003–2004 season, which topped the previous record of 6 issued during the 2000–2001 and 2002–2003 seasons. The very first permit for the Black Gap WMA population was among these. In addition, the first TBS permit was issued to assist in generating revenue for bighorn sheep restoration efforts. The hunting opportunity was auctioned at the annual fundraiser for a record $102,000. On 2 March 2004, Mr. Glenn Thurman successfully harvested a new state record at Elephant Mountain WMA. Scoring 180 B&C, the ram surpassed the previous 1997 record of 176 1/8 B&C harvested in the Baylor Mountains. Permits issued for the 2003–2004 hunting season included: 5 private landowner (1 Black Gap WMA, 2 Sierra Diablo Mountains, 1 Baylor Mountain, and 1 Beach Mountain), 1 Grand Slam Permit (Elephant Mountain WMA) and 1 TBS permit (Elephant Mountain WMA).

Several milestones were reached during the 2004–2005 hunting season. A record 8 bighorn hunting permits were issued including: 4 private landowner (2 Sierra Diablo Mountains, 1 Baylor Mountain, and 1 Beach Mountain), 1 Grand Slam Permit (Elephant Mountain WMA), 2 public hunter permits (1 Sierra Diablo WMA and 1 Black Gap WMA) and 1 FNAWS permit (Elephant Mountain WMA). In February 2005, Mr. Terry Fricks purchased the FNAWS permit for $77,000. The previous one-year-old state record was short-lived. In March 2005 Mr. Fricks made history by harvesting a new state record that scored 183 5/8 B&C. The ram won the 2005 FNAWS gold medal.

Problems-Opportunities

- Survey efforts must continue to be expanded to properly evaluate the status and condition of desert bighorn sheep populations in new areas.
- The future of desert bighorn sheep management in Texas must be addressed through appropriate planning strategies. Evaluation of existing management efforts, establishment of long-term goals, and long-term planning are critical for proper management.
- Planning efforts are currently in progress for landscape-level restoration along the border region. Restoration will be accomplished through the cooperative efforts of conservation groups on both sides of the river including: TBS, CEMEX, landowners, and TPWD. Big Bend Ranch State Park is considered as the top priority for future releases in Texas. Success ultimately depends on our ability to work cooperatively in overcoming obstacles such as human disturbances, predators, and exotic issues.
- Elephant Mountain will continue to serve as the primary source of brood stock for reintroduction efforts. However, additional out-of-state

brood stock may be needed to facilitate restoration of desert bighorn sheep in areas of suitable habitat.
- The private landowner remains the single most important factor in restoring and maintaining viable desert bighorn sheep populations in Texas. Efforts to educate landowners regarding proper management of desert bighorn sheep must continue to be expanded.
- Aoudad sheep (*Ammotragus lervia*) continue to be observed mixing with bighorn sheep in Texas. TPWD has the authority, coupled with landowner consent, to eliminate aoudads by lethal means for controlling encroachment in habitat used by desert sheep. These efforts must continue to be expanded on both public and private land.
- Mountain lion predation continues to be one of the limiting factors of desert bighorn sheep populations in Texas. Predator control efforts must be continued in sheep restoration areas to minimize losses to desert bighorn sheep brood stock.
- Construction of wind generators within critical desert bighorn sheep habitat areas has recently been proposed. The noise and motion produced by the structures themselves, and increased human disturbances resulting from road construction and other maintenance activities, are among the concerns. Prevention of wind-power development within bighorn sheep habitat is critical.

Table 1. Summary of desert bighorn sheep numbers and locations in Texas, 2003–2004

	Rams		Ewes		Lambs		Totals	
Location	2003	2004	2003	2004	2003	2004	2003	2004
Black Gap WMA	15	27	34	41	22	8	71	76
Chilicote Ranch[a]	a	a	a	a	a	a	a	a
Elephant Mt. WMA	24	17	32	22	20	8	76	47
Metapopulation	-	-	-	-	-	-	-	-
Baylor Mt.	14	26	26	46	9	23	49	95
Beach Mt.	36	25	31	60	20	16	87	101
Sierra Diablo Mts.	47	74	87	126	54	52	188	252
Van Horn Mts	4	3	2	5	0	2	6	10
Totals	140	172	212	300	125	109	477	581

[a] Survey not conducted

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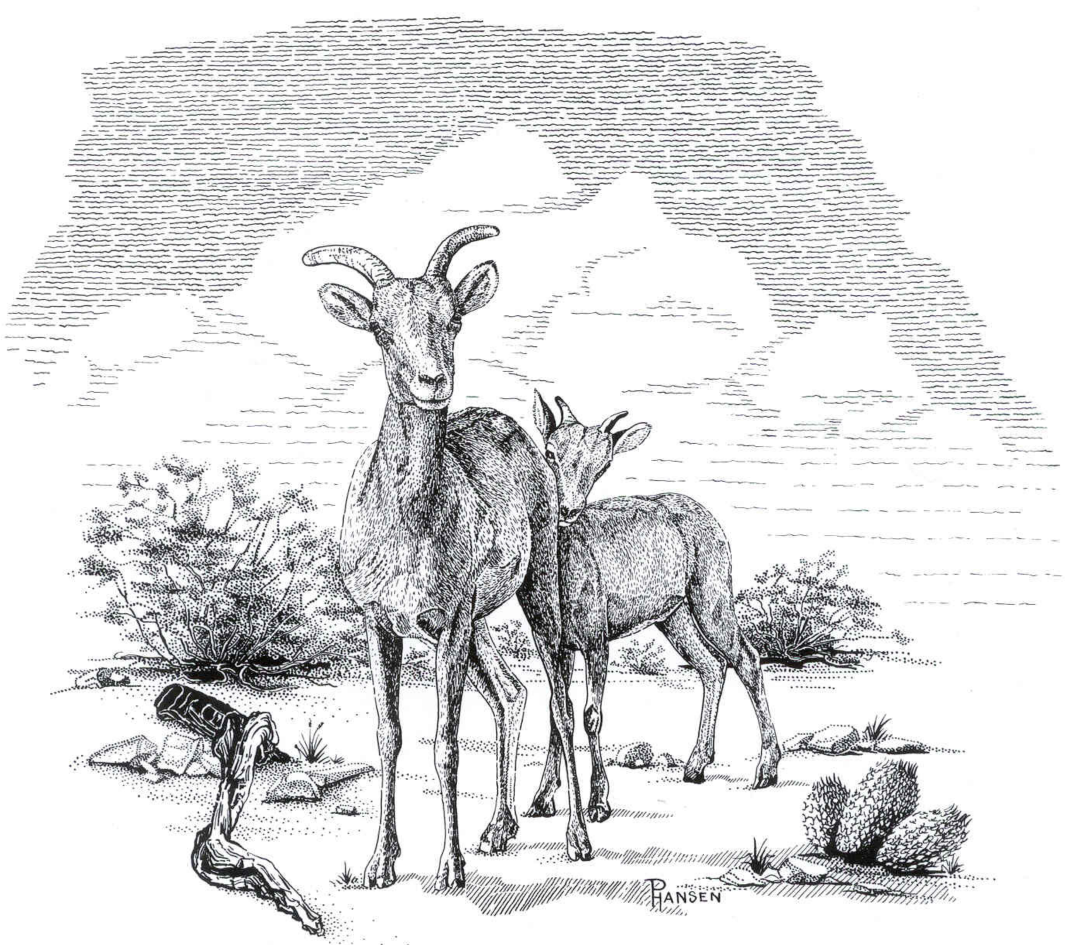

