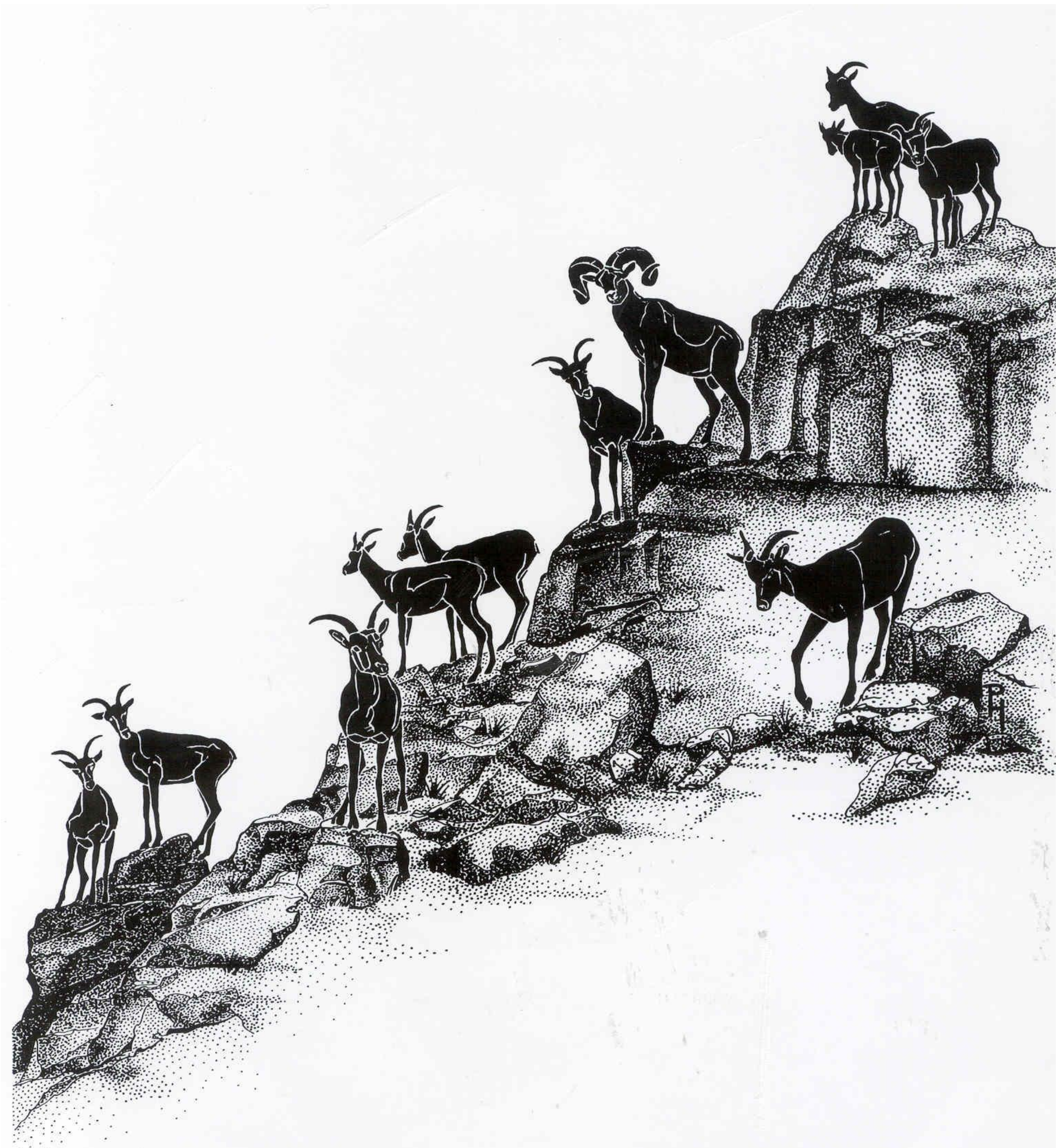
DESERT BIGHORN COUNCIL TRANSACTIONS



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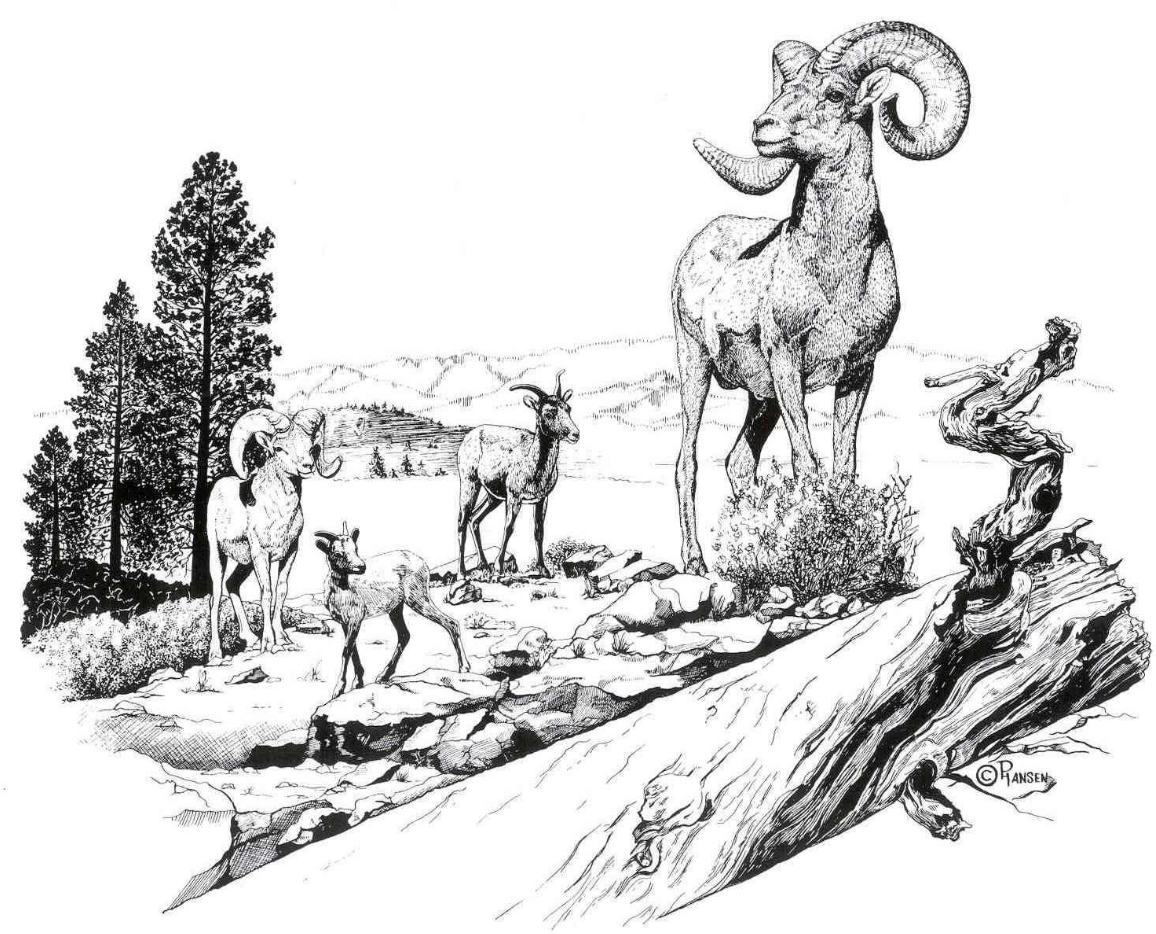

Trans-highway movements and use of underpasses by desert bighorn sheep

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Abstract Highway construction can affect desert bighorn sheep (*Ovis canadensis*) populations by increasing habitat fragmentation and isolation, which in turn can impede access to important habitat, increase effects of stochastic events, and reduce gene flow. With rapid expansion of road networks in bighorn sheep habitat and use of high fencing along roads to reduce wildlife-vehicle collisions, proper design and placement of crossing structures becomes imperative. With the realignment and widening of State Route 68 between Kingman and Bullhead City, Arizona, 3 underpasses were incorporated in part to facilitate movement of bighorn sheep. To evaluate effectiveness of the underpasses, we fitted 25 bighorn sheep with Global Positioning System (GPS) telemetry collars and tracked movements for 23 months during 2005-2007. We also installed 5 remotely-triggered cameras at each underpass to evaluate use of underpasses by large desert mammals. Using location data from collared bighorn sheep, we developed a predictive habitat map to examine habitat quality around each underpass. Cameras at underpasses documented 25 crossing events by collared and un-collared male bighorn sheep (≤32 individuals). We did not document use of underpasses by collared or un-collared female bighorn sheep. Most (90%) of the bighorn sheep crossings occurred at the easternmost underpass which had high visibility through the structure and was situated among high quality habitat. There were 3 highway crossings by bighorn sheep at the westernmost underpass and no crossings at the remaining underpass, which had higher use by other ungulates and humans, respectively. Proximity to quality habitat, sightability through the underpass, underpass structure, and presence of other species may all be important factors affecting bighorn sheep use of highway underpasses.

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Key words Arizona, habitat connectivity, fragmentation, highway crossings, maximum entropy modeling, *Ovis canadensis*, underpass

With greater demand to improve highways to handle increased traffic volumes and speeds, the negative effects of the nation's roadways on wildlife have increased (Cook and Daggett 1995, Federal Highway Administration 1998). Higher traffic volumes and speeds on highways lead to increased wildlife mortalities (Hughes et al. 1996). Furthermore, tall right-of-way fencing designed to reduce wildlife-vehicle collisions can increase habitat fragmentation affecting animal movements across the landscape to access needed resources on a daily and seasonal basis, their ability to move in response to short- and long-term environmental changes, and can limit dispersal of young (Mader 1984, Beier 1995, Foster and Humphrey 1995, Forman and Alexander 1998, McRae et al. 2012). Habitat fragmentation can also lead to reduced genetic exchange and diversity while intensifying the vulnerability of wildlife populations to heavy predation pressure, exposure to disease, localized resource deficiency or other challenges to population persistence (Wilcox and Murphy 1985, Schwartz et al. 1986, Hanski and Gilpin 1997, Forman and Alexander 1998, McKinney et al. 2003).

During the past 3 decades, substantial effort has been expended with varying success in designing and building mitigation passages, or crossing structures for wildlife, but wildlife responses to different characteristics of crossing structure design and placement seem to be species-specific (Clevenger and Waltho 2000). For example, white-tailed deer (*Odocoileus virginianus*) were quick to adapt to using underpasses in North Carolina (Kleist et al. 2007). However, Olsson et al. (2008) reported that moose (*Alces alces*) highway crossings decreased when right-of-way fencing was installed to funnel animals through underpasses rather than allowing them to cross at grade. Factors found to influence differential use of wildlife crossing structures among species include proximal habitat, terrain, crossing structure configuration, and human activity (Foster and Humphrey 1995, Clevenger and Waltho 2000, Ng et al. 2004, Gagnon et al. 2007).

Habitat fragmentation associated with highway construction and improvement projects has been problematic for desert bighorn sheep (*Ovis canadensis*) populations in Arizona (Cunningham and Hanna 1992). Previous studies on bighorn sheep in the Black Mountains in northwestern Arizona indicated the potential for adverse impacts of highway construction, and road expansion to this metapopulation. For example, high numbers of vehicle-related bighorn sheep mortalities during 1989-1991 along a portion of U.S. Highway 93 raised concern about persistence of the local sheep population (Cunningham and deVos 1992, Cunningham et al. 1993). Moreover, U.S. Highway 93 was known to form a boundary to the home ranges of many collared bighorn sheep in those studies, suggesting that the highway also discouraged sheep movement. High (> 2 m) right-of-way fencing added later likely further reduced highway permeability to bighorn sheep (McKinney and Smith 2007).

The realignment and widening of State Route (SR) 68 through the Black Mountains in Arizona between Kingman and Bullhead City (Fig. 1) may increasingly bisect the local bighorn sheep population with greater traffic volume and the addition of high right-of-way fencing, in place of a standard barbed wire fence (e.g., 4 strands, 1.2 m high). The SR 68 realignment project was finished in 2001, complete with high fencing and 3 underpasses designed, in part, to funnel and facilitate movements of wildlife, particularly bighorn sheep, along and under the highway. Underpasses have been widely used in the United States to mitigate effects of roadways on animal movements and to reduce collisions (Clevenger 1998, Clevenger and Waltho 2000, Ng et al. 2004). Research evaluating wildlife use of highway underpasses has focused primarily on ungulates such as elk (*Cervus canadensis*) and deer (*Odocoileus* spp.; Clevenger 1998), but information on bighorn sheep use of underpasses is limited.

An understanding of bighorn sheep movements and their use of the SR 68 underpasses can inform highway design efforts to incorporate wildlife crossing structures that increase public safety and ensure highway permeability to wildlife. Such knowledge may help reduce adverse impacts to bighorn sheep by improving highway permeability, thereby increasing probability of population persistence. By identifying key habitat and design features associated with crossing sites for bighorn sheep, we hope to inform the design and placement of mitigation features for highway projects and potentially avoid construction costs incurred by building ineffective highway crossing structures. Our objectives were: 1) to determine if and how often large desert mammals used underpasses incorporated into the SR 68 realignment; 2) determine the movement patterns of bighorn

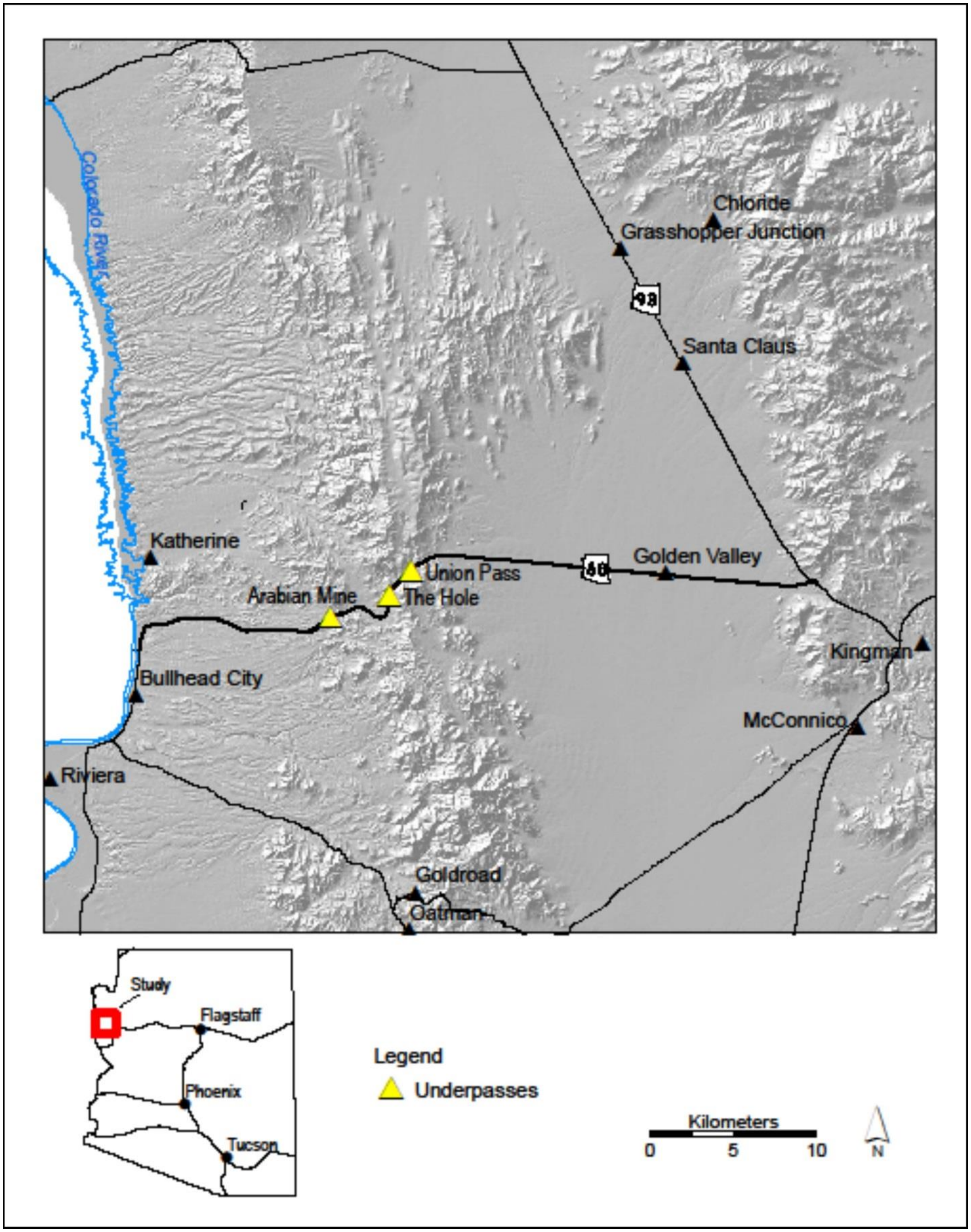

Figure 1. Study area showing crossing structures along State Route 68 in northwestern Arizona, 2005-2007.

sheep in the vicinity of SR 68 to assess potential impacts to bighorn sheep distribution and identify trans-highway movements; and 3) identify factors potentially affecting bighorn sheep use of underpasses.

STUDY AREA

Our study site encompasses an area 10 miles north and south of SR 68 in the Black Mountains of northwestern Arizona, bound on the west by the Colorado River and by the town of Golden Valley to the east (Fig. 1). Elevations range from about 150 m on the Colorado River to 1,496 m, and topography varies from mountainous terrain with steep talus slopes and rugged cliffs to dry washes among rolling hills (Cunningham and Hanna 1992). The lower bajadas, flats and desert wash areas are dominated by creosote-bursage (*Larrea tridentata-Ambrosia dumosa*) while mixed-cacti and shrub communities dominate the mountainous regions of the study area (Brown et al. 1979). Although domestic livestock are not common in most of the study area, feral burros (*Equus asinus*) are common. Predators include coyotes (*Canis latrans*), bobcats (*Lynx rufus*), gray foxes (*Urocyon cinereoargenteus*), and mountain lions (*Puma concolor*). Mule deer (*Odocileus hemionus*) are also present.

Although historically one of the largest bighorn sheep populations in Arizona, aerial surveys suggested a population decline of 54% between 2001 and 2004 (Arizona Game and Fish Department [AGFD] 2014 unpublished data). Annual surveys after 2004 indicated that the population had stabilized at a lower density than prior to 2001 (AGFD 2014 unpublished data). The decline in bighorn sheep was most apparent in the northern portions of the population. Many factors may have been involved and no single source was identified as the cause for the decline (AGFD 2008 unpublished data).

Three underpasses were incorporated into the realignment and improvement of SR 68 between Kingman and Bullhead City, in part to facilitate wildlife movements under the highway. Union Pass underpass (UP) at milepost 12.1 is 51 m wide, 25 m high, and 17 m long (Fig. 2). Union Pass has good visibility through the underpass and has the shortest length of the 3 underpasses, because it lacks a median separating east- and west-bound traffic lanes. The Hole underpass (TH) at milepost 10.8 is 56 m wide, 19 m high, and 38 m long with low visibility from both sides (Fig. 3). Arabian Mine underpass (AM) at milepost 7.8 is 116 m wide, 18 m high, and 37 m long (Fig. 4). Arabian Mine is the widest structure and visibility through the underpass is good even though the underpass does not lie perpendicular to the wash that it crosses.

METHODS

Capture, GPS collars, and cameras

We captured adult bighorn sheep via tranquilizer darting from a helicopter in November 2005 and net-gunning in November 2006 (Krausman et al. 1985). We equipped all bighorn sheep with one of two types of GPS telemetry collars (Telonics, Inc., Mesa, AZ). Store-on-board collars were programmed to acquire a GPS location every 5 hours and spread-spectrum collars recorded a fix every 6 hours. All collars also had VHF beacons and mortality sensors and were programmed to automatically drop off after 22.5 months to facilitate transmitter recovery. Animal location data could be uploaded remotely from spread-spectrum transmitters every 14 days, while location data collected on store-on-board transmitters could be downloaded only after collar recovery.

We deployed 5 remotely-triggered cameras at each of the 3 underpasses along SR 68. We programmed 4 cameras (Reconyx, LLP., Holmen, WI) to take 30 images (one image every quarter of a second) every time movement was detected and to record the date and time on each image. We positioned these cameras for full coverage of the underpass to record wildlife use of the underpass and also on approach trails nearby to document wildlife that approached underpasses without crossing. We defined a crossing event as

Figure 2. Union Pass underpass (MP 12.1) on State Route 68 in northwestern Arizona, 2005-2007. Black arrow points to underpass in photo.

Figure 3. The Hole underpass (MP 10.8) on State Route 68 in northwestern Arizona, 2005-2007. Black arrow points to underpass in photo.

Figure 4. Arabian Mine underpass (MP 7.8) on State Route 68 in northwestern Arizona, 2005-2007. Black arrow points to underpass in photo.

confirmation of 1 or more bighorn sheep crossing fully from one side of the highway to the other. We deployed 1 additional video camera (Leaf River, Inc., Taylorsville, MS) at each underpass and programmed it to take 90 seconds of video every time motion was detected to record wildlife behavior in proximity to SR 68.

We also established track beds at each underpass to supplement data collected by the cameras. Each track bed was at least 2 m wide and all were of variable length depending on the span of the underpass. We counted tracks once a week and cleared and resurfaced track beds after each examination.

Bighorn sheep crossing SR 68

We documented trans-highway movements by collared bighorn sheep by connecting consecutive GPS location fixes in ArcGIS® Version 10.0 software (ESRI, Redlands, California) and inferred crossings where lines between fixes crossed SR 68 despite high fencing unless we had photo documentation of the collared animals crossing at one of the underpasses. Whenever possible, we verified crossing events by collared bighorn sheep using ground or aerial telemetry. In addition, to estimate bighorn sheep habitat use near underpasses, we calculated the number of locations of collared bighorn sheep within 1 km of each underpass.

Habitat modeling and underpass structure

To describe the configuration of the underpasses, we calculated an "index of openness" as (height x width)/(length) for each underpass. To assess the quality of bighorn sheep habitat near the underpasses, we developed a predictive habitat model using maximum entropy modeling in MaxEnt (Phillips et al 2004, Phillips et al 2006). MaxEnt uses an iterative machine-learning process that measures the correlation between environmental characteristics and animal locations to generate a spatial probability of occurrence distribution, which we interpreted as an index of habitat quality (Phillips et al. 2006). A detailed explanation of MaxEnt can be found in Phillips et al. (2006) and Elith et al (2011). We ran MaxEnt using its default settings to develop our habitat quality model (Phillips and Dudik 2008).

To develop and evaluate the predictive habitat model, we used location data collected between November 2005 and September 2007 from GPS-collared bighorn sheep. To ensure that all animals were represented equally and that the model was not skewed by data from a particular season, we only included animals for which we had data representing three seasons: late gestation/lambing/lamb rearing (January – May), pre-rut/rut (June – September), and post-rut/early gestation (October-December; Etchberger and Krausman 1999). We then randomly removed data points from individual animal datasets so that all animals were represented by the same number of data points. Finally, we randomly selected 50% of each animal's locations for use in developing the model and retained the remaining 50% of data for model evaluation.

We delineated the habitat modeling area using bighorn sheep locations. First, we created a 100% minimum convex polygon using GPS locations of all collared bighorn sheep (White and Garrott 1990). Next, we buffered the edges of the polygon by half the distance of the longest axis of the largest home range of any collared animal in this study (29,250 m). We then clipped the buffered area at the western border of northern Arizona, which follows the Colorado River, with the assumption that sheep do not commonly cross the river. We assumed further that the total area of the polygon plus the buffered area offered the predictive model a range of habitat types both used and unused by bighorn sheep.

We generated GIS layers for 9 available ecogeographic variables we believed might influence the distribution of bighorn sheep (Table 1). We used ArcGIS 10.0 to determine slope and elevation for each 30 × 30 m cell of the study area. To estimate land surface ruggedness, we calculated a Vector Ruggedness Measure for each 150 × 150 m cell (Sappington et al. 2007). We also calculated the distance from the center of each 30 × 30 m cell to the nearest cell with ≥ 60% (i.e., escape terrain; Holl 1982). We generated a daily index of solar radiation as a continuous measure of energy (watt-hours/m^2) influenced by aspect and slope and recorded the annual mean value for each 30 × 30 m cell (Rich et al. 1994) using the area solar radiation tool in ArcGIS® Version 10.1 software (ESRI, Redlands, California). We also estimated the distance from the center of each 30 × 30 m cell to the nearest major road, developed land (2008 Tiger data, U.S. Census Bureau), and known permanent water sources (AGFD unpublished data). Major vegetation types were compiled from the Southwestern Regional GAP Analysis Project digital landcover dataset (fws-mcfwru.nmsu.edu/swregap; USGS 2004). Lastly, we used a Spearman rank sum matrix to determine correlation among all ecogeographic variables and removed strongly correlated variables (i.e., when correlation coefficient > 0.70; Sokal and Rohlf 1995, Table 1).

Table 1. Ecogeographic variables included in development of a predictive habitat model.

Ecogeographic variable	**Description**
Slope	Slope (%) of individual 30 × 30 m pixel.
Elevation	Elevation (m) of individual 30 × 30 m pixel.
Ruggedness*	Index of ruggedness over a 150 × 150 m area (22,500 m^2) centered on each 30-m^2 pixel.
Distance to 60% slope*	Shortest distance (m) to individual 30-m^2 pixel with 60% slope
Solar Radiation	Watt hours/square meter, calculated for each individual 30-m^2 pixel, and based on the annual value.
Distance to major roads	Shortest distance (m) from each 30 × 30 m pixel to a major road.
Distance to developed land	Shortest distance (m) from each 30 × 30 m pixel to an anthropogenic structure.
Distance to water	Shortest distance (m) from each 30 × 30 m pixel to perennial water source (Colorado river or AZGFD water development).
Vegetation type	Categorical- Southwestern Regional GAP Analysis Project digital landcover dataset.

* These variables were correlated with slope and were not included in the final model.

We evaluated the resulting predictive habitat map by overlaying the 50% of animal locations held back as test data. We used receiver-operator characteristic (ROC) analysis to evaluate the model (Hanley and McNeil 1982, Chen et al. 2007). We calculated the area under the ROC curve (AUC) to test the sensitivity (i.e., absence of omission error, or increased risk of false positives) and specificity (i.e., absence of commission error or increased risk of false negatives) of the model's predicted habitat quality relative to its ability to successfully predict presence of test data (Wiley et al. 2003, Iguchi et al. 2004, Chen et al. 2007). A model with an AUC value > 0.50 indicates a better than random prediction and shows increasing predictive capabilities as AUC approaches 1.0.

We used the predictive habitat model to assess the quality of bighorn sheep habitat in proximity to underpasses by comparing predicted quality within a 1-km buffer around each of the 3 underpasses. We assigned 5 habitat quality classes based on natural breaks in the probability of occurrence scores inside the 3 buffered areas and used Kruskal-Wallis ANOVA to compare distributions of habitat quality classes between the 3 buffers around underpasses (Sokal and Rohlf 1995). As traffic exiting or entering SR 68 within our study area was minimal, traffic volume at each underpass should have been nearly equal. Thus we assumed that potential differences in bighorn sheep use of the three underpasses was not related to differing traffic volume at each underpass.

RESULTS

Captures, GPS collars, and cameras

We captured and collared 25 bighorn sheep during two capture efforts and combined data from both for our analyses. In total, we placed collars on 6 females and 6 males north of SR 68 and 8 females and 5 males south of SR 68 (Fig. 5). We attempted to capture male and female bighorn sheep on both sides of the highway such that each highway crossing structure could be accessed by each collared sheep based on documented dispersal distances for bighorn sheep within the Black Mountains (McKinney and Smith 2007). We were unable to recover data from one collar that failed to drop off. In all, 24 collared bighorn sheep provided 38,790 usable locations.

Based on images captured by cameras, bighorn sheep composed only 25% of crossing events at UP, <1% of the animals at AM, and were completely absent at TH (Fig. 6). Burros made up 53% of animals crossing at UP, 25% of animals at AM, and 86% of those at TH (Fig. 6). Humans infrequently crossed at UP (22%) but were more common at AM (71%) where most of their activity was in vehicles, with some stopping to rest in the shade of the underpass. Mule deer were uncommon at AM (<1%) and were most frequent at TH (14%). Foxes, coyotes, and bobcats also travelled through underpasses, but we did not document mountain lion use of underpasses with either remote cameras or track beds. All large animals that we documented using track beds were also observed in digital images.

Bighorn sheep crossing SR 68

We rarely captured images of bighorn sheep using underpasses to cross SR 68 (Fig. 6). Our remote cameras captured only 25 crossing events through underpasses by collared or un-collared bighorn sheep, accounting for at most 32 individuals (Table 2). Three crossing events included ≥ 2 bighorn sheep, while the rest were single animals. Bighorn sheep crossed SR 68 in both directions, and all crossings occurred between 8 am and 6 pm. The majority (84%) of bighorn sheep crossings occurred between May 1 and October 31. Not all approaches to underpasses resulted in bighorn sheep crossing the highway. We documented 3 incidents (about 9%) in which bighorn sheep approached SR 68 from the south side of the UP underpass but did not cross the highway.