HISTORIC DISTRIBUTION OF DESERT BIGHORN SHEEP (*OVIS CANADENSIS*) IN COAHUILA, MEXICO

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Historically, the desert bighorn sheep occurred throughout Coahuila, Mexico, as far south as latitude 25 º 43´ 02 ´´N. The species apparently was extirpated approximately by 1970. We determined the historic range of desert bighorn sheep through a review of the available literature, interviews with long-term local residents, and a subjective habitat assessment. We found historic documentation for 14 different mountain ranges, including 4 without previous documentation. In addition, two archeological sites with bighorn sheep remains were identified. The introduction of domestic livestock, particularly sheep (*Ovis aries*) and goats (*Capra hircus*), and unregulated hunting evidently were the major factors contributing to the extirpation of the species in Coahuila. These factors still exist in 7 areas, and we found the presence of aoudad *(Ammotragus lervia),* in 3 mountain ranges.

RESTORATION OF BIGHORN SHEEP ON THE NAVAJO NATION

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Desert bighorn sheep (*Ovis Canadensis nelsoni)* are native to the San Juan River Canyon that forms the northern boundary of the Navajo Nation in Utah. Bighorn sheep disappeared from the San Juan River Canyon both above Mexican Hat (Upper Canyon) and below Mexican Hat (Lower Canyon) in the early to mid 1960's after declines concurrent with illegal hunting, extensive mining and heavy grazing of cattle and domestic sheep. After an absence of about 20 years bighorn sheep miraculously reappeared in the Upper Canyon. The herd grew to about 30 bighorn sheep in 1997 when a study on the ecology of the bighorn sheep was initiated by the Navajo Department of Fish and Wildlife. Change in the population trajectory from increasing to stable and range extension by rams into an area where they could contact domestic sheep precipitated a decision to transplant bighorn sheep from the Upper Canyon to the Lower Canyon. The transplant was viewed as a way to preserve the Upper Canyon herd by reducing population density and pressure to expand into hazardous areas. It also restored bighorn sheep to a range that was isolated from domestic stock, difficult to access for poaching and historically supported a viable desert bighorn sheep population. Twenty-four bighorn sheep were transplanted from the Upper Canyon to the Lower Canyon in fall 2003. During their first year bighorn sheep in the Lower Canyon explored over 20 miles of river canyon and demonstrated high productivity however mortality of adult ewes increased and two adult rams deserted their new range.

CASCADING EFFECTS OF SUBSIDIZED MOUNTAIN LION POPULATIONS IN THE CHIHUAHUAN DESERT

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The primary proximate cause of mortality in 4 recently extinct or nearly extinct desert bighorn sheep (*Ovis canadensis mexicana*) populations in New Mexico has been mountain lion (*Puma concolor)* predation. This has occurred in habitats with native ungulate densities hypothesized to be insufficient to maintain resident mountain lion populations. Mountain lions in the Chihuahuan desert ecosystem are a subsidized predator, with domestic livestock the principal subsidy. We hypothesize that the ability to prey switch from native ungulate prey to domestic livestock or exotic wild ungulates may result in an artificially high density of mountain lions. Livestock prey reduces the probability of starvation in mountain lions when native ungulate populations decline to low numbers. This may result in an inversely density dependent mortality rate in desert bighorn sheep populations. The high proportion of cattle in the diets of mountain lions in Arizona (Cunningham et al. 1999) is the basis for this hypothesis. Similar data on the proportion of cattle in mountain lion diets in New Mexico are lacking. However considerable livestock predation is reported and a high percentage of mountain lions harvested in the Chihuahuan desert are pursued from livestock kills. The potential cascading effects of a subsidized predator include population level impacts on alternate prey. In much of the Chihuahuan desert, mule deer (*Odocoileus hemionus*) populations have declined drastically and lion predation has become an additive mortality factor. Another native mammal, porcupine (*Erethizon dorsatum*), was reported to be relatively common less than 30 years ago but appears to have been nearly extirpated from southwestern New Mexico. Empirical data correlates the substantial decline of porcupines with a hypothesized increase in mountain lions in southwestern New Mexico during this time period. Evidence implicating mountain lion predation in the decline of porcupines is lacking in New Mexico. However, the near extirpation of porcupines by mountain lions in a Nevada mountain range (Sweitzer et al. 1997) suggests that this may have occurred in southwestern New Mexico. Numbers of mountain lions harvested, in an effort to protect state

endangered desert bighorn sheep, suggest that historical sport harvest in the Chihuahuan desert is an ineffective method for reducing subsidized mountain lion populations.