All but one of the bighorn sheep caught on

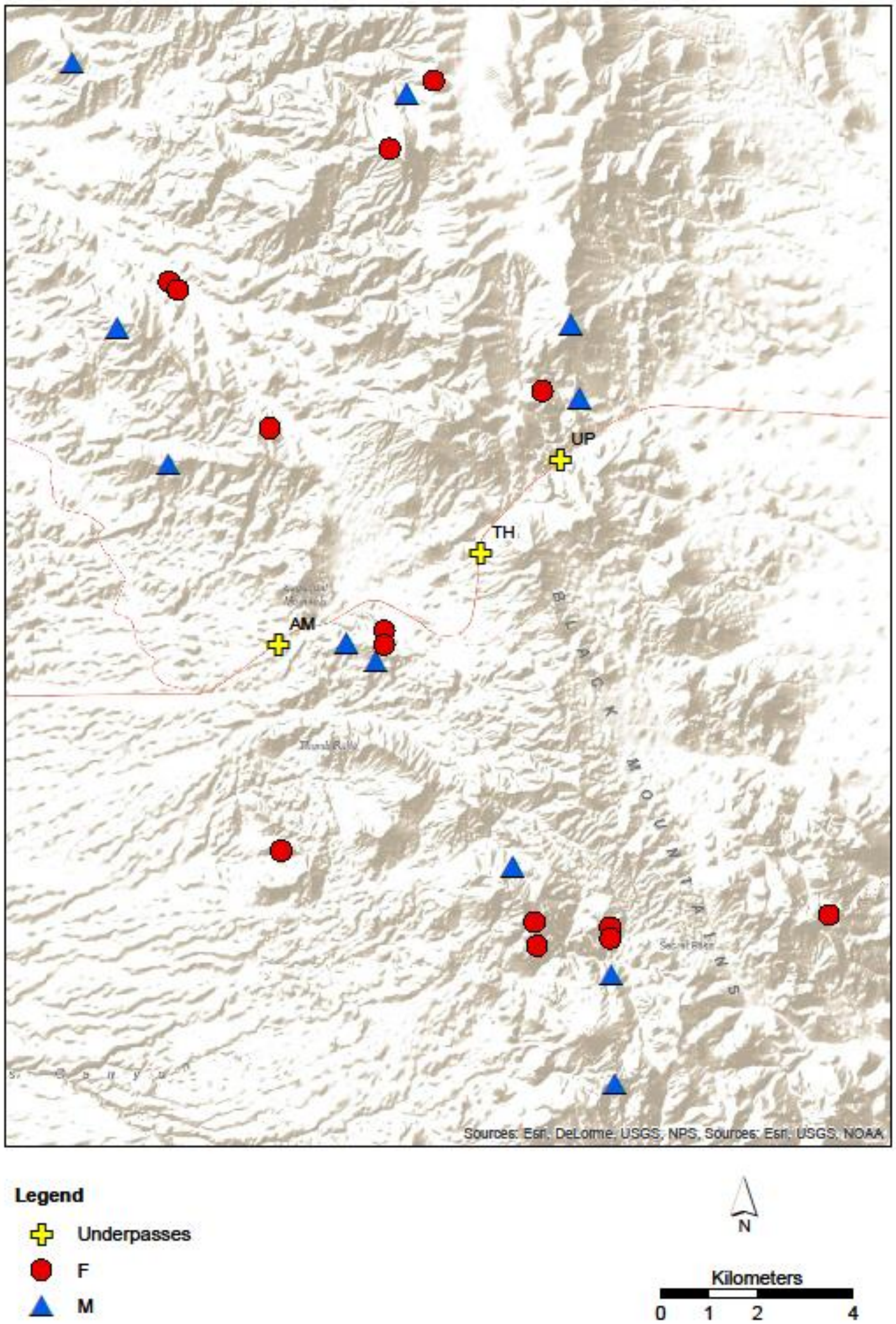

Figure 5. Locations of bighorn sheep captures and wildlife underpasses along State Route 68 in northwestern Arizona, 2005-2007.

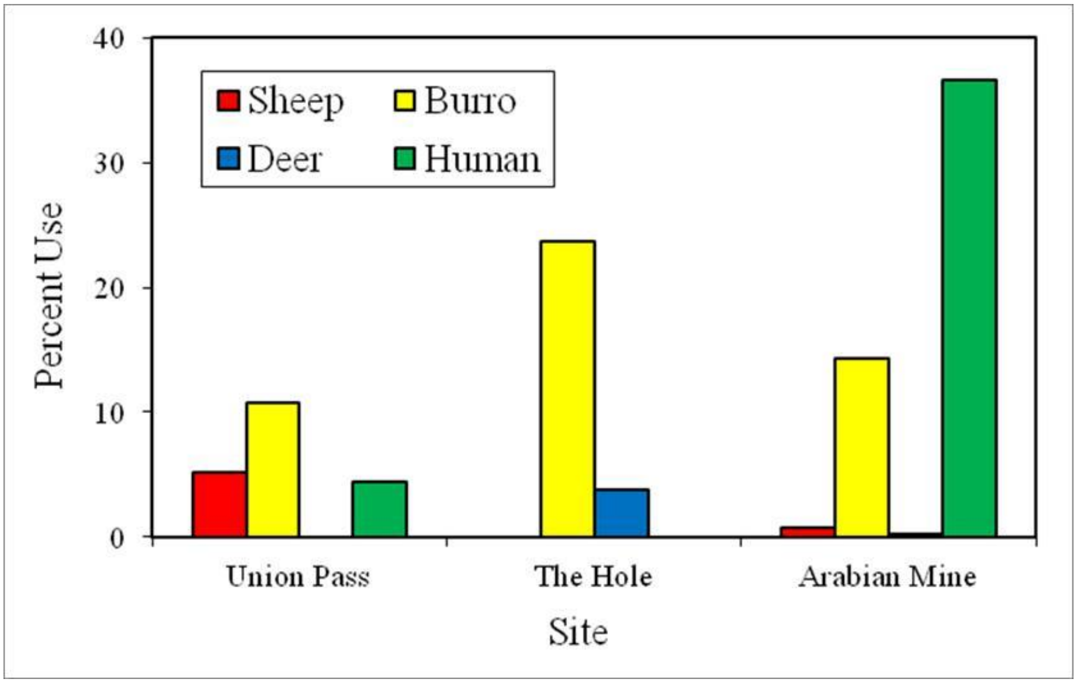

Figure 6. Percent use of underpasses by ungulates and humans along State Route 68 in northwestern Arizona, 2005-2007.

Table 2. Collared bighorn sheep use within 1 km of underpasses, photo-documented bighorn sheep crossing events, and index of openness [(height x width)/(length)] of wildlife underpasses on State Route 68 in the Black Mountains, northwestern Arizona, 2005-2007.

	Wildlife Underpass		
	UP	TH	AM
Collared male (*n* = 10) locations	427	97	239
Collared female (*n* = 14) locations	56	35	588
Bighorn sheep crossing events	22	0	3
Index of Openness	75	28	56

remote cameras in underpasses were males (i.e., 31 of 32 individuals); we were unable to determine sex of one animal from camera images. Based on GPS locations, only 3 males (12% of all collared animals and 27% of collared males) crossed SR 68 (Fig. 7). We documented that collared males crossed 6 times at UP, once at AM, and not at all at TH. Additionally, we estimated by connecting consecutive GPS locations that one of these collared males crossed SR 68 near MP9 between AM and TH in an area where the right-of-way fencing was low (less than 2 m) and there were numerous gaps in the fence > 0.5 m off the ground. We also documented the mortality of an uncollared male struck by a vehicle in this stretch of SR 68. Still, the majority of collared bighorn sheep were not known to cross the highway (Fig.

8). We did not document females moving through the underpasses, nor did we document any of our collared females to have even crossed SR 68.

Males and females also differed in their proximity to each underpass. For example, the number of male locations ≤ 1 km from underpasses was greatest at UP (Table 2), however, bighorn female locations ≤ 1 km from the underpasses were most numerous at AM (Table 2).

All bighorn sheep documented on approach to underpasses were walking and exhibited cautious or vigilant behavior. Of the bighorn sheep that crossed, 15 walked through the underpass, 11 ran and 2 both ran and walked. We were unable to accurately infer the behavior of the 4 remaining bighorn sheep that used the underpasses. Six bighorn sheep (32%) stopped in the UP underpass to look around, and each looked toward a shadowed bench located on the northeast corner of the abutment. Bighorn sheep that crossed in groups did not stop while under the roadway, and the first half in any group walked while the second half ran. Approximately 50% of individuals who crossed alone at UP ran through the underpass. No bighorn sheep were seen running after passing through, and 3 were seen feeding close to the underpass after crossing.

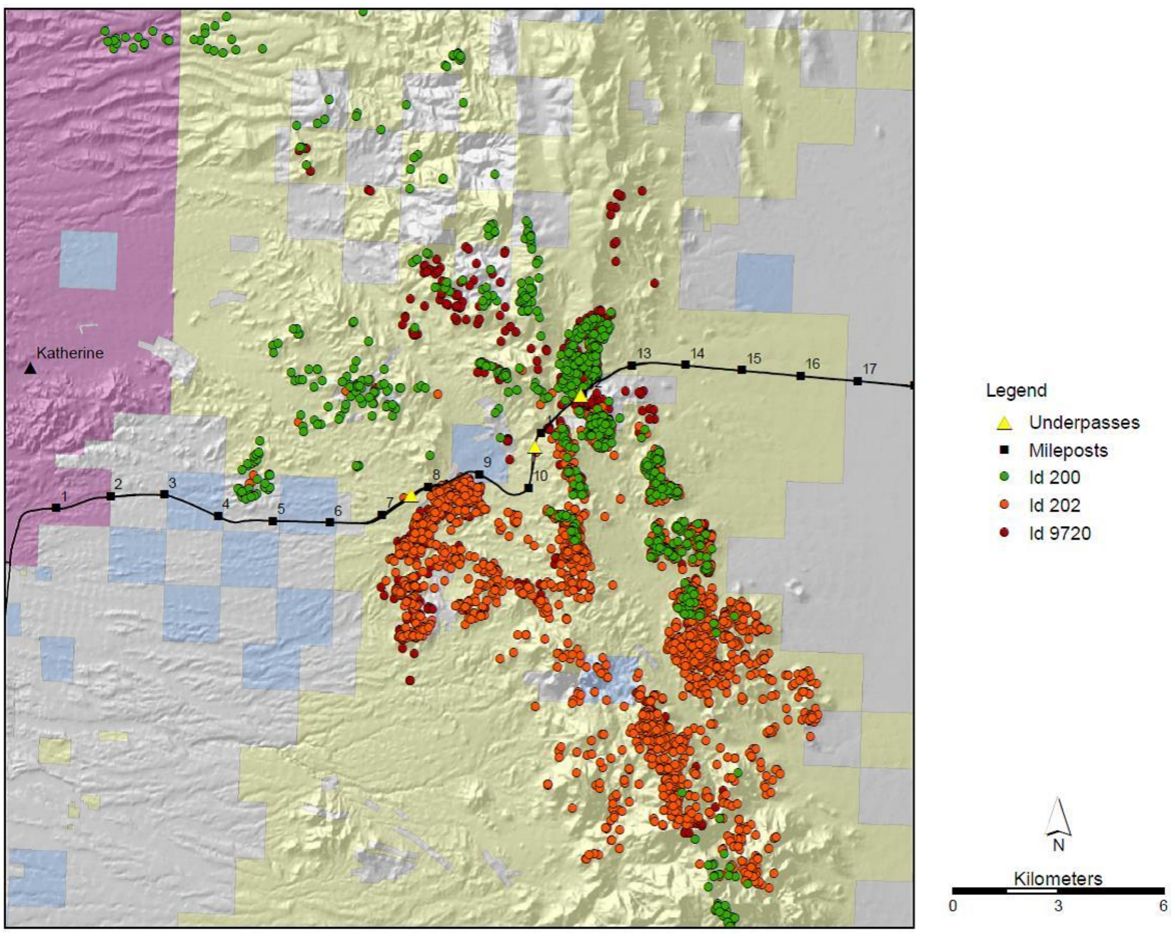

Figure 7. Locations of collared bighorn sheep rams (by animal ID number) known to have crossed State Route 68 in northwestern Arizona, 2005-2007.

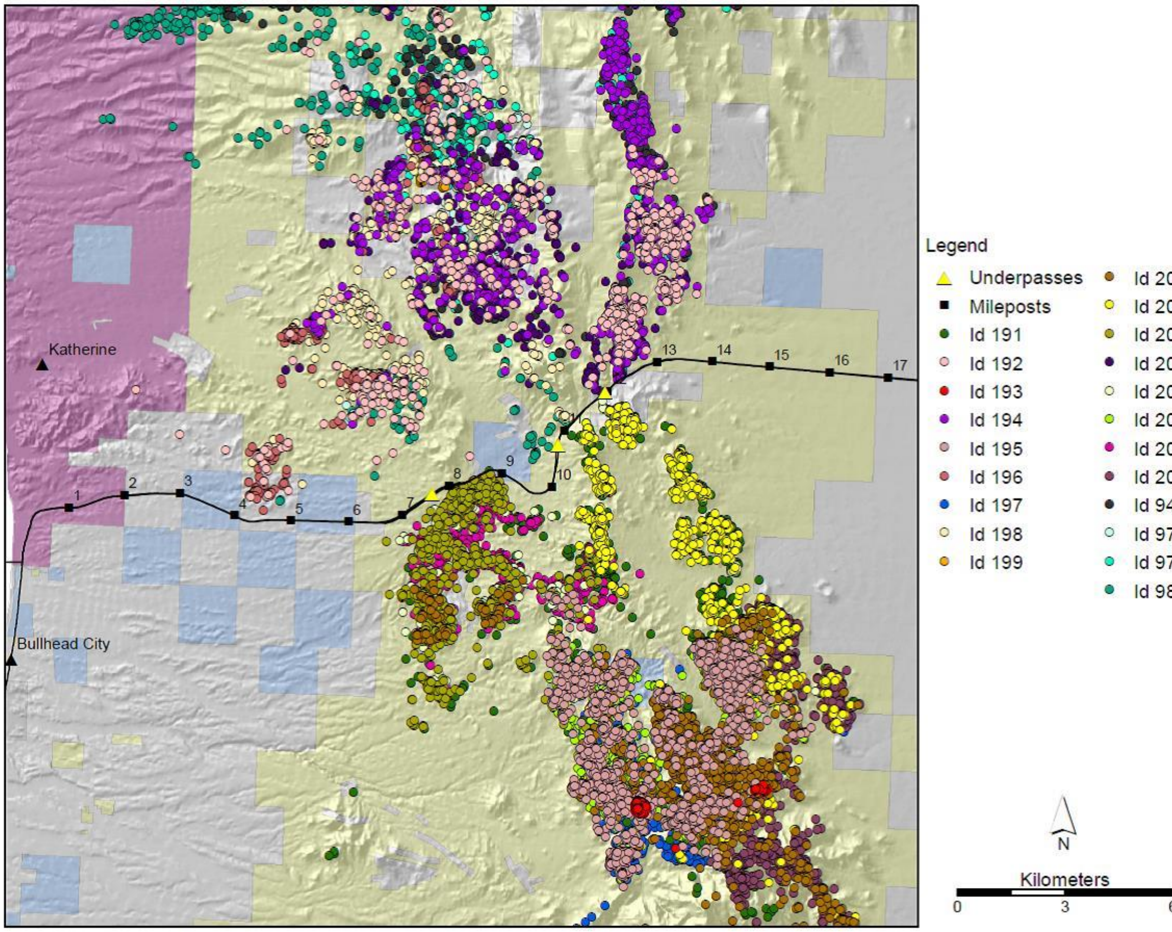

Figure 8. Locations of collared bighorn sheep (by animal ID number) not known to cross State Route 68 in northwestern Arizona, 2005-2007.

Habitat Modeling and Underpass Structure

Our MaxEnt habitat quality model indicated that habitat quality for bighorn sheep varied greatly across the study area (Fig. 9). Percent slope, ruggedness, and distance to cells with ≥ 60% slope were highly correlated within the study area, so we excluded distance to cells with ≥ 60% slope and ruggedness from our MaxEnt habitat quality modeling. The AUC scores for training (0.712) and testing (0.714) data demonstrated that MaxEnt performed well at predicting habitat quality for bighorn sheep. An analysis in MaxEnt of the relative contributions of individual environmental covariates (e.g., percent slope, vegetation, distance to roads) suggested that percent slope was the single most effective variable for predicting the distribution of occurrence data from bighorn sheep that were set aside for testing in the model.

The index of openness, calculated to describe underpass architecture, was higher at UP than either TH or AM (Table 2). Similarly, the UP underpass had a greater predicted area of high quality habitat within 1 km of the underpass than either TH or AM underpasses (KW χ^2 = 2,239, 2 df, P < 0.001, Fig. 10). Further, UP had habitat of high quality distributed more evenly on both sides of the highway while predicted areas of higher habitat quality near AM and TH were concentrated on the south side of the highway (Fig. 10).

DISCUSSION

Highways have widespread potential to significantly alter natural ecosystems (Noss and Cooperrider 1994, Trombulak and Frissell 2000, Farrell et al. 2002). Vehicle collisions with wildlife result in extensive human and animal deaths, injuries, and property damage (Forman 2000). Moreover, highways often block animal movements, sever habitat connectivity, and fragment animal populations (Forman 2000), especially when animals are reluctant to use crossing passages or structures. Thus, the permeability of any highway should be assessed for its impacts on resident wildlife to ensure that animals maintain access to critical food and habitat resources.