PRELIMINARY ANALYSIS OF THE EFFECTIVENESS OF MOUNTAIN LION CONTROL IN DECREASING MORTALITY RATES OF DESERT BIGHORN SHEEP (OVIS CANADENSIS MEXICANA)

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Desert bighorn sheep (*Ovis canadensis mexicana*) have been listed as a state-endangered species in New Mexico since 1980. Approximately 85% of all known-cause non-hunter killed radiocollared individuals have been killed by mountain lions between 1992-2004. In 2001, a mountain lion removal program was implemented in several desert bighorn sheep mountain ranges in New Mexico. As a preliminary evaluation of the effectiveness of mountain lion removal to protect desert bighorn sheep, we used program MARK to compare mortality rates of desert bighorn sheep in the Peloncillo Mountains in SW New Mexico following two bighorn sheep releases. We used a known-fate model framework, considering several models and ranking them using Akaike's Information Criterion (AIC_c) model selection. Sex was the most important factor in explaining survival rates. In 1997, 24 radiocollared desert bighorn sheep were released from the Red Rock captive breeding facility to the Peloncillo Mountains with no mountain lion removal prior to release. The management strategy was offending mountain lion removal only. The mortality rate from mountain lions during the 16 months post-release was 0.29 for the herd, 0.0 for rams, and 0.55 for females. Eight of 12 ewes were killed by mountain lions, with mountain lions taken at 3 of the kills and a 4th mountain lion pursued from another kill. In contrast, in 2003, 30 radiocollared desert bighorn sheep were released into the Peloncillo Mountains from Red Rock following two years of mountain lion control in which seven mountain lions were removed. The mortality rate from mountain lions during the 16 months post-release was 0.10 for the herd, 0.0 for rams, and 0.15 for females. Three of 21 ewes were killed by mountain lions, but after the removal of one mountain lion, bighorn sheep mortalities from mountain lion predation ceased. Mortalities occurred during a six-week period when there was no field technician monitoring the bighorn sheep herd. In the Peloncillo Mountains, 100% of the mountain lion kills were ewes during these periods. This is in contrast to other mountain ranges in New Mexico where mountain lions killed both rams and ewes. In desert bighorn sheep herds where mountain lion predation is a known predominant mortality factor, we recommend range-wide removal of mountain lions for six months prior to a bighorn sheep release. This should be followed with intensive bighorn sheep monitoring to enable rapid detection and removal of mountain lions until the herd has grown large enough to sustain predation without annual population numbers declining.

MOUNTAIN LION PREDATION ON BIGHORN SHEEP: AN EXAMINATION OF RISK FACTORS AND SEASONAL MORTALITY PATTERNS

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Predation by mountain lions (*Puma concolor*) has emerged as an important cause of mortality in many bighorn sheep (*Ovis canadensis*) populations. Bighorn sheep are believed to use several predator avoidance strategies, including use of steep "escape" terrain, use of habitat with high visibility, gregariousness, and philopatric behavior. The factors that put bighorn sheep at risk of lion predation are, however, still poorly understood. We examined this topic using data on 231 bighorn sheep that were radiocollared during 1992 - 2003 in the Peninsular Ranges of southern California. Bighorn sheep are native to these mountains and mountain lion predation has been identified as the primary cause of mortality among adults. We used a Cox proportional hazards model to examine factors such as age, gender, subpopulation, group size, and habitat use patterns that potentially influence a bighorn sheep's risk of lion predation. We also examined the characteristics of sites where mountain lions had killed bighorn sheep, and tested the null hypothesis that mortality sites did not differ from live sites with respect to habitat characteristics such as slope, elevation, aspect, distance to water, or vegetation type. Lastly, we investigated the relationship between temporal predation patterns and variables such as climate and group size, and also determined whether kill sites occurred within or outside of bighorn sheep core-use areas. During our study, 64 radio-collared bighorn sheep were killed by mountain lions in our study area. Results of these analyses will be discussed in the context of predator avoidance strategies and implications for bighorn sheep conservation.

SYNOPSIS OF A 5 YEAR MOUNTAIN LION CONTROL EFFORT ON ENDANGERED DESERT BIGHORN SHEEP RECOVERY

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Desert bighorn sheep (*Ovis canadensis mexicana*), are a state-listed endangered species in New Mexico. The total population estimate declined to <170 in 2001. After determining that the principle proximate cause of mortality was mountain lion predation, a management action to mitigate this high level of mortality was initiated. New Mexico Department of Game and Fish (NMDGF) using contract hunters and trappers attempted to reduce mountain lion numbers in 4 desert bighorn sheep ranges. Lion control, measured by number of lions removed, did not occur in any range during the first 2 years of the management action. Between years 3 and 5 partial mountain lion control was attained in 3 of 4 ranges. However, this has allowed for just 2 years analyses following some level of mountain lion control. Preliminary results are reported for individual desert bighorn sheep populations in a case-study format due to variable conditions among populations. A total of 54 mountain lions were culled using contractors during the 5 years, with only 4 mountain lions culled the first 2 years. Sport hunters harvested an additional 11 mountain lions during this period. Because the number of adult ewes in these 4 populations was estimated to have declined to fewer than 30 prior to the initiation of mountain lion control, a population level response is not detectable. We have assessed mortality of adult radiomarked bighorn sheep attributed to mountain lion predation and lamb:ewe ratios in each of the populations. Percent mortality of adult desert bighorn sheep declined each year following partial mountain lion control. No mortality attributed to mountain lion predation has occurred on radiomarked bighorn sheep (n = 54) in the last 9 months in any of the 3 partially treated ranges. However, in the untreated range, mortality of radiomarked adults increased from 16% the first 2 years to 25% during the last 3 years. In 2 ranges with pretreatment data, spring lamb:ewe ratios increased from 36:100 and 28:100 to 67:100 and 52:100 respectively, following partial mountain lion control. In the San Andres Mountains where 19 mountain lions were culled prior to and following translocation of 51 desert bighorn sheep, the spring lamb:ewe ratios have been 79:100 the 2 years since translocation. The 2-year recruitment ratio has been 49:100. Expenditures for the 5-year lion control program were approximately $150,000 US. In 2004, the New Mexico State Game Commission increased the length of time for the lion control management by 3 years to allow for the collection of 5 years of data as was originally designed.