We determined that 12% of all collared individuals used the SR 68 underpasses. Although not a large proportion of the population, some sheep did use the underpasses, as did many other animals, such as burros. Indeed, some wildlife species have been observed to readily use underpasses. For instance, 61% of deer migrated safely through underpasses (Reed et al. 1975), 89% of mountain goat (*Oreamnos americanus*) crossings were successful (Singer and Doherty 1985), and up to 96% of elk used underpasses (Waters 1988). Although Reed (1981) reported that deer showed reluctance to use underpasses even after 10 years, others have demonstrated that animals may increase their use of underpasses over time (Reed et al. 1975, Singer and Doherty 1985, Waters 1988). Differences among studies may have been driven by differences in underpass design, placement, fencing, in addition to species differences.

All crossings in our study were made by males crossing the highway primarily between May 1 and October 31 each year. These dates coincided with pre-rut, rut, and post-rut periods in the area. Bighorn males will travel great distances to access female groups for breeding, and this behavior helps ensure genetic diversity among meta-populations scattered across mountain ranges in a naturally fragmented distribution (Bleich et al. 1997). Our observations suggest that the highway appears to preclude crossings by female bighorn sheep, even with the added underpasses. However, observed movement of males through the underpasses likely provides gene flow between bighorn sheep on either side of SR 68.

Habitat fragmentation can intensify the risk of extirpation to any group of bighorn sheep. As suggested above, the philopatric tendencies of female groups and the natural isolation among groups on different mountain ranges may increase sensitivity to habitat fragmentation from both man-made and behavioral barriers (Geist 1971, Krausman and Leopold 1986, Gilpin 1987, Bleich et al. 1990, Rubin et al. 1998, Andrew et al. 1999). Lack of bighorn sheep movement across highways such as SR 68 further contributes to population isolation and potentially amplifies vulnerability to episodes of disease, predation, localized resource deficiencies, or other challenges to population persistence (Wilcox and Murphy 1985, Schwartz et al. 1986, Forman and Alexander 1998, McKinney et al. 2003). For instance, it has been suggested that preventing or even delaying males from accessing traditional breeding areas could extend the breeding season, thereby reducing reproductive success (Cunningham et al. 1993). Moreover, mature bighorn males may travel large distances to access high quality forage to restore body condition after the physically taxing rut (Bleich et al. 1997), and fragmentation of habitats could prohibit access to that resource.

Environmental features associated with wildlife crossing structures may influence their use by ungulates (Clevenger 1998, Ng et al. 2004). For example, Dodd et al. (2007) found that elk selected crossing structures associated with riparian-meadow habitat while white-tailed deer selected crossing structures connecting forested habitat on both sides of Highway 260 in Arizona.

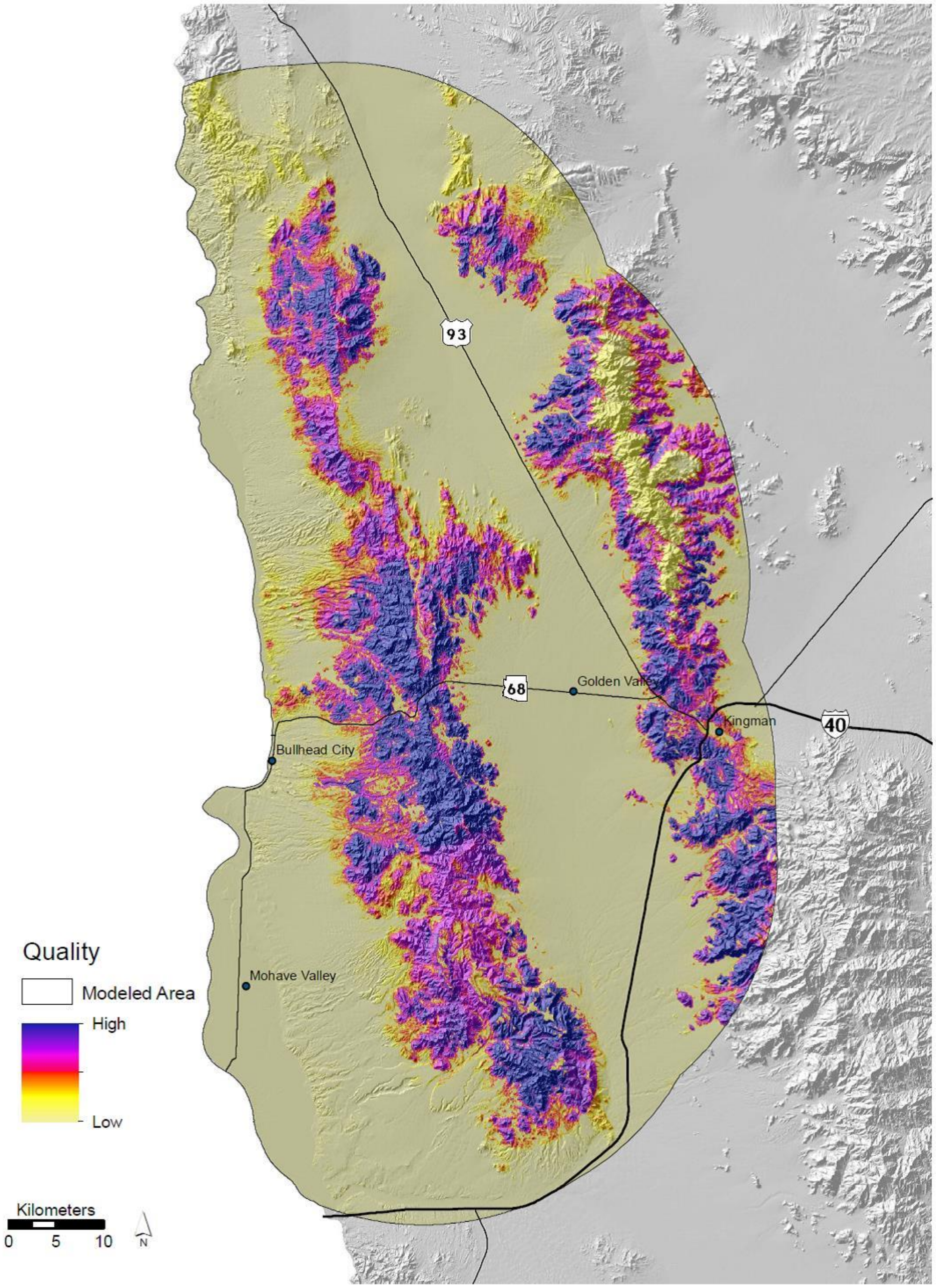

Figure 9. Habitat quality model for bighorn sheep in the area around State Route 68 in northwestern Arizona, 2005-2007. Darkest colors represent highest predicted habitat suitability and follow the mountain chains across the study area.

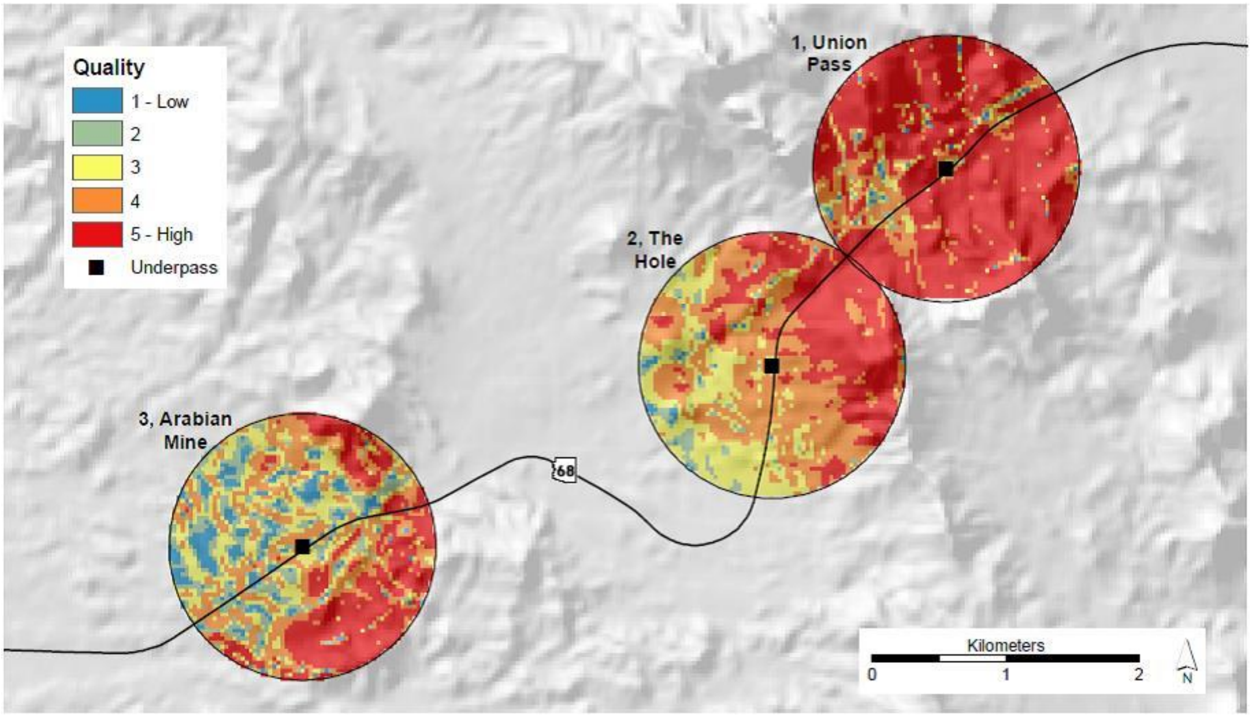

Figure 10. Bighorn sheep habitat quality within 1 km of crossing structures placed along State Route 68 in northwestern Arizona, 2005-2007.

Likewise, the most commonly used underpass on SR 68, UP, had the greatest modeled area of high quality habitat due to being located in the most mountainous terrain rather than among gentler slopes. Correspondingly, our MaxEnt model showed that percent slope was positively correlated with habitat quality and it was the single-most important covariate for predicting habitat quality for bighorn sheep. McKinney and Smith (2007) found that bighorn sheep used habitats near highways associated with ridgelines that offered good visibility and connected habitats on both sides of the highway. Similarly, bighorn sheep males in our study primarily used the underpass located closest to the main spine of the Black Mountains (UP).

Thus, in considering placement of underpasses, both environmental and social elements should be considered. Otherwise, crossing structures built in favorable topography but without reference to established animal travel corridors may prove ineffective in enhancing highway permeability to wildlife (Hanna 1982). For instance, bighorn sheep follow established traditions in their movements, with young sheep learning seasonal patterns and travel routes from older individuals (Geist 1967). Given the conservative nature of bighorn sheep movement patterns and the passing on of generational knowledge (Geist 1967), maintaining traditional routes within a complex of habitats is critically important to population persistence (Bleich et al.1990). Therefore, proximity to steep rugged terrain may not in itself be enough to influence bighorn sheep use of an underpass if that area is not also part of their traditional movements and trails.

Wildlife use of underpasses may also be altered further by the presence of other species or humans (Clevenger and Waltho 2000). For example, feral equids can displace bighorn sheep from seasonally critical habitats (Ostermann-Kelm et al. 2008), and bighorn sheep may be poor competitors in social interactions with some species (Geist 1985). Burro numbers at AM and TH were higher than at UP, which had the highest use by bighorn sheep. Human traffic was also greatest at AM, and bighorn sheep may abandon areas associated with high human use (Jorgenson 1988). Even though collared bighorn sheep were found most commonly close to AM, it is possible that human activity at or near the underpass discouraged bighorn sheep from using it. Bighorn sheep seek predictable living environments and may become habituated to human activities that follow a predictable pattern (Bristow et al. 1996). Bighorn sheep may not use or abandon areas with unpredictable or erratic and unpredictable human activities (Wiedmann and Bleich 2014). Human activity at the AM underpass was not predictable and vehicle traffic often bisected potential travel corridors for bighorn sheep.

Architectural features and placement of wildlife underpasses can influence their use by ungulates. Most animals, and particularly herbivores, are unlikely to travel through areas where their abilities to detect predators are compromised (Dodd et al. 2007). Thus, underpasses situated between steep, sloped roadsides over loose substrates or with deep, shadowed benches may be entirely avoided by bighorn sheep. This appeared to be the case with TH, which had the lowest index of openness and a narrow, deep architecture, and even though roughly half of the area around it was quality bighorn sheep habitat, we did not document any crossings there. Conversely, underpasses with a high degree of openness, such as at UP, likely provide visibility adequate to detect or evade predators (Geist 1971, Krausman et al. 1999). The index of openness for the UP underpass may represent a minimum since we documented 3 approaches by bighorn sheep that did not cross as a possible result of inadequate visibility through the underpass.

To increase highway permeability to wildlife, underpasses should be designed such that predator avoidance strategies are not compromised (Little et al. 2002). Underpasses should be designed to minimize or eliminate shaded areas or deep shadows where predators may hide or that bighorn sheep may perceive to be risky. For instance, a shelf or game trail below underpass abutments that extends the length of the abutments may be favored over other designs simply because it allows bighorn sheep to cross through the underpass at the top of the slope as opposed to being forced to cross at the lowest point. Incorporating more natural features and substrates throughout the crossing structure without creating spaces for predators to hide may further enhance permeability.

Wildlife crossing structures intended to reduce the habitat-fragmenting influence of highways should be designed so that all segments of a population will use them (Ng et al. 2004). While we observed that males used underpasses on SR 68, females did not. We have proposed a few reasons aside from structural underpass characteristics for why this might be the case, yet perhaps underpass structure was a determining factor for use by females. Whereas breeding behavior may drive males to cross through undesirable habitats or structures to access female groups across the highway, philopatric females are slower to adopt new travel corridors (Geist 1967). Recent observations of bighorn sheep, including females and lambs, crossing newly installed overpasses along U.S. Highway 93 on the north end of the Black Mountains (AGFD unpublished data) suggest a preference for more open crossing areas than the underpasses found along SR 68.

While our study suggests that bighorn sheep may not readily traverse underpass structures, our interpretations are limited by the circumstances of the study. For instance, we were unable to quantify sheep movements along or across the highway prior to the road being realigned and widened and the underpasses installed so we do not know if, historically, the sheep moved freely across the highway or not. Likewise, as roads and fencing have demonstrated abilities to fragment populations (Wilcove et al. 1986), we acknowledge that we were unable to reconstruct a complete history of fencing present along stretches of the highway at times prior to road improvements. We recognize that fences or the presence of the road may have deterred sheep, and particularly females, from crossing in the past. Since young females learn home ranges by following their mothers or other older females (Geist 1971), even a few generations of females who learned not to cross the highway could have established a behavioral barrier that has been retained by the population (Gilpin 1987, Rubin et al. 1998) even after prior fencing was removed and underpasses were developed. The observation of higher rates of crossing among males than among females is consistent with sex-based differences in habitat use and dispersal patterns in bighorn sheep (Geist 1971, Bleich et al. 1997).

MANAGEMENT IMPLICATIONS

Ideally, placement of any crossing structure should also be situated in areas of traditional sheep movements or along existing bighorn sheep travel routes. Where feasible, they should be designed to connect high quality habitat on both sides of a highway where human activity and other ungulate use is minimal. To that end, animal location data and predictive habitat quality models can further aid managers in characterizing potential sites where installation of crossing structures will likely prove most effective. To encourage use, underpasses should have a high index of openness to enhance visibility through the underpass.

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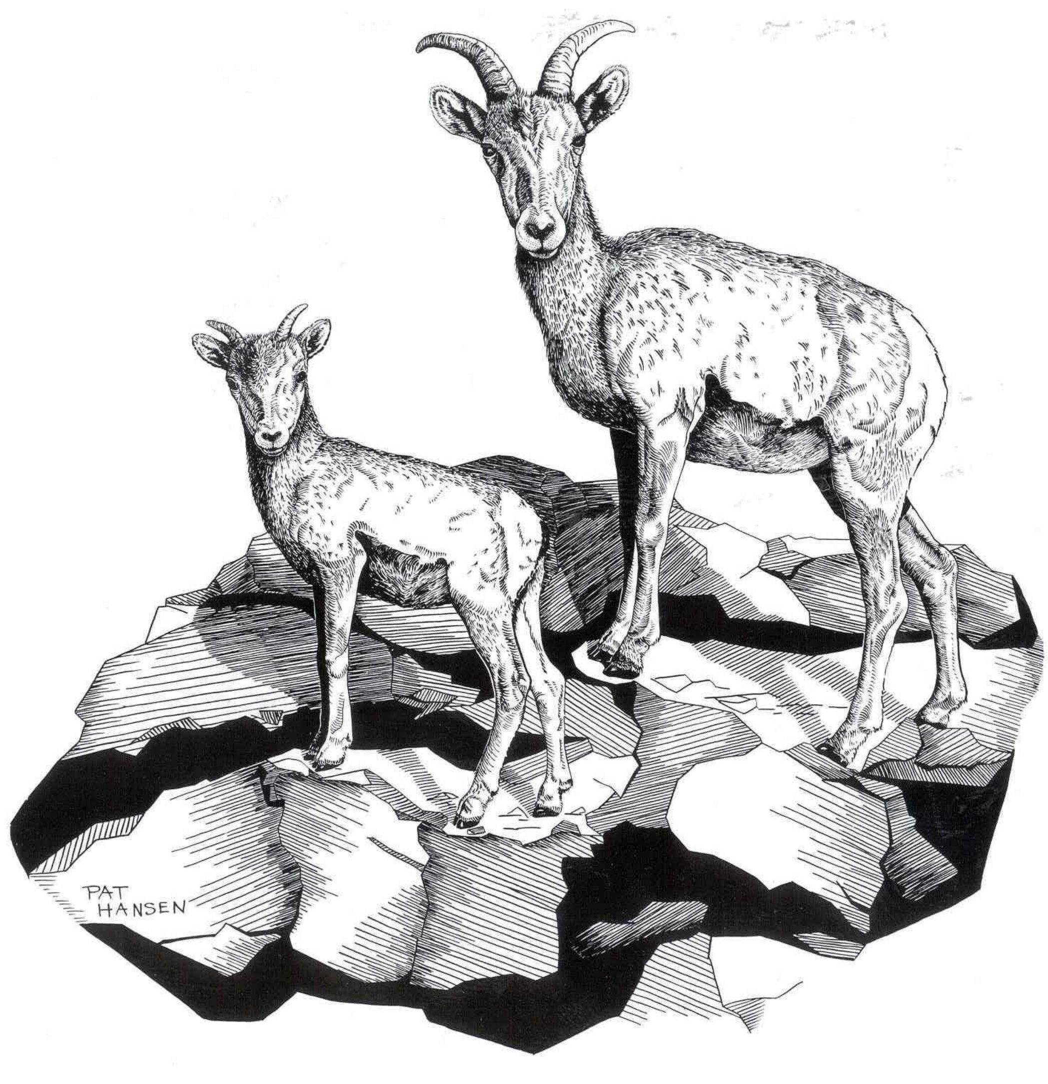

Records of goats and exotic caprines in or near bighorn sheep habitat in California

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Abstract Literature encountered opportunistically and combined with interviews, personal observations, unpublished reports, and correspondence identified ≥22 separate locations in 9 California counties where caprines have been reported in or adjacent to bighorn sheep (*Ovis canadensis*) habitat. These records, dating back to the early 1900s, have potential value from historical and pragmatic perspectives, particularly as they relate to disease profile histories among populations of bighorn sheep. This contribution hopefully will inspire others to compile similar records, many of which could be useful in the future.

Desert Bighorn Council Transactions 53:24–33

Key words *Ammotragus lervia*, aoudad, bighorn sheep, California, *Capra hircus*, exotic ungulate, goat, *Ovis aries*, *Ovis canadensis*, *Ovis dalli*, thinhorn sheep

Diseases caused by pathogens contracted from domestic livestock—particularly domestic sheep (*Ovis aries*)—likely are the greatest challenge to the conservation of bighorn sheep (*O. canadensis*) and thinhorn sheep (*O. dalli*; Garde et al. 2005, McClintock and White 2007, Besser et al. 2012b, WSWG 2012, Brewer et al. 2014, Jex et al. 2016). Pathogens resulting in respiratory disease are especially problematic, and have frequently been linked to widespread or otherwise severe effects to populations of wild sheep in the western United States and Canada following association with domestic sheep. Mortality events often occur from respiratory disease involving multiple infectious agents, among which are several species of bacteria (*Mycoplasma ovipneumoniae*, *Pasteurella multocida*, *Mannheimia haemolytica*, and *Bibersteinia trehalosi*) (Dassanayake et al. 2010, Besser et al. 2012a, b; Besser et al. 2013).

Domestic goats (*Capra hircus*; Fig. 1), which arrived in the New World with Spanish explorers and missionaries, have been present in western North America for several hundred years (Browne 1869, Wagoner 1952, Holechek et al. 1998) and potentially transmitted diseases to wild sheep. Indeed, Tinker (1978) described a pestilence that killed many wild sheep following the arrival of the Spaniards and their livestock in northern Mexico. *Mycoplasma ovipneumoniae* is thought to be an important agent of respiratory disease in domestic goats (Rifatbegovic et al. 2011). Moreover, clinically healthy domestic goats have been shown to harbor 2 potentially infectious species of bacteria: *Pasteurella* [*Mannheimia*] spp. (Ward et al. 2002, Rudolph et al. 2003, Foreyt 1994, Foreyt et al. 1996, Drew et

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Figure 1. Ray Quigley, an amateur naturalist from Hemet, California photographed what he described as a bighorn sheep near golden eagle eyrie #79 in the Sidewinder Mountains, San Bernardino County, California in 1941. Subsequently, V. C. Bleich (California Department of Fish and Game) determined that the animal was not a bighorn sheep. Beginning in 1937 Quigley had visited the site regularly and reported what he described as sheep trails, tracks, scat, and horns seen on those visits. See footnote 'w' in Table 1 and Appendix A for additional information.

al. 2014) and *M. ovipneumoniae* (Besser et al. 2008, 2012a). There is little to suggest domestic livestock other than sheep or goats transmit pathogens that could result in respiratory disease in bighorn sheep (Wehausen et al. 2011), although cattle have been implicated in one case (Wolfe etal. 2010). Hence, records of free-ranging or feral goats in or near bighorn sheep habitat are of interest from historical and pragmatic perspectives.

METHODS

I began accumulating records of goats in or near bighorn sheep habitat in 1977 following my observation of a feral goat in the Santa Rosa Mountains, Riverside County, California. Among sources for those records are the technical and popular literature, newspapers, unpublished reports, personal observations, and correspondence or conversations with other investigators, but I did not conduct an extensive literature review. To the extent possible I have documented the date of occurrence, the location, the circumstance under which the information was obtained, and provided details regarding the sources of unpublished information.

RESULTS

From 1977 to 2015 I recorded evidence or records of goats or other caprines in or proximate to 21 mountain ranges inhabited currently or historically by bighorn sheep, and distributed

Table 1. Locations, dates of occurrence, and sources of documentation for the presence of goats or goat-like animals in or proximate to current or historical bighorn sheep habitat in California, 1913-2015. References marked with a superscript are explained in detail in Appendix A.

Location	Date of Occurrence	References
Imperial County		
West Chocolate Mountains	2009	N. Andrew, L. Lesicka, and T. Glenner[a]
Inyo County		
Deep Springs Range[b]	<1970	Weaver and Mensch 1970; Bleich and Weaver 2007
Grapevine Mountains	<1961	Welles and Welles 1961
Inyo Mountains[b]	<1973	Weaver 1973
Owens Valley	<1940; ≤2015	Jones 1980; Few et al. 2015[c];
Panamint Range	≤1935; 1953; 1955	Borell 1935; Welles 1955; McKnight 1961; Weaver 1972; Jones 1980
Sierra Nevada	≤2015	Few et al. 2015
Los Angeles County		
San Gabriel Mountains	1917; 1963	Lewis 1963; Kennedy 1963
Modoc County		
Warner Mountains	1988	Coggins 2002
Mono County		
White Mountains	≤1910; 2005; 2012–2015	Mitchell 2003[d]; V. Bleich[e]; M. Morrison[f]; Few 2015
Sierra Nevada	≤2015	Few et al. 2015
Riverside County		
Big Maria Mountains	1953; 1961	McKnight 1961; V. Bleich[g]; Jones 1980
Chuckwalla Mountains	1955–1956	Weaver and Vernoy nd
San Jacinto Mountains	2009; 2015	D. Harkleroad[h]; T. Glenner[i]; J. Villepique[j]; J. DeForge[k]
Santa Rosa Mountains	<1950; 1953; ≤1965–2004; 1977; 1980; 1983–1985; 2004	F. Jones[l]; Jones et al. 1953, 1957; V. Bleich[m, n]; BI 1983, 1984a,b, 1985a,b; Turner et al. 2004; CDFW WIL[o]; J. DeForge[p]
San Bernardino County		
Bell Mountain (~5 km SSW)	2013	J. Villepique[q] ; Eisen and Eisen 2013
Granite Mountains (Ft. Irwin)	2014	J. Villepique[r]
Marl Mountains	2012	T. Anderson[s]
Old Woman Mountains	≤1986	Wehausen and Hansen 1986
San Bernardino Mountains	<1960; 1984; 2007	R. Weaver[t]; V. Bleich[u]; Bleich and Jessup (1991); J. Villepique[v];
San Gabriel Mountains	1917; 1963	Lewis 1963; Kennedy 1963
Sidewinder Mountains	1941	K. Berry[w]
San Diego County		
Jacumba Mountains (S of I-8)	<1970	USFWS 2000
Siskiyou County		
Near Lava Beds NM	<1961	McKnight 1961

among 9 counties, all but 2 of them (Modoc and Siskiyou) in southern California (Table 1). Among those records are a young male bighorn sheep that was attracted to a penned female domestic goat, domestic goats pastured proximate to a bighorn sheep winter range, a goat-like ungulate observed during an aerial survey in the San Bernardino Mountains, 2 goat farms located adjacent to bighorn sheep habitat, and a fenced zoological facility in bighorn sheep habitat that occasionally displayed exotic bovids (Turner et al. 2004).

DISCUSSION

With few exceptions, most reports appeared to be of feral animals (*sensu* Howard and Marsh 1986; Fig. 1). The goat-like ungulate observed in the San Bernardino Mountains had a neck ruff (long hairs extending the length of the front of the neck), chaps (prominent long hair on the anterior of the upper part of the front legs), and stocky build (Schaller 1977, Valdez 1985, Damm and Franco 2014). It was scrutinized at close range and resembled an aoudad (*Ammotragus lervia*); it was not photographed. At the time of the observation a commercial 'game ranch' operating on the south-facing slope of the San Bernardino Mountains was a plausible source of that unusual caprine.

Respiratory disease has been a major factor in the historical reduction of bighorn sheep, and bighorn sheep habitat is considered less valuable due to the presence of or proximity to domestic ungulates (Turner et al. 2004, Shannon et al. 2014). Moreover, disease has a negative influence on growth or recovery of bighorn sheep populations (Gross et al. 2000, Singer et al. 2000b), and the potential for disease transmission must be a consideration in management strategies (Krausman 2000, Singer et al. 2000a). Although the nexus for disease transmission from domestic goats to wild sheep is less clear than with domestic sheep, goats have been implicated in extensive episodes of disease among bighorn sheep in Arizona (Jansen et al. 2006), California (Coggins 2002), Idaho (Coggins 2002), New Mexico (Gross 1960), North Dakota (Wiedmann and Hosek 2013), and Oregon (Coggins 2002). Further, the potential for goats to compete with bighorn sheep for forage or water has long been recognized (Kelly 1960, Van den Akker 1960). Thus, managers are advised to prevent contact between North American wild sheep and domestic sheep and domestic goats (Fuller 1988, Garde et al. 2005, WSWG 2012, Grimaldo 2016, Kreutz 2016), recommendations that have been well heeded. For example, the federal recovery plan for bighorn sheep inhabiting the peninsular ranges (USFWS 2000) and that for Sierra Nevada bighorn sheep (USFWS 2007) emphasize the need to prevent comingling between domestic goats and wild sheep. Effective separation of domestic goats and domestic sheep from wild sheep currently is recognized as the most effective method of reducing risk of pathogen transfer between the species (WSWG 2012).

MANAGEMENT IMPLICATIONS

Historical records of domestic sheep grazing allotments enabled Epps et al. (2004) to conclude that past presence of domestic sheep within or near habitat occupied by bighorn sheep was an important variable associated with the extirpation of those bighorn populations. Records of domestic goats in or near bighorn sheep habitat have been documented much less frequently. Despite this, free-ranging or feral goats have occurred at one time or another in ≥22 locations in or adjacent to 21 mountainous areas occupied by bighorn sheep in California, and this information should be of interest to managers and researchers. Although these records cannot be considered to be complete, they document the widespread occurrence of free-ranging caprines in or near bighorn sheep habitat in California. Hopefully, these data will encourage others to compile similar records, many of which could be of scientific interest in the future.

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Appendix A. Footnotes for details associated with references in Table 1.

[a] N. Andrew (California Department of Fish and Game; CDFG) observed 3 feral goats; a subsequent removal effort by Andrew, T. Glenner (CDFG), and L. Lesicka (Desert Wildlife Unlimited) was not successful.

[b] Although the proper names differ, both refer to the same location in Deep Springs Valley, Inyo County.

[c] In a paper presented at the 53rd meeting of the Desert Bighorn Council in Borrego Springs, California, A. Few (California Department of Fish and Wildlife; CDFW) described a large number of domestic goats in a fenced area at the base of the Sierra Nevada, Inyo County; Few et al. 2015.

[d] Mitchell (2003) described a goat ranch owned by Queen Dicks at the base of the White Mountains in the early 1900s. The date (<1910) was approximated by V. Bleich.

[e] A domestic goat was on 8 December 2005 during a bighorn sheep capture event and transported alive to the California Animal Health and Food Safety Laboratory (CAHFS; Case Number S0514602) in San Bernardino, where it was euthanized. Diagnostic *Mycoplasma* culture of lung tissue was negative; no other pathogenic bacteria were detected.

[f] In an e-mail from M. Morrison (CDFW) to V. Bleich dated 4 March 2013, Morrison noted that CDFW was first notified on 31 July 2012 that four goats had escaped from a holding facility near the Barcroft Laboratory and gained access to the White Mountains.

[g] The weathered skull of a female goat was collected by V. Bleich (CDFG) in the Big Maria Mountains west of Midland, Riverside County, on 17 January 1984.

[h] In a letter to V. Bleich dated 12 December 2009, D. Harkleroad (an independent researcher) included photographs of a young male radio-collared bighorn sheep drinking from a water bucket at a goat ranch located in Blaisdell Canyon adjacent to bighorn sheep habitat.

[i] A domestic goat was observed with a male bighorn sheep in Blaisdell Canyon; both animals were removed by T. Glenner on 19 September 2009. The animals were examined at the CAHFS Laboratory in San Bernardino (Case Number S090513). Diagnostic *Mycoplasma* culture of lung tissue was negative; no other pathogenic bacteria were detected.