QUALITY OF WATER AVAILABLE TO WILDLIFE: COMPARISONS AMONG ANTHROPOGENIC AND NATURAL SOURCES

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Quality of water at anthropogenic sources and its potential detrimental affects on wildlife recently have become issues of interest. Broyles (1995) elevated those concerns to an unprecedented level, and his essay has been referenced extensively, but not appropriately, by critics of wildlife water developments as evidence that water quality at such locations is problematic. We examined quality of water at 8 natural tinajas and two types (n = 8 and 9, respectively) of anthropogenic catchments in the deserts of southeastern California, and tested for differences among them. The analytes were pH, conductivity, alkalinity, aluminum, Ammonium, arsenic, cadmium, calcium, chloride, chromium, copper, iron, lead, manganese, magnesium, mercury, nickel, nitrate, organophosphate, potassium, silica, silver, sodium, sulfate, zinc. Of these, only pH failed to meet minimum standards of water quality available for livestock, and then only infrequently. Only levels of calcium, copper, lead, magnesium, silica, and zinc differed among type of water source, and those differences may be related to construction materials, design, or substrate. Based on our results, we conclude there is a very low probability that water quality is problematic for wildlife that use man-made water sources in desert environments.

EFFECTS OF WILDFIRES ON DESERT BIGHORN SHEEP HABITAT IN THE SANTA CATALINA MOUNTAINS, ARIZONA

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The desert bighorn sheep (*O. c. mexicana*) population in the Santa Catalina Mountains, Arizona has declined since the 1920s and was virtually extirpated in the late 1990s. Urban development, human recreation, and changes in habitat conditions due to wildfire suppression have contributed to the decline. Wildfires in 2002 and 2003 burned approximately 46,701 ha in the Santa

Catalina Mountains, including areas previously inhabited by desert bighorn sheep. Our objectives were to estimate the amount of potential and historic bighorn sheep habitat remaining in the Santa Catalina Mountains and to determine if the fires improved habitat quality for bighorn sheep. Historic bighorn sheep habitat in the western Santa Catalina Mountains declined 64% since 1989. Wildfires burned approximately 21% of potential habitat and 24% of historic bighorn sheep habitat, however, most of which experienced low burn severity, which was not high enough to remove vegetation that decreases habitat quality for desert bighorn sheep. The use of natural and prescribed fires to create the habitat conditions preferred by bighorn sheep has been recommended and will likely be a necessary component of habitat restoration plans. Any plans for the translocation of desert bighorn sheep back to the Santa Catalina Mountains should further assess the suitability of the areas identified as potential habitat. Furthermore, other factors (i.e., urban development and recreation) associated with the original decline of desert bighorn sheep also need to be addressed in any translocation plans.

CALIFORNIA'S PENINSULAR BIGHORN SHEEP REBOUND FROM THE BRINK OF EXTINCTION

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In 1996, the population of desert bighorn sheep in the Peninsular Mountain Ranges of California reached a low of 296 and two years later, in 1998, they were officially listed as endangered specie. In 2000, the USFWS published a Recovery Plan for these Peninsular desert bighorn sheep. Since then, to my knowledge, the responsible wildlife agencies have presented no serious update on the status of the Peninsular bighorn sheep or their remarkable population rebound. By 2004, the unofficial estimate of bighorn sheep population stood at or near the de-listing recovery target of 750. The professional communities as well as the general public have been ignorant for almost a decade about the status of Peninsular bighorn sheep. While the absence of information on the bighorn sheep has served some interests who wish to derail development projects, the general public has not been well served. Additionally, in recent years wildlife agencies have supported trails policies that have no relationship to the bighorn sheep recovery.

SURFACE MINING AND DESERT BIGHORN SHEEP ECOLOGY

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Surface mining operations alter landscapes and may result in altered or discontinued use of those areas by certain species. We studied the response of a population of desert bighorn sheep (*Ovis canadensis*) to a surface mining operation in the Silver Bell Mountains of south, central Arizona. We incorporated 2 study periods that related to differing mine activity levels; period 1, 1993-1995; period 2, 2003-2005. We placed radiocollars on male and female bighorn sheep during period 1 and 2 and followed them for ≤2 yrs during each period to assess each animal's use of the mining area. We calculated seasonal 95% (home range) and 50% (core area) utilization distributions for each animal using the same number of locations according to sex and season with an adaptive kernel home range estimator. We also calculated the amount of overlap between each animal's home range and core area and the mining area available to them according to study period. We used a geographic information system (GIS) to calculate sizes and locations of home ranges and core areas. We found that adult male home ranges and core areas of use were significantly larger during the breeding seasons during mine closure (period 1) than during mine operation (period 2), but that during the non-breeding season those home ranges and core areas were not statistically different in size. Female home ranges and core areas during both seasons were not different in size. We found that adult male bighorn sheep home ranges overlapped the mining area more during mine operation than during mine closure during both breeding and non-breeding seasons, but that no difference in the amount of core area overlap occurred during either season. However, female home ranges did not differ in the amount of overlap, but core areas of use by female bighorn sheep showed more overlap with mining areas during mine operation than during mine closure. We documented differences in use of a mining area by bighorn sheep during 2 time periods that relate to human activity. Understanding how mining operations affect bighorn sheep habitat and movements is critical to the long-term management of populations that inhabit areas in and around mining operations.

HOW NOT TO MANAGE RECREATIONAL TRAIL USERS AND THE RECOVERY OF BIGHORN SHEEP: LESSONS FROM COACHELLA VALLEY CALIFORNIA

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This study takes a critical look at wildlife agency documents dealing with Peninsular bighorn sheep recovery and recreational trail use. After a year of study, we found these management documents deficient due to: (1) absence of time series data on the population of bighorn sheep, (2) absence of statistically valid trail use data, and (2) absence of the best available science as an appropriate, required foundation. Furthermore, public policy affecting trails, such as the voluntary trail avoidance program, hot season closures, and quota permit system were based upon assumptions and speculation rather than on evidence and analysis.

The recent Coachella Valley, California conflict regarding bighorn sheep public policy and trail use is a case study in mismanagement of endangered species relevant to recreational trail users. To uphold respected public policy, it is essential that wildlife agency managers recognize trail user groups as their staunchest ally, rather than an adversary, in the struggle to protect wildlife and habitat. In making public policy, we advocate that agency managers and field personnel come out from behind the scenes and work closely with trail users, to gain their trust, and to insure the suitability and scientific basis of public policy. It is our goal to encourage open discussion of the matter to avoid similar difficulties elsewhere.

A CLOSER LOOK AT SEXUAL SEGREGATION IN BIGHORN SHEEP: WHAT DO THE PATTERNS TELL US ABOUT CAUSAL FACTORS?