[j] In an e-mail dated 24 March 2016, J. Villepique (CDFW) confirmed that C. Davis (CDFW) observed two free-ranging goats north of Paradise Corners in the San Jacinto Mountains. D. Harkleroad had earlier reported an observation of 3 free-ranging goats on the Pacific Crest Trail, and two of these are thought to be the same animals observed by Davis. Efforts to remove these goats were not successful.

[k] In an e-mail dated 20 April 2010 to B. Gonzales (CDFW), J. DeForge (Bighorn Institute) described the prior presence of a petting zoo at the base of the Palm Springs Tramway in the

San Jacinto Mountains during the early 1980s.

[l] In his monthly report dated 24 July 1953 to H. Hjersman (CDFG), F. Jones (CDFG) noted the presence of cattle, wild horses, goats, and mules in Martinez Canyon, Riverside County.

[m] A domestic goat, reddish in color, was observed with 7 bighorn sheep at South Fork Spring in the south fork of Martinez Canyon, Riverside County, by J. Harris (CDFG) and V. Bleich on 8 July 1977.

[n] During an aerial survey on 21 April 1980 a domestic goat, gray in color, was observed by V. Bleich, B. Blong (CDFG), and T. Paulek (CDFG) in Sumac Canyon, Riverside County, along with 8 female and two young-of-the-year bighorn sheep.

[o] A map prepared by the California Department of Fish and Game Wildlife Investigations Laboratory and provided to V. Bleich in 2006 includes the location at which a feral goat was shot near LaQuinta on 21 October 2004; the carcass could not be retrieved for examination.

[p] In an e-mail to B. Gonzales (CDFW) dated 20 April 2010, J. DeForge described the past presence of several domestic goat farms in Cahuilla Hills, adjacent to the Santa Rosa Mountains, and the removal of several feral goats from that range by BI personnel during the early 1980s.

[q] In an e-mail dated 24 March 2016, J. Villepique confirmed that he investigated a report of a bighorn sheep proximate to a penned domestic goat; an attempt to capture the bighorn sheep on 6 February 2013 to move it from the immediate area was not successful.

[r] On 9 April 2014, J. Villepique and T. Glenner removed 3 goats that had escaped into the Granite Mountains on Ft. Irwin following a military exercise. The animals were examined at the CAHFS Laboratory in San Bernardino (Case Number S1402679); *Mycoplasma ovipneumoniae* and other pathogenic bacteria were detected.

[s] T. Anderson (Society for the Conservation of Bighorn Sheep) reported that a domestic goat encountered in bighorn sheep habitat was killed by a hunter on 16 December 2012. The animal was examined at the CAHFS Laboratory in San Bernardino (Case Number S1210479); *Mycoplasma ovipneumoniae* was not detected by culture or PCR.

[t] In a letter to V. Bleich from R. A. Weaver (CDFG) dated 20 July 1986, Weaver noted that feral goats occurred in Cushenbury Canyon in the 1950s and were hunted by CDFG personnel D. Garton and B. Blong.

[u] An ungulate strongly resembling an aoudad was observed by B. Blong, T. Paulek (CDFG), and V. Bleich in the Whitewater River drainage while conducting an aerial survey of deer winter range in January 1985. The fate of this animal is not known.

[v] In an e-mail to V. Bleich dated 24 March 2016, J. Villepique confirmed his observation of 5 goats and 18 domestic sheep in Crystal Creek Canyon, near Cushenbury Canyon on 6 October 2007. The fate of those goats and domestic sheep is not known.

[w] A letter and photograph sent to V. Bleich by K. A. Berry (Bureau of Land Management) and dated 2 July 1984 reported that R. Quigley, an amateur naturalist, provided a photograph (taken in 1941) of what he described as a bighorn sheep at golden eagle eyrie #79. Upon examination of the photograph (Fig. 1), the animal was determined by V. Bleich to be a domestic goat.

State Status Reports

Status of bighorn sheep in Arizona, 2014

Amber Munig

Arizona Game and Fish Department, Game Branch,
5000 West Carefree Highway, Phoenix, AZ 85086, USA

Desert Bighorn Council Transactions 53:35–36

Populations

Estimates of Arizona's desert bighorn sheep (*Ovis canadensis mexicana* and *O. c. nelsoni*) populations have remained relatively stable over the past 2 years statewide. Ram:100 ewes:lamb ratios averaged 55:100:29 in 2014 (n = 2,093 bighorn observations). Based on survey data, Arizona currently has an estimated population of 4,500–5,000 desert bighorn sheep

The desert bighorn sheep population in the Kofa Mountains (Units 45A, 45B, and 45C) in southwestern Arizona has recovered to approximately 500 animals (the population was estimated at 800 bighorn sheep in 2000). The Black Mountains (Units 15C and 15D) of northwestern Arizona continues to do well and has served as a source for multiple translocations recently.

Rocky Mountain bighorn sheep (*O. c. candensis*) continue to prosper in Arizona. The statewide population is estimated at about 1,000 animals. Ram:100 ewes:lamb ratios aver-aged 43:100:37 in 2014 (n = 542). For both Rocky Mountain and desert bighorn sheep, Arizona surveys about one third of the population annually, although some areas of specific concern or recent translocations have been surveyed annually.

Research

Some ongoing monitoring of roadways and mitigating features on permeability for desert bighorn sheep continues within a mountain range complex but across highways, and ongoing research examining bighorn sheep habitat use and the factors that put a bighorn sheep at risk of mortality in 2 desert mountain ranges. The Regions conducted 2 translocations that provided an excellent opportunity to gather information to help guide future management decisions. In Region 5, 61 bighorn sheep were translocated, during 2 translocations, into the Catalina Mountains where the remnant bighorn sheep population disappeared in the 1990s. In this area, research is focusing on bighorn sheep habitat selection and mortality patterns in relation to habitat attributes, including fire history and areas of human activity. In Region 3, 80 bighorn over 2 years were moved from the Black Mountains to the Arrastra Mountains to augment an existing remnant population. This study is focusing on habitat selection and mortality patterns, but will also include a predator-prey component. Mountain lions are being collared to examine their prey selection, space use, and movement patterns in relation to bighorn sheep in this population.

Habitat

The Department works with private organizations (primarily ADBSS and the Wild Sheep Foundation) and federal agencies to achieve habitat improvements for bighorn sheep. 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 3 bighorn sheep tags.

In 2014, the Department and ADBSS coordinated on projects for $344,642 USD. Projects involved building or maintaining water sources, improving habitat connectivity, sheep surveys, and translocations.

Translocations

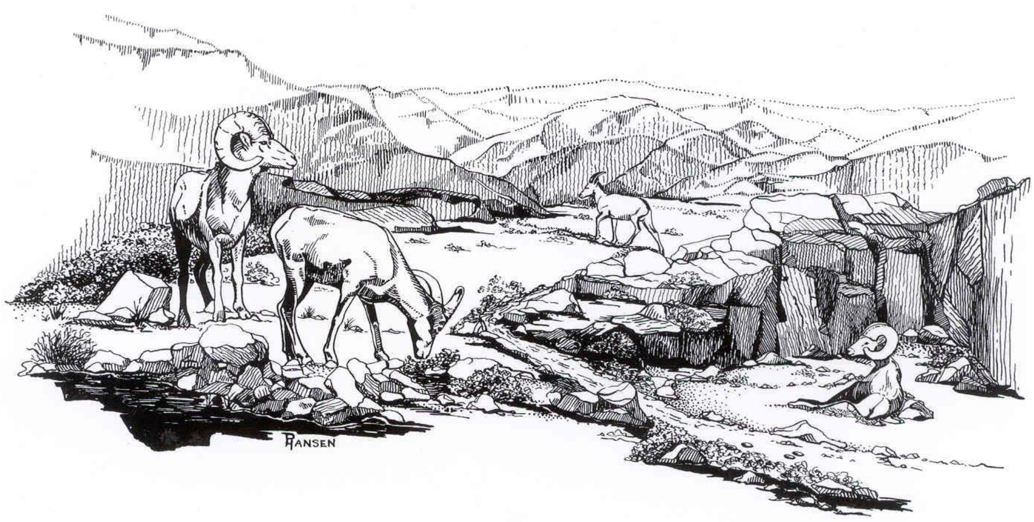
Arizona relocated 97 bighorn sheep through 2 desert bighorn sheep and 1 Rocky Mountain bighorn sheep translocations in 2014. Forty desert bighorn sheep (in a ratio of about 1 young male:3 females) were captured using established Department helicopter capture and handling protocols. The bighorn sheep were released in People's Canyon in Unit 16A, in an effort to augment the bighorn sheep population in that area. This was the third and final release into People's Canyon. During the second desert bighorn sheep translocation, 15 bighorn sheep were captured in Units 22 and 24B (Superstition Mountains) and 15 more were capture in the Plomosa Mountains in Unit 44B. All 30 were released in the Catalina Mountains in Unit 33, for the second release into that area. Twenty-seven Rocky Mountain bighorn sheep were captured opportunistically during 3 attempts in June and July and one attempt in December 2014; all were released on the South Fork of the Little Colorado River in Unit 1. This brings the total of bighorn sheep moved in Arizona to 2,184 since our first translocation in 1955.

Harvest

Bighorn sheep permits remain the most sought after hunting permits in Arizona. In 2014, 14,236 individuals applied for the 104 available.

During the 2014 season, 100 hunters participated, harvesting 99 rams in 632 days of hunting. Hunt success was 99%. The age of harvested rams ranged from 3 to 11 ($\bar{x}$ = 8), with green scores from 128 2/8 to 185 5/8 ($\bar{x}$ = 162 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 2014, with a third tag to the Arizona Big Game Super Raffle (AZBGSR). Each year, ADBSS has traditionally auctioned 1 tag at the Wild Sheep Foundation Annual Convention and auctions the second at their fundraising banquet. The third is raffled through AZBGSR. In 2014, $476,800 USD was raised with these permits to fund conservation and management of bighorn sheep in Arizona.



Colorado desert bighorn sheep status report, 2015

Brad Banulis

Colorado Parks and Wildlife, 2300 S. Townsend Avenue, Montrose, CO 81401, USA

Desert Bighorn Council Transactions 53:37–38

Population status

The overall trend of Colorado's bighorn sheep herds have remained stable to slightly increasing over the last 2 years. Rocky Mountain bighorn sheep (*Ovis canadensis canadensis*), the predominant bighorn in Colorado, has increased slightly from an estimated posthunt population of 6,895 in 2013 to 7,035 in 2014. Over the last couple of years, Colorado's Desert bighorn (*Ovis canadensis nelsoni*) populations have been stable with posthunt population estimates for all herds totaling 515 in 2013 and 2014. Colorado's desert bighorn population is made up of 3 different populations: the Black Ridge herd (GMU S-56) in Mesa County near Grand Junction, the Uncompahgre/Dominguez herd (GMU S-62 on the northeast corner of the Uncompahgre Plateau, and the Dolores River herd (GMUs S-63 and S-64) along the Dolores River from Dove Creek down to Bedrock. The Black Ridge herd has remained stable at 200 bighorns. The Uncompahgre herd has remained stable at 160. The Dolores River population (comprising the Upper and Middle Dolores herds) has been stable to slightly increasing to a posthunt population estimate of 160 in 2014.

Harvest status

Conservative hunter harvest is taking place in all of the Colorado Desert bighorn herds. The Black Ridge herd (S-56) receives the most licenses of any herd at 5, with license allocation at 2.5% of the population and a 3 year average hunter success rate of 100%. The 3-yr average growth rings measured from the harvested rams in S-56 is 6.2. Four ram licenses are allocated for harvest in the Uncompahgre bighorn herd (S-62) at 1.9% of the population, with a 3 year hunter success rate of 100%. The average rams harvested in S-62 are the youngest, with 5.5 growth rings measured on a 3-year average. The Dolores River population (S-63 and S-64) has the most conservative license allocation at 3 ram licenses per year at 1.3% of the population estimate. The 3 year harvest success rate is 93% with the 3 year average growth rings measured from harvested rams being 7.8. Discussions are taking place to split up allocation of licenses between the two Dolores River herds and increase licenses.

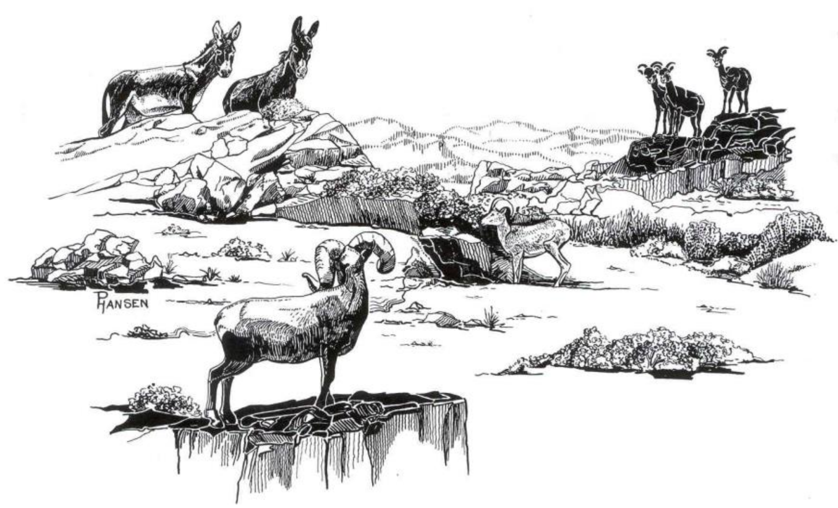
Ongoing projects

In 2010, Colorado Parks and Wildlife (CPW) initiated a project to transplant 30 desert bighorn sheep from the Upper Dolores River herd (S-64) to the Middle Dolores River herd (S-63) as a range expansion project. Previous transplants into the Middle Dolores herd have been done with marginal success. This project received authorization from the Wildlife Commission to remove mountain lions that were observed to be killing transplanted bighorns. Most of the transplanted bighorns were fitted with satellite GPS collars to provide real time data, however, canyon topography appeared to have reduced satellite contact frequency and most lion kills were not examined until too much time had passed to attempt to capture and remove the offending lion. Staff is currently analyzing data to look at habitat use and changes in habitat use over time, post release.

CPW and the Bureau of Land Management initiated a new project in 2012 to evaluate habitat use of desert bighorns in proximity to domestic sheep grazing allotments in the Uncompahgre (S-62) population. The S-62 population utilizes habitat mostly encompassed by the newly designated Dominguez-Escalante National Conservation Area (DENCA). As part of the legislation developing the DENCA, a new resource management plan is being developed and the BLM requested assistance to try to get better data about bighorn sheep and how they utilize the landscape. To date, 23 bighorns (13 rams and 10 ewes) have been collared with satellite GPS collars, collecting 6 GPS locations per day to monitor habitat use, survival, and spatial and temporal use of the landscape.

Management Issues

Currently, disease issues associated with domestic sheep and goats, recreation, and drought are our primary management issues associated with bighorn sheep in Colorado. Of our desert bighorn herds, the Uncompahgre/Dominguez herd has the greatest conflict with livestock and disease as bighorn sheep range overlaps active winter grazing allotments. Our other desert bighorn herds do not overlap domestic sheep public land grazing allotments, but private domestic sheep flocks are still a concern. Increases in recreation are also creating concerns for our bighorn sheep as more people are getting out and hiking in proximity to bighorns, especially during the lambing season. Weather is probably the most influential factor affecting our desert bighorn populations. Drought conditions have caused problems with water availability and forage availability and quality. Lack of water sources and quality forage created an increase in susceptibility to predation. During the worst drought years in recent history during the early 2000s, a disease event was also a factor in mortality in the Uncompahgre and Dolores River herds. Fortunately, over the last 2 years, weather patterns have been mild with good moisture, especially in the summer months. Abundant water sources and forage have spread out bighorns across the landscape, which has helped to lessen predation issues.