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Sexual segregation, a behavioral phenomenon in which males and females are found in separate groups for part of the year, is observed in many species but a unified explanation has not been found. Two primary hypotheses have emerged as likely explanations for sexual segregation in bighorn sheep. The "reproductive strategies" hypothesis suggests that males and females use different habitat for part of the year because of differences in reproductive strategies, and that males and females should select habitat that provides them with resources such as food, water, or cover that maximize their reproductive success. Recent field studies on bighorn sheep have provided evidence for this hypothesis. The "activity budget" hypothesis suggests males and females segregate into same-sex groups for part of the year because of differences in metabolic rates and consequent activity budgets, both arising from differences in body size, and that habitat differences need not be present. A recent field study on bighorn sheep provides evidence for this hypothesis, in the absence of apparent gender-based habitat differences. We revisited this question by examining patterns of sexual segregation in a free-ranging population in a study conducted during all seasons over multiple years. We used GPS collars to collect high-resolution habitat-use data on 12 males and 12 females, and coupled this information with data on forage availability and quality, visibility measures, and detailed behavioral observations. In this population, male and female home ranges did not change dramatically between seasons; however, a clear pattern of sexual segregation was observed. Our behavioral data did not provide evidence for the activity budget hypothesis. However, we detected very subtle gender-based habitat use differences, such as differences in use of aspects and distance to major drainages, which provide evidence for the reproductive strategies hypothesis. We discuss the similarities and differences between our findings and the findings of previous studies, and how consistent patterns observed in multiple bighorn sheep populations may help us better understand sexual segregation in bighorn sheep.

A NEW METHOD OF ARGALI (*OVIS AMMON*) CAPTURE USING HORSEMEN AND DRIVE-NETS

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Argali sheep (*Ovis ammon*) were live captured for radiocollaring using horsemen as the primary means to herd them into drive nets. Two adult argali ewes, one argali lamb, and one adult ibex ewe were captured by drive-netting in five days effort in Ikh Nartiin Chuluu Nature Reserve, Mongolia, in September 2002. This represents the first use of this low tech, efficient, and low cost method for live capture of argali. Subsequent modifications to this method by Amgalanbaatar, Reading and others, has yielded higher rates of success.

DOMESTIC GOATS, INFECTIOUS KERATOCONJUNCTIVITIS, AND DESERT BIGHORN SHEEP

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In November 2003, domestic goats trespassed onto occupied bighorn sheep (*Ovis canadensis*) habitat in the Silver Bell Mountains, Arizona. Less than 4 weeks later, bighorn sheep began showing clinical symptoms of infectious keratoconjunctivitis (IKC). We captured, radiocollared, tested, and treated infected and uninfected bighorn sheep to determine the impact of this disease on the survival, movements, and productivity of bighorn sheep. The epizootic occurred from 1 December 2003 to 31 March 2004. We located 33 clinically affected bighorn sheep during the epizootic, which represented approximately 41% of the estimated population. We captured 27 (14M, 13F) bighorn sheep in varying stages of disease development and treated 24 with antibiotics. We found clinically affected bighorn sheep were blind for 38.4 days (95% C.I. 23.5–53.4, n = 9) and ranged from 4–72 days. We found 44% of the blind animals died (1M, 11F) and 44% recovered their eyesight (10M, 2F), whereas 1 of 12 non-

clinically affected bighorn sheep died during the epizootic. Blind bighorn sheep moved less than did non-clinically affected animals during the epizootic (Male, 2-sample t_8 = -3.41 m/hr, 2-sided P = 0.009; Female, 2-sample t_{13} = -2.32 m/hr, 2-sided P = 0.04). Productivity estimates were biased by the number of radiocollared females during the study. However, the greatest number of lambs observed during the same months between years should be a reasonable indicator of lamb production in the given year. The greatest number of lambs observed on a single daily ground-telemetry survey conducted daily between June and August was 11 in 2003, prior to the epizootic and 5 in 2004 during the epizootic. We documented the distribution of the epizootic and known locations of domestic goats. Our data strongly suggest the domestic goats as a vector for disease transmission to bighorn sheep. We urge managers to refrain from allowing domestic goats near bighorn sheep.

USING GENETIC ANALYSES TO DESCRIBE AND INFER RECENT COLONIZATIONS BY DESERT BIGHORN SHEEP

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Species that occur largely in small, naturally-fragmented populations depend on colonization or recolonization of empty habitat patches to persist, especially if local extinction is common. Managing such systems requires understanding and predicting natural colonization processes. However, detecting natural colonization events and identifying the source can be difficult. We used genetic data obtained primarily from fecal samples to characterize and infer recent colonizations of desert bighorn sheep (*Ovis canadensis nelsoni*) in southeastern California. We analyzed 14 microsatellite loci and 515 base pairs of mitochondrial DNA control-region sequences, as well as the sex-identifying molecular marker SE47/SE48, for 397 desert bighorn sheep in 27 populations. We used conventional F-statistics, Bayesian population-level assignment tests, and individual-level assignment tests to describe patterns of gene flow for two suspected recent colonizations, and use our findings to infer the probable source population for another apparent recent colonization. We map the distribution of mitochondrial DNA haplotypes to make inferences about the direction of gene flow between populations and to infer the movement of ewes between populations. We also diagnose a probable cryptic extinction event, followed by recolonization from at least two source populations. This array of genetic techniques, particularly when used in conjunction with radio telemetry and other field observations, provides additional tools for monitoring and managing systems of small, fragmented populations.

EVALUATING ERRORS IN GPS-COLLAR LOCATIONS

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We investigated the accuracy of location information from GPS collars deployed on desert bighorn sheep. Analysis of sequential locations suggested that a portion of GPS fixes have large (>2km) errors. We investigated the frequency and magnitude of errors using locations from GPS collars deployed at known locations. Methods of detecting errors in animal locations are explored through the application of algorithms to detect anomalous movements. Erroneous animal location data may be minimized through the application of screening algorithms. We suggest that users of GPS collars beware of the potential for error and apply a method to screen data for integrity, particularly in those instances when equipment suppliers refuse to divulge the technology incorporated in their products for proprietary or other reasons.

RECRUITMENT DYNAMICS IN DESERT BIGHORN SHEEP

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Density-dependent population regulation is a fundamental underpinning of important wildlife management concepts. Its importance relative to density-independent factors has been a topic long debated in population ecology. Few data sets of adequate length and quality of information have been developed for bighorn sheep that can be analyzed relative to this question. Bighorn sheep offer ideal opportunities for comparative studies because of the great variation in the habitats they occupy. I will

discuss demographic data I have developed over the past 30 years on a variety of populations of bighorn sheep in different desert ecosystems relative to recruitment dynamics and variables driving those dynamics.