Status of bighorn sheep in Nevada, 2006–2014

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Desert Bighorn Council Transactions 53:39–44

Populations

Nevada bighorn sheep (*Ovis canadensis*) population status and trend reports have not been published since Cox and Cummings (2005). Since that time, overall population trend has been increasing to stable, although Nevada's bighorn sheep populations are facing increased challenges from exposure to respiratory diseases. Nevertheless, translocations and pioneering herds have increased the distribution and abundance (Fig. 1).

Nevada is occupied by desert bighorn sheep (*Ovis candensis nelsoni*), Rocky Mountain bighorn sheep (*O. c. canadensis*), and California bighorn sheep (*O. c. californiana*). The various populations number 9,600 for desert (up from 5,500 in 2005), 230 for Rocky Mountain (down 110 from 2006), and 1,900 for California (up from 1,500 in 2005) bighorn sheep. Currently, about 12,000 bighorn sheep inhabit Nevada.

Ram to ewe ratios have remained relatively high. Based on annual surveys conducted during October–November, desert bighorn sheep had a ram to ewe ratio of 59 and 48:100, and a lamb to ewe ratio of 34 and 34:100 in 2013 and 2014, respectively. During the same survey period, Rocky Mountain bighorn sheep had a ram to ewe to lamb ratio of 46:100:32 in 2013 and 48:100:38 in 2014, whereas California bighorn sheep ratios were 33:100:39 in 2013 and 46:100:32 in 2014. Although all subspecies had lamb ratios in that exceeded 30:100, only Rocky Mountain bighorn sheep populations have not been increasing in Nevada.

Harvest

Tag numbers have increased during 2006–2014 across all subspecies of bighorn sheep in Nevada, with little change in mean age or Boone and Crockett (B&C) score (Fig. 2). There were 287 tags for desert bighorn sheep in 2014, whereas there were only 154 in 2006. Rocky Mountain bighorn sheep dipped to 4 tags in 2014 from a high of 13 in 2008, although there were only 6 tags in 2006. California bighorn sheep supported 66 tags in 2014, while only 41 tags were offered in 2006. Mean annual B&C scores of harvested rams remained stable for desert bighorn sheep between 2006 and 2014, varying from a low of 149 5/8 in 2007 to a high of 154 in 2012. Harvested Rocky Mountain bighorn sheep had a wider range of mean annual B&C scores, with a low of 150 in 2014 and a high of 172 2/8 in 2009. During the same time period, mean annual B&C scores for harvested California bighorn sheep ranged from 147 4/8 in 2007 to a high of 156 in 2010. In 2014, harvested mean California bighorn sheep B&C scores was 153 1/8.

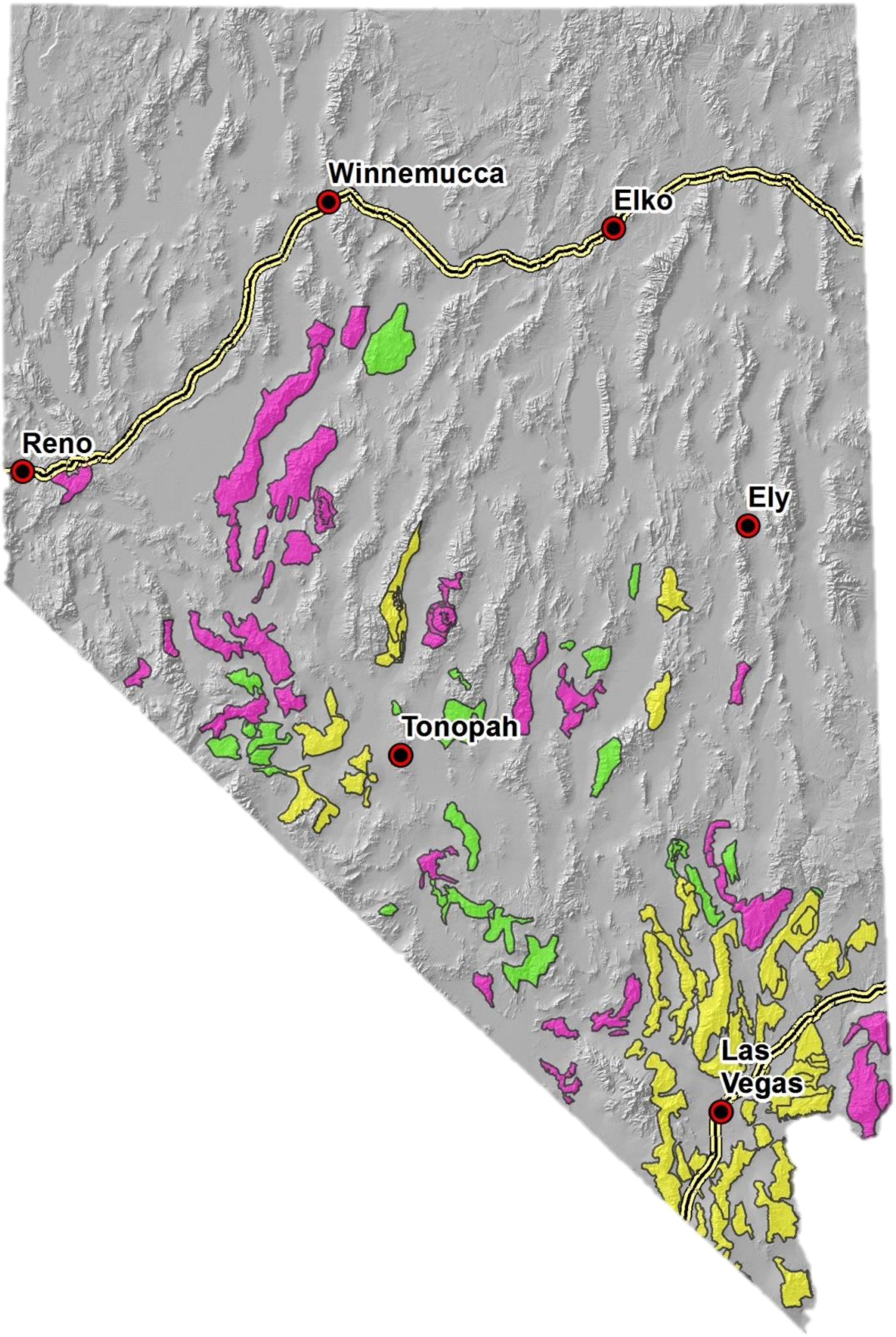

Figure 1. Yellow polygons identify relict desert bighorn sheep population distributions, pink polygons identify reintroduced desert bighorn sheep populations, and green polygons identify distributions of desert bighorn sheep pioneered without anthropomorphic aid in Nevada.

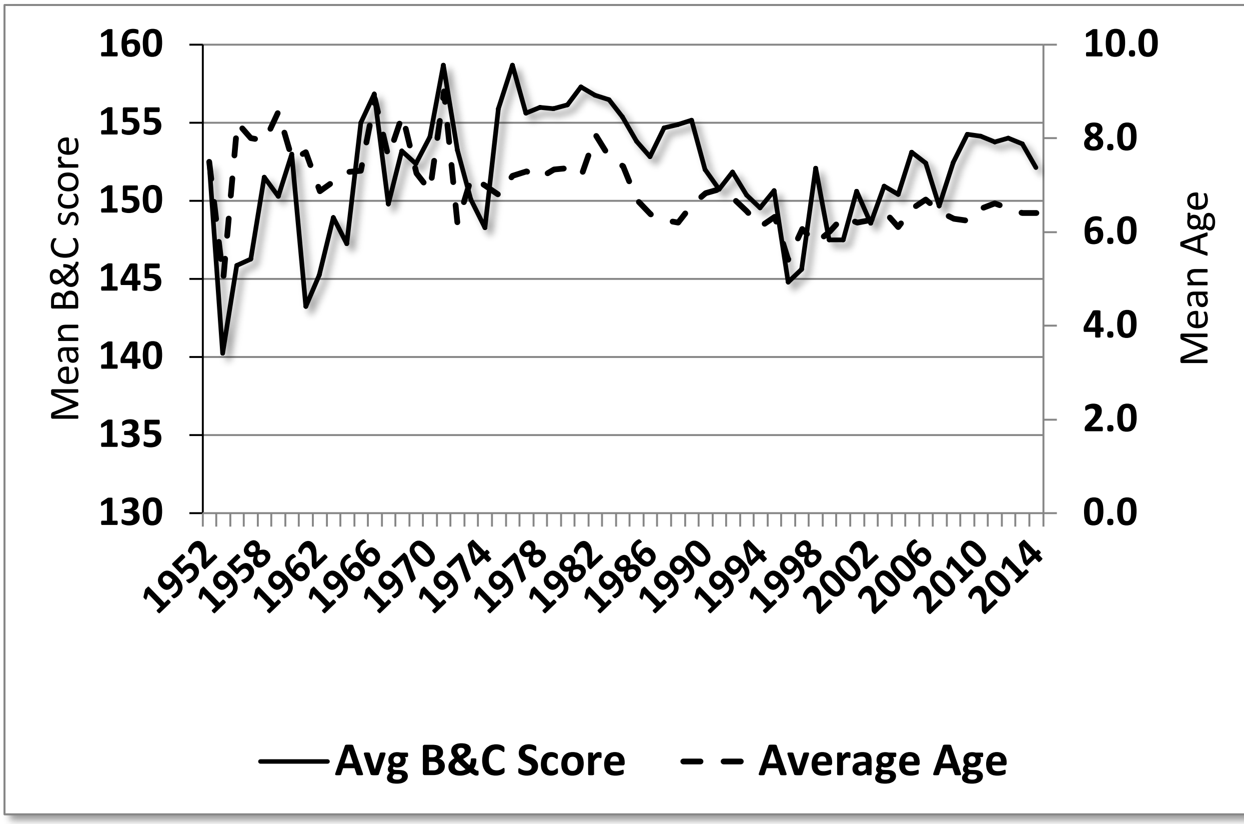

Figure 2. Relationship between mean age and mean Boone and Crockett (B&C) score of harvested bighorn sheep rams in Nevada, 1952–2014. In 1996, regulations were changed which allowed the take of any ram without regulation to minimum size.

During fall 2014, the Nevada Department of Wildlife (NDOW) held its first bighorn sheep ewe hunts. Ewe hunts were controversial when suggested, but NDOW believed that these hunts were essential to maintain herd numbers at lower densities to avoid greater risk of disease outbreaks. Eighty-five desert bighorn ewe tags were authorized in 2014, and 62 hunters successfully harvested animals. There were an additional 15 California bighorn sheep ewe tags authorized and 10 successful hunters. Demand for these tags ranged from 2:1 to 4:1 drawing odds. One hundred thirty bighorn sheep ewe tags have been authorized for fall 2015.

Herd Restoration, Disease Monitoring, and Management Challenges

Nevada's restoration efforts are still ongoing, although dramatically reduced in frequency and number of animals translocated (Fig. 3). Lee (2011) first reported Nevada's intent to investigate ewe hunts due to limited opportunities to continue translocations. Disease transmission risk has become better understood, leaving managers with more questions than answers. Traditionally, concern about intermingling of bighorn sheep populations with domestic sheep and goats has been paramount, but recently the risk of intermingling infected bighorn sheep has become

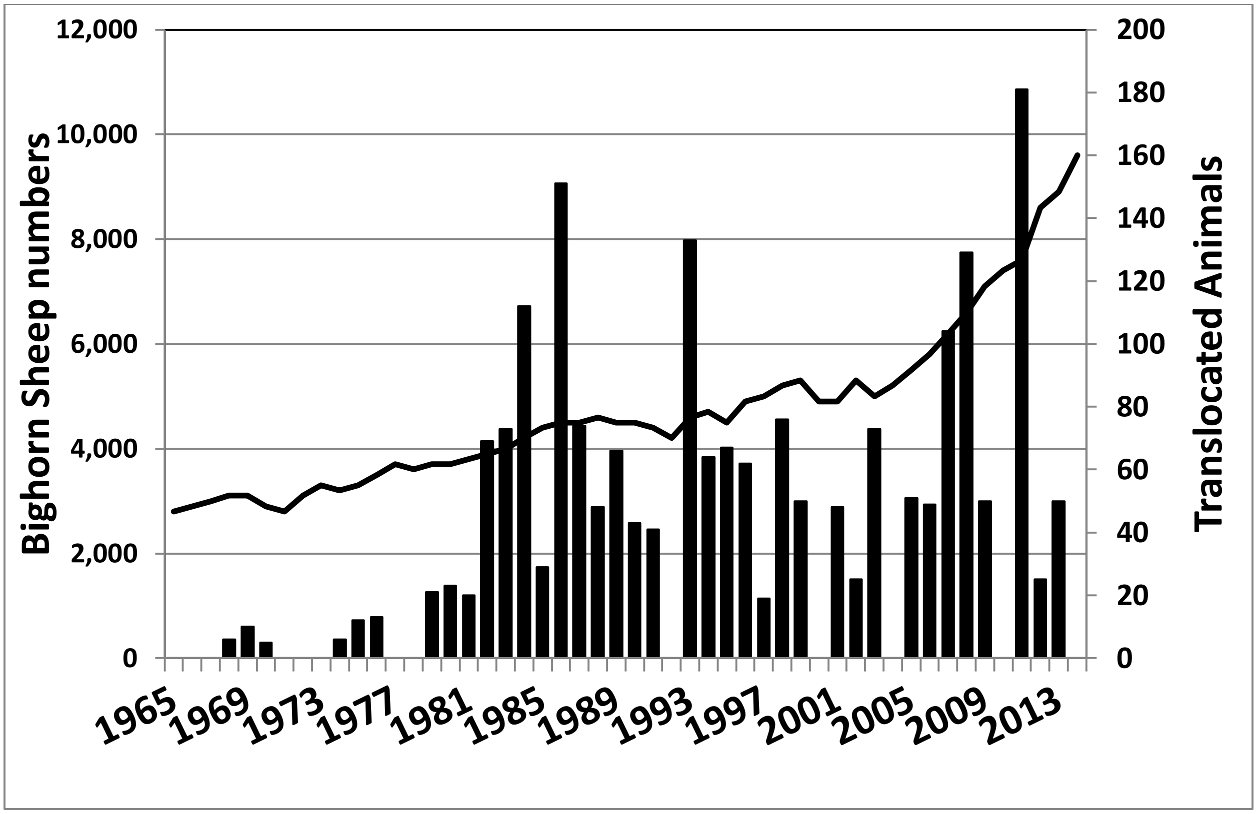

Figure 3. Desert bighorn sheep estimated population size (line) and translocated numbers (bars) by year in Nevada, 1965–2014.

more understood. Recently, both the Western Association of Fish and Wildlife Agencies (WAFWA) and The Wildlife Society have collaborated on position papers arguing for effective separation and caution for intermingling (Norris and Wolff 2015).

Following is a recent example of this risk from Nevada. As already mentioned, bighorn sheep are susceptible to diseases that cause pneumonia. These diseases, along with unregulated hunting and habitat exploitation, have been implicated in the original extirpation of bighorn sheep herds. This exposure was not premeditated or nefarious; livestock operators were exercising their legitimate rights when they began grazing the West. In most cases, managed grazing today is consistent with approved and carefully analyzed allotment management plans with a basis in better science than ever before. But the inadvertent damage that has been done presents challenges going forward.