MAINLAND RESTOCKING WITH DESERT BIGHORN SHEEP FROM ISLA EL CARMEN, BAJA CALIFORNIA SUR, MÉXICO

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In 1995, OVIS and Salinas del Pacífico started the Recovery Program for *Ovis canadensis weemsi* in Southern Baja California. One of the main objectives in this program is to contribute in the recovery of the bighorn sheep population in Baja California Sur, through the reintroduction of sheep resulting from the reproduction of the herd brought to Isla El Carmen during 1995-1996. In order to meet this objective, the Program for Mainland restocking with desert sheep from Isla El Carmen was presented in October 2004 to the Federal Government, receiving its total approval. The program started in February 2005 with a first capture-release of 10 animals (3 male, 7 female) at Ejido Ley Federal de Aguas Número Dos, BCS, having a working agreement established in order to give follow up for the success of this release. The goals of the program are to continue releasing sheep in the Peninsular area; to continue producing animals to contribute re-establishing the *weemsi* sub-species in Baja California Sur, and in the states where the representative species have already extinguished. Currently, the *O. c. weemsi* population is considered around 1000 animals in the whole state, being very much below the population level they could have, considering that the potential habitat of the species in the peninsular land is for sustaining a population of around 15,000 animals.

MOUNTAIN LION PREDATION ON BIGHORN SHEEP: AN EXAMINATION OF RISK FACTORS AND SEASONAL MORTALITY PATTERNS

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Predation by mountain lions (*Puma concolor*) has emerged as an important cause of mortality in many bighorn sheep (*Ovis canadensis*) populations. Bighorn sheep are believed to use several predator avoidance strategies, including use of steep "escape" terrain, use of habitat with high visibility, gregariousness, and philopatric behavior. The factors that put bighorn sheep at risk of lion predation are, however, still poorly understood. We examined this topic using data on 231 bighorn sheep that were radiocollared during 1992–2003 in the Peninsular Ranges of southern California. Bighorn sheep are native to these mountains and mountain lion predation has been identified as the primary cause of mortality among adults. We examined the relationship between temporal predation patterns and variables such as climate and group size, and also determined whether kill sites occurred within or outside of bighorn sheep core-use areas. We then investigated the characteristics of sites where radiocollared bighorn sheep had been killed by mountain lions, and tested the null hypothesis that mortality sites did not differ from live sites with respect to habitat characteristics such as slope, elevation, or distance to water. In addition, we used a Cox proportional hazards model to examine factors such as age, gender, subpopulation, group size, and habitat use patterns that potentially influence a bighorn sheep's risk of lion predation. During our study, 64 radio-collared bighorn sheep were killed by mountain lions in our study area. Results of these analyses will be discussed in the context of predator avoidance strategies and implications for bighorn sheep conservation.

POSTERS

DIRECT AND INDIRECT INTERFERENCE COMPETITION BETWEEN FERAL HORSES AND DESERT BIGHORN SHEEP AT WATER

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Bighorn sheep (Ovis canadensis) and feral horses (Equus caballus) are sympatric in much of the arid western United States; however, few data exist on the interspecific relations of these species. In the Peninsular Ranges of California there is evidence of niche overlap between feral horses and a federally endangered population of desert bighorn sheep (O. c. nelsoni), creating the potential for either interspecific competition or facilitation between these species. We studied sympatric populations of desert bighorn sheep and feral horses in Anza-Borrego Desert State Park to document and quantify their spatial and temporal overlap and to determine whether direct or indirect interference competition or facilitation occurred between bighorn sheep and horses near water. Our observational and transect data showed that feral horses and bighorn sheep both used the same watering sources and occasionally interacted with each other near water. We also found that where horse use was highest (hours of use/day), bighorn sheep use was lowest. To test for direct interference competition, we conducted observations from dawn to dusk for 30 days, but found no evidence of direct interference competition between feral horses and bighorn sheep. To test whether feral horses affected bighorn sheep watering habits through indirect interference competition or facilitation, we conducted an experiment using domestic horses. Bighorn sheep watering rates at 4 sections of Coyote Creek were recorded over a period of 55 days: 25 days with horses present and 30 days without horses present. A poisson regression model indicated that when horses were present, significant spatial partitioning of water resources occurred. We found no evidence of temporal resource partitioning by bighorn sheep when horses were present. The results of our experiment suggest that feral horses may reduce resource availability for bighorn sheep, although the biological importance of indirect interference competition likely depends on the densities of both species and the relative availability of the resources they share.

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DESERT BIGHORN SHEEP DISTRIBUTION, ABUNDANCE, AND CONSERVATION STATUS IN SIERRA EL MECHUDO, BAJA CALIFORNIA SUR, MEXICO

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We conducted an aerial survey in spring of 1999 to determine current distribution and abundance of the bighorn sheep (*Ovis canadensis*) in Sierra El Mechudo, Baja California Sur. Forty nine animals were observed throughout 3.6 flight hours. The observation rate was 13.6 bighorn sheep observed per hour with an average group size of 2.0. The population estimate for this area based on the results of this survey would be 270 animals (145 in the area of the hill El Mechudo and 125 in Sierra Las Tarabillas). We recorded 5 rams (2 class I, 1 class III, and 2 class IV), 33 ewes, 6 lambs and 5 yearlings. Ram to ewe to lamb to yearling ratios were15:100:18:15. During the survey, rams and ewe/lambs were found grouped separately. We made comparisons with other censuses to determine distribution and population changes. We also discuss some conservation issues of this population.

DATA ACQUISITION SUCCESS RATES OF GPS COLLARS: AN EVALUATION IN DESERT BIGHORN SHEEP HABITAT

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Global positioning system (GPS) collars have become a popular tool in studies of wildlife habitat use. Biases in the ability of the collars to successfully acquire locational data can, however, influence research results. For example, previous studies has shown that canopy cover can impact collar success rates, and it has been suggested that potential biases should be evaluated in habitat where GPS collars are used. As part of a larger study on bighorn sheep habitat use, we evaluated the acquisition success rate of Televilt GPS-Simplex™ collars in bighorn sheep habitat in the Sonoran desert of southern California. Ten collars were first

tested to determine that all were functioning properly, and were then placed in the field at a total of 75 locations, with a collar placed at each location for approximately 3 days. We evaluated the effect of slope, aspect, elevation, vegetation height, and an index of available sky on the ability of the collars to acquire locations. At each site, we measured the angle to the horizon in eight compass directions and used the sum of these values as an index to available sky. In addition, we conducted a controlled study to determine if bighorn sheep horns potentially blocked satellite coverage to collars, by comparing success rates of collars set under ram horns, ewe horns, and no horns (control). We found that slope, elevation, and aspect had no significant impact on collar success rates. In addition, variation in the height of the relatively sparse vegetation in our study area had no significant effect. However, available sky significantly influenced success rate, with lower success rates in narrow canyons. Collars set under ram horns had significantly lower success rates than those under ewe horns or no horns, indicating that ram horns can obstruct satellite coverage. We discuss implications for the design and interpretation of studies using GPS collars.

DIETS OF DESERT BIGHORN SHEEP AT ELEPHANT MOUNTAIN WILDLIFE MANAGEMENT AREA, TEXAS

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We estimated food habits of an introduced population of desert bighorn sheep (*Ovis canadensis* spp.) at Elephant Mountain WMA (Brewster County, Texas) by comparing dietary differences between: (1) sexes, (2) seasons, (3) wet and dry periods, (4) critical biological periods, and (5) bighorn sheep populations located in the Baylor, Beach, Elephant, and Sierra Diablo Mountains of Texas. Diet composition was determined through microhistological analysis of 432 fecal pellet groups (209 M, 209 F, 14 lambs), collected every 2 weeks between September 1998 and August 2000. Ninety-four dietary items were identified, with overall bighorn sheep diets consisting of 50% browse, 35% forbs, 11% grasses, and 4% succulents. Comparison of dietary proportions between sexes indicated a significant difference only for the combined (1998-2000) winter seasons (G_3 = 8.772, P = 0.032). Shannon-Wiener diversity indices of the taxa consumed by each sex did not differ (t = -1.182, P > 0.05). Diet proportions were consistent between years, seasons, and critical biological periods. Mountain range comparisons reflected significant differences in male bighorn sheep diets between Elephant and Beach Mountains (G_3 = 10.154, P = 0.017) throughout the study. Seasonal comparisons between mountain ranges indicated no significant differences between sexes. Seasonal differences were indicated among male diet proportions between Elephant Mountain and Beach Mountain during fall (G_3 = 7.930, P = 0.047) and spring (G_3 = 12.752, P = 0.005), Baylor Mountain during winter (G_3 = 26.810, P < 0.001), and the Sierra Diablo Mountains during spring (G_3 = 13.507, P = 0.004) and summer (G_3 = 19.233, P < 0.001). Differences were reflected among female diets between Elephant Mountain and Beach Mountain during winter (G_3 = 16.559, P = 0.001) and the Sierra Diablo Mountains in fall (G_3 = 18.674, P = 0.003), winter (G_3 = 30.050, P < 0.001), and summer (G_3 = 24.622, P < 0.001). Dietary overlap was greatest among the Elephant Mountain and the Sierra Diablo Mountain populations (57.6%) followed by Baylor Mountain (55.7%), and Beach Mountain (52.0%). The highest average overlap was reflected in the browse component (50%), followed by forbs (22%), grasses (11%) and succulents (3%). Restoration and management of desert bighorn sheep in Texas must consider the important influence of diet on reproduction and maintenance of viable populations. Management strategies should include: determining diets of all existing free-ranging bighorn sheep populations; evaluation of the forage component prior to desert bighorn sheep introductions; and implementation of techniques for evaluating habitat manipulations and monitoring forage use, status, condition, and trends, including key indicator species.

A WEB-BASED DIGITAL CAMERA FOR MONITORING REMOTE WILDLIFE

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Passive and active infrared camera systems and more recently videography have been used in wildlife research to assist in data collection. Traditional camera systems can be expensive, labor intensive, and are limited in operation time due to film length and battery life. Current camera systems are neither computer nor network oriented and do not allow for near real-time retrieval and storage of data. We describe a web-based, digital camera system for monitoring wildlife in remote, inaccessible environments. Between February 2002 and December 2003, our web-based camera system collected 486 digital photographs of west Texas wildlife. The key advantage of our camera system is that it allows for unobtrusively monitoring of secretive and often unobservable species in their natural habitat. Because our system is web-based, high-resolution photographs of wildlife can be posted on a web page for viewing offering a unique teaching tool for grade school and university students who may not have the opportunity to visit these remote inaccessible areas. Although our camera system was expensive ($12,000 US), it offers a self-sustaining technique for monitoring wildlife in remote regions that allows for easy data retrieval and storage.

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, and case histories and notes provide for philosophical presentations and the presentation of ideas and concepts. These papers are also peer reviewed. Additional papers may be published when reviewed and approved by the Editorial Board. Papers must be submitted to the Editor within 1 year of the Council's annual meeting to be considered for the current edition of the *Transactions*.

COPY: Use good quality white paper 215 x 280 mm (8.5 x 11 inches), or size A4. Do not use "erasable," light weight, or mimeo bond paper. Double space throughout, with 3-cm margins. Do not hyphenate at the right margin. Type the name and complete address of the person who is to receive editorial correspondence in the top left corner of page 1. On succeeding pages, type the senior author's last name in the top left corner and the page number in the top right corner. The author's name and affiliation at the time the study was performed follows the title. Present address, if different, should be indicated in a footnote on the first page. Keep 1 copy. Submit 4 good xerographic copies. Do not fold any copy.

STYLE: Proceed from a clear statement of purpose through introduction, study area, methods, results, and discussion. Sequence of contents: title, authors, abstract, key words, introduction, study area, methods, results, discussion, literature cited, tables, and figures. Follow the CBE Style Manual Committee 1994. The former guidelines for the *Wildlife Society Bulletin* are the preferred style and are available from the editor on request. See a recent volume of the *Desert Bighorn Council Transactions* for examples.

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

FOOTNOTES: Use only for author's address if it differs from the byline address or there are multiple addresses for authors, and in tables.

ACKNOWLEDGEMENTS: Include acknowledgements at the end of the introduction as a titled 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 use.

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.

REFERENCES: Authors are responsible for accuracy and completeness and must use the style in **Guidelines for Authors and Reviewers of *Wildlife Society Bulletin* manuscripts**. Avoid unnecessary references. Order multiple references consecutively by date. Show page numbers for quotations, paraphrases, and for citations in books or bulletins unless reference is to the entire publication. Cite unpublished reports only if essential. Include source, paging, type of reproduction, and place published reports are filed parenthetically in the text.

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SUBMISSION AND PROOF: All papers will be reviewed for acceptability by the Editorial Board and 2 outside reviewers. Submit papers to Brian F. Wakeling, Arizona Game and Fish Department, Game Branch, 2221 West Greenway Road, Phoenix, AZ 85023, USA. When papers are returned to authors for revision, please return revised manuscripts within the time allotted. Galley proofs should be returned within 72 hours.

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DESERT BIGHORN COUNCIL MEETINGS 1957 - 2005

Year	Location	Chairperson	Secretary	Treasurer	Transactions Editor
1957	Las Vegas, NV	M. Clair Albous			
1958	Yuma, AZ	Gale Monson & Warren Kelly			
1959	Death Valley, CA	M. Clair Albous	Fred Jones	Fred Jones	
1960	Las Cruces, NM	Warren Kelly	Fred Jones	Fred Jones	
1961	Hermosillo, MX	Jon Akker	Ralph Welles	Ralph Welles	
1962	Grand Canyon, AZ	James Blaisdell	Charles Hansen	Charles Hansen	Charles Hansen & L. Fountein
1963	Las Vegas, NV	Al Jonez	Charles Hansen	Charles Hansen	Jim Yoakum
1964	Mexicali, MX	Rudulfo Corzo	Charles Hansen	Charles Hansen	Charles Hansen & D. Smith
1965	Redlands, CA	John Goodman	John Russo	John Russo	Jim Yoakum
1966	Silver City, NM	Cecil Kennedy	John Russo	John Russo	Jim Yoakum
1967	Kingman, AZ	Claude Lard	John Russo	John Russo	Jim Yoakum
1968	Las Vegas, NV	Ray Brechbill	John Russo	John Russo	Jim Yoakum
1969	Monticello, UT	R. & B. Welles	W. G. Bradley	W. G. Bradley	Jim Yoakum
1970	Bighop, CA	William Graf	W. G. Bradley	W. G. Bradley	Jim Yoakum
1971	Santa Fe, NM	Richard Weaver	Tillie Barling	Tillie Barling	Jim Yoakum
1972	Tucson, AZ	George Welsh	Doris Weaver	Doris Weaver	Charles Hansen
1973	Hawthorne, NV	Warren Kelly	Doris Weaver	Doris Weaver	Juan Spillet
1974	Moab, UT	Carl Mahon	Lanny Wilson	Lanny Wilson	Juan Spillet
1975	Indio, CA	Bonnar Blong	Lanny Wilson	Lanny Wilson	Charles Hansen
1976	Bahia Kino, MX	Mario Luis Cossio	Peter Sanchez	Peter Sanchez	Charles Hansen
1977	Las Cruces, NM	Jerry Gates	Peter Sanchez	Peter Sanchez	Charles Hansen
1978	Kingman, AZ	Kelly Neal	Peter Sanchez	Peter Sanchez	Charles Hansen
1979	Boulder City, NV	Bob McQuivey	Peter Sanchez	Peter Sanchez	Charles Hansen
1980	St. George, UT	Carl Mahon	Peter Sanchez	Peter Sanchez	Charles Hansen
1981	Kerrville, TX	Jack Kilpatric	Peter Sanchez	Peter Sanchez	Charles Hansen
1982	Borrego Sprs., CA	Mark Jorgensen	Rick Brigham	Rick Brigham	Charles Hansen
1983	Silver City, NM	Andrew Sandoval	Rick Brigham	Rick Brigham	Charles Hansen
1984	Bullhead City, AZ	Jim deVos, Jr.	Rick Brigham	Rick Brigham	Charles Hansen
1985	Las Vegas, NV	David Pullman, Jr.	Rick Brigham	Rick Brigham	Charles Hansen
1986	Page, AZ	Jim Guymon	Bill Dunn	Bill Dunn	Paul Krausman
1987	Van Horn, TX	Jack Kilpatric	Bill Dunn	Bill Dunn	Paul Krausman
1988	Needles, CA	Vernon Bleich	Don Armentrout	Don Armentrout	Paul Krausman
1989	Grand Junction, CO	Jerry Wolfe	Don Armentrout	Don Armentrout	Paul Krausman
1990	Hermosillo, MX	Raul Valdez	Don Armentrout	Don Armentrout	Paul Krausman
1991	Las Cruces, NM	Bill Montoya	Don Armentrout	Don Armentrout	Paul Krausman
1992	Bullhead City, AZ	Jim deVos, Jr.	Stan Cunningham	Stan Cunningham	Paul Krausman
1993	Mesquite, NV	Kathy Longshore	Charles Douglas	Charles Douglas	Walter Boyce
1994	Moab, UT	Jim Guymon	Charles Douglas	Charles Douglas	Walter Boyce
1995	Alpine, TX	Doug Humphries	Charles Douglas	Charles Douglas	Ray Boyd
1996	Holtville, CA	Andy Pauli	Charles Douglas	Charles Douglas	Ray Boyd
1997	Grand Junction, CO	Dale Reed & Van Graham	Steve Torres	Charles Douglas	Raymond Lee
1998	Las Cruces, NM	Eric Rominger & Dave Holdermann	Darren Divine	Charles Douglas	Raymond Lee
1999	Reno, NV	Rick Brigham & Kevin Hurley	Darren Divine	Charles Douglas	Allan Thomas & Harriet Thomas
2000	Bullhead City, AZ	Ray Lee & Jim deVos	Darren Divine	Charles Douglas	Jon Hanna
2001	Hermosillo, Sonora, Mexico	Carlos Castillo & Jim deVos	Darren Divine	Charles Douglas	Jon Hanna
2002	Palm Springs, CA	Mark Jorgenson	Darren Divine	Charles Douglas	Jon Hanna
2003	St. George, UT	Jim Karpowitz	Darren Divine	Darren Divine	Brian Wakeling
2005	Alpine, TX	Clay Brewer	Esther Rubin	Stacey Ostermann	Brian Wakeling