In Nevada, the bighorn sheep population in the East Humboldt Range and Ruby Mountains exemplify these challenges. Bighorn sheep were extirpated from this range in the mid-1930s. Thirty-one Rocky Mountain bighorn sheep were first released in 1992 in the East Humboldt Range. By 1998, the population had grown to over 90 adults, and 13 of these were captured for translocation to another mountain range in northeastern Nevada. By 2005, the herd was estimated at around 140 animals, and 30 ewes and lambs were translocated from the range in January 2006. The herd continued to grow and was estimated at 160 adults in late 2009 when it and the nearby Ruby Mountain herd experienced an all-age dieoff caused by an epizootic pneumonia event. During this same winter, about

900 bighorn sheep died in 9 herds inhabiting 5 western states from similar pneumonia outbreaks.

The East Humboldt Range and the Ruby Mountains have many things in common. In addition to the all-age dieoff of bighorn sheep, the habitat is similar, the bighorn sheep share the range with domestic livestock, including domestic sheep, and Rocky Mountain goats (*Oreamanos americanus*) inhabit both ranges. An intensive capture and monitoring effort followed in both mountain ranges during 2010 to document the pathogens involved with the surviving animals. Only 16 adult bighorn sheep in the East Humboldt Range were known to have survived by fall 2010.

NDOW developed an applied management project for both mountain ranges. The most devastating long-term effect of an all-age bighorn sheep die-off is realized through the years of poor lamb survival that routinely follow such an event (all lambs died in 2010 and 2011 and only 1 survived in 2012). This effect is currently thought to be due to a small number of survivors that remain as chronic carriers of the pneumonia-causing bacteria. The applied management proposed removing the survivors from the East Humboldt Range and releasing healthy bighorn sheep afterward to restore the herd, while monitoring respiratory pathogen transmission and epidemiology among bighorn sheep and sympatric mountain goats and domestic livestock.

On February 6, 2012, the remaining 10 ewes and 1 lamb from the East Humboldt Range were captured and translocated into the resident herd in the Ruby Mountain; 4 rams were placed into a research facility because they posed the greatest risk to future transmission because of the propensity for male bighorn sheep to roam widely during the breeding season. In February 2013, 17 ewes and 3 rams from the Luscar Mine in Alberta, Canada were captured, transported to Nevada, and released into the East Humboldt Range.

Since that time, bighorn sheep and mountain goats have been sampled annually in both ranges. This endeavor has been expensive. Funds from the Heritage Trust Fund raised through the sale of Heritage tags have topped $110,000; Nevada Bighorns Unlimited in Reno contributed $136,000; Elko Bighorns Unlimited spent $105,000; and Eastern Chapter of the Wild Sheep Foundation committed $5,000 – all toward the implementation of this management project. Mountain goats in both ranges have been repeatedly confirmed to carry the same strain of bacterial agents as have the bighorn sheep during the die-off. Bighorn sheep in the Ruby Mountains still test positive for this strain as well. Currently, no bighorn sheep in the East Humboldt Range have tested positive for the primary bacteria associated with pneumonia.

This has the making of a great success story, yet the sympatric mountain goats are suffering reduced recruitment from the same disease agents. Perhaps it is a matter of time until this disease, which was once most closely tied to domestic livestock, becomes endemic and is transmitted primarily among wildlife. The management questions we collectively face include: Is our use of translocations a vector by which disease is moved about and healthy herds exposed? Is the construction of artificial waters, which once made inhospitable areas habitable by desert wildlife, now a point of concentration where diseases are transmitted among wildlife? No cure or vaccine has been developed for these diseases. If they are developed, the ability to administer the appropriate cocktail will be complicated by the fact that these are free-ranging wildlife that do not lend themselves to common domestic husbandry practices, and adequate doses and exposures may be impossible to deliver to the appropriate proportion of the population to be effective.

WAFWA has recently initiated a West-Wide Adaptive Disease Management Initiative through the Wild Sheep Working Group. NDOW intends to support this effort so that we can continue to manage restoration efforts, but to do so intentionally and deliberately to learn from our future translocations. There remains unoccupied habitat, which NDOW intends to repopulate. But any mistakes our profession collectively makes must become a learning experience that we all benefit from.

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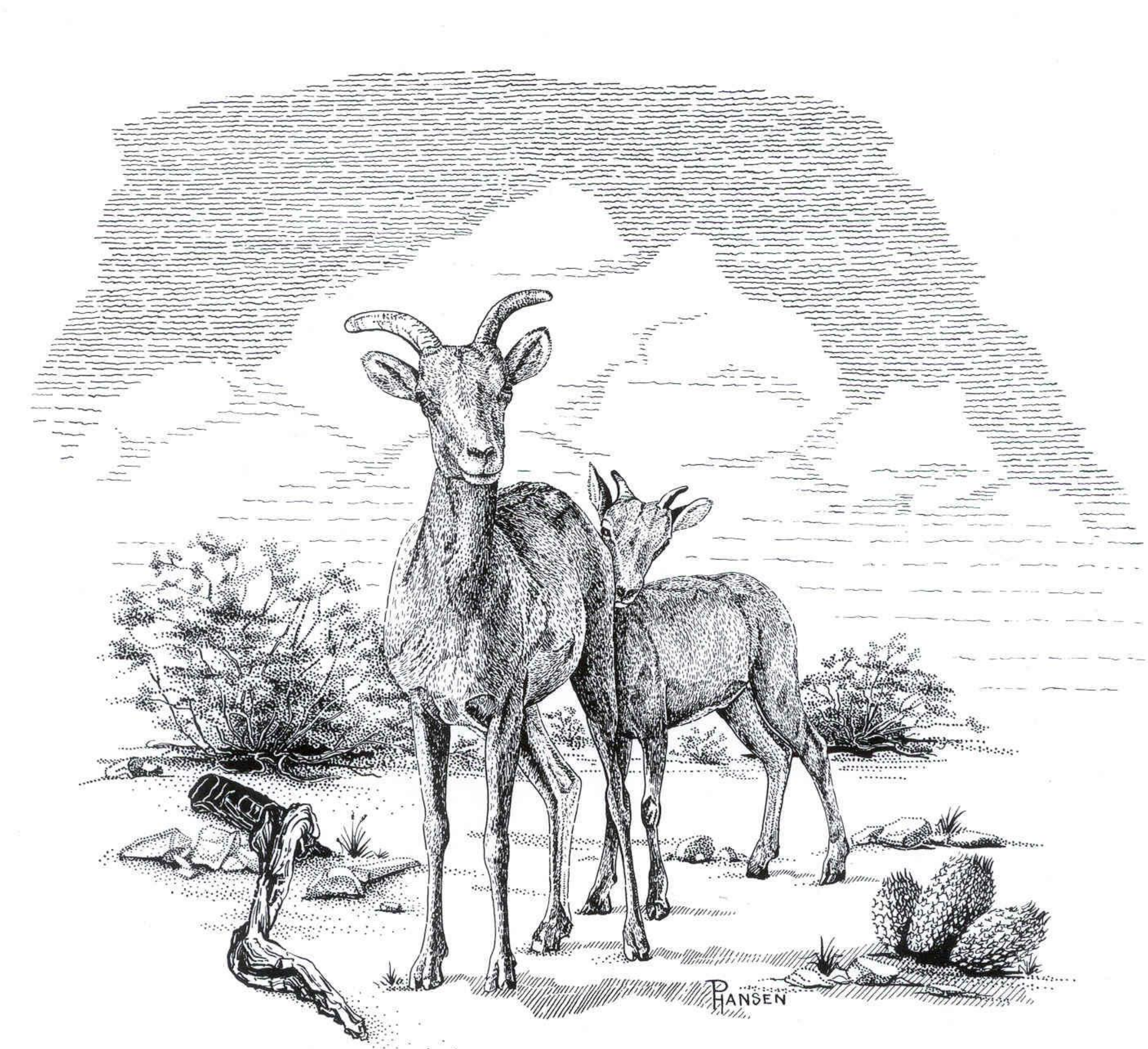

Status of desert bighorn sheep in New Mexico, 2013–2014

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Desert Bighorn Council Transaction 53:45–48

Synopsis

Desert bighorn sheep in New Mexico continue to increase following their delisting from state threatened and endangered species list in 2011 (Figure 1). The statewide estimate in 2014 was 839 sheep (range = 786-891). Six of 7 desert bighorn populations increased in 2013 and 2014, following the statewide trend in growth. Discussion of these herds in the context of their metapopulations follows. Management strategies including translocations and mountain lion control remain important factors in the continued success of desert bighorn restoration. State, federal, and private partners, as well as committed individual constituents, remain crucial to realizing program goals and supporting the conservation of New Mexico's desert bighorn.

Fra Cristobal-Caballo Mountains Metapopulation

This metapopulation has grown to 325-355 wild sheep. The Fra Cristobal herd is the largest population of desert bighorn (220-240) and subsequently has served as a source for desert bighorn translocations. Most recently, 40 sheep (20 ewes/20 young rams) were moved into the Big Hatchet Mountains in November 2014. The estimate for the Caballo herd is 105-115 desert bighorn.

Bootheel Metapopulation

The Bootheel metapopulation is currently estimated to be 265-300. This includes the Big Hatchet, Little Hatchet, and Peloncillo Mountains. The Big Hatchet Mountains were augmented with 66 sheep in November 2014. Based on survey estimates, the Peloncillo herd decreased in both 2013 and 2014. For this reason it is a high priority candidate for future augmentation.

San Andres Mountains

The last survey in the San Andres occurred in fall of 2012. This aerial survey resulted in an estimate of 115-135 bighorn. San Andres National Wildlife Refuge (SANWR) developed a desert bighorn sheep hunt plan with input from White Sands Missile Range, and New Mexico Department of Game and Fish. This hunt plan will be implemented starting in 2015-2016 and will grant SANWR access to hunters possessing desert bighorn ram licenses in GMU 19. This will increase the San Andres hunt area by 57,215 acres.

Ladron Mountains

The Ladron herd is the smallest of New Mexico's desert bighorn populations. Current estimates are 70-80 sheep, up from 2012 estimates of 50-60. The Ladron herd is another candidate for upcoming desert bighorn translocations.

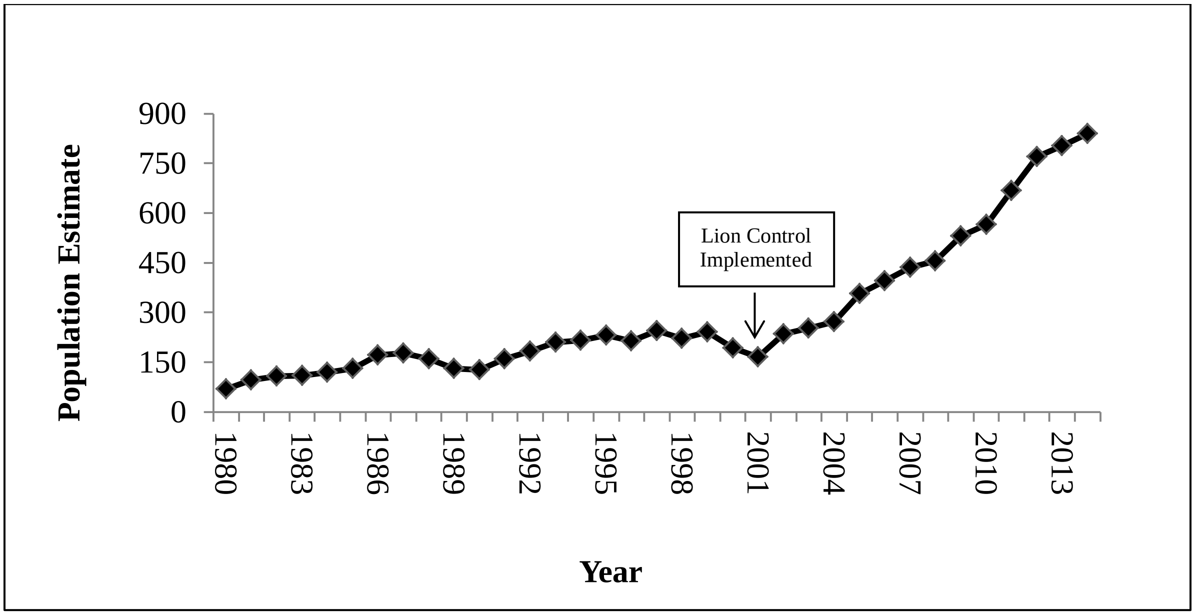

Figure 1. New Mexico statewide desert bighorn population trend from 1980-2014.

Mountain lion control

Removal of mountain lions in desert bighorn range has been essential to the speed and success of their recovery (Rominger et al 2008). The mountain lion removal program initiated in 2001 continues to be an effective tool in desert bighorn management. They were the primary predator responsible for collared sheep mortalities in 2013-2014. Currently, snaremen and/or hounds men work in all ranges excluding the San Andres. For the past two years, an average of 2.2 lions were removed per range per year.

Red Rock Captive Facility

The Red Rock facility is maintained by 2 part-time contractors who are responsible for fence and drinker maintenance, supplemental feed when necessary, and removal of mountain lions near and within the facility. In the past 15 years the average removal rate at the Red Rock facility has been 2.9 mountain lions per year. Despite efforts to keep the facility lion free, mountain lion predation remains a primary mortality factor for desert bighorn at Red Rock.

Red Rock contained an estimated 90 desert bighorn prior to the November 2014 removal of 26 sheep (18 rams/8 ewes) for translocation. These bighorn, in addition to 40 from the Fra Cristobal Mountains, augmented the Big Hatchet population. Collars were deployed on 48 of the transplanted bighorn. Monitoring of these collared sheep will provide information on mortality and movement of desert bighorn in the Hatchets. To date, 446 desert bighorn sheep have been released from Red Rock.

A recent manuscript assessed the genetic diversity of the Red Rock herd and found that the heterozygosity levels were low compared to values seen in other wild herds, yet overall were higher than expected (observed heterozygosity = 0.505, and expected heterozygosity = 0.490; Wehausen 2010). Wehausen did not find evidence of a bottleneck in his analysis. In 2011, shortly after this genetic assessment, 10 rams from Pilares, Mexico were introduced into

Red Rock in an effort to increase genetic diversity. Although the bighorn from Pilares and the bighorn from Red Rock were each characterized by low genetic variation, the combination of these two differentiated populations would increase genetic variation in Red Rock (Hedrick 2013). Future analyses and strategic reintroductions will be necessary to continue to ensure the genetic viability of Red Rock sheep as well as wild desert herds in New Mexico.

Research

Graduate students at New Mexico State University completed two research projects on desert bighorn in New Mexico. In the Peloncillo Mountains the characteristics of parturition sites, nursery sites, and lamb mortality were evaluated (Karsch 2014). Foraging efficiency and behavior in desert bighorn were assessed in the cattle-grazed Caballo Mountains and the ungrazed San Andres Mountains (Garrison 2014). Results from both studies are being prepared for publication.

Hunting

NMDGF issued 16 public draw licenses for desert bighorn rams in both 2013 and 2014. Additionally, 3 private land tags, 1 auction tag, and 1 raffle tag were issued each year. The auction of a desert ram permit is facilitated by the Wild Sheep Foundation (WSF) Convention. It was sold in 2013 for $180,000 and in 2014 for $270,000 (Table 1). The New Mexico Chapter of WSF conducts the annual raffle of one desert ram permit and one Rocky Mountain ram permit. Hunter harvest success was 100% both years. In 2013, a new state record desert ram was harvested in the Ladron Mountains and received an official Boone & Crockett score of 195 3/8. In 2014, state law was amended such that 84% of bighorn sheep draw licenses must be allocated to New Mexico residents, establishing consistent draw quotas amongst all big game species.

Table 1. Enhancement license proceeds from auction and raffle authorizations.

	2011	2012	2013	2014
Auction Tag Proceeds	$130,500	$144,000	$324,000	$396,000
Lottery Tag Proceeds	$28,850	$45,252	$83,008	$143,000

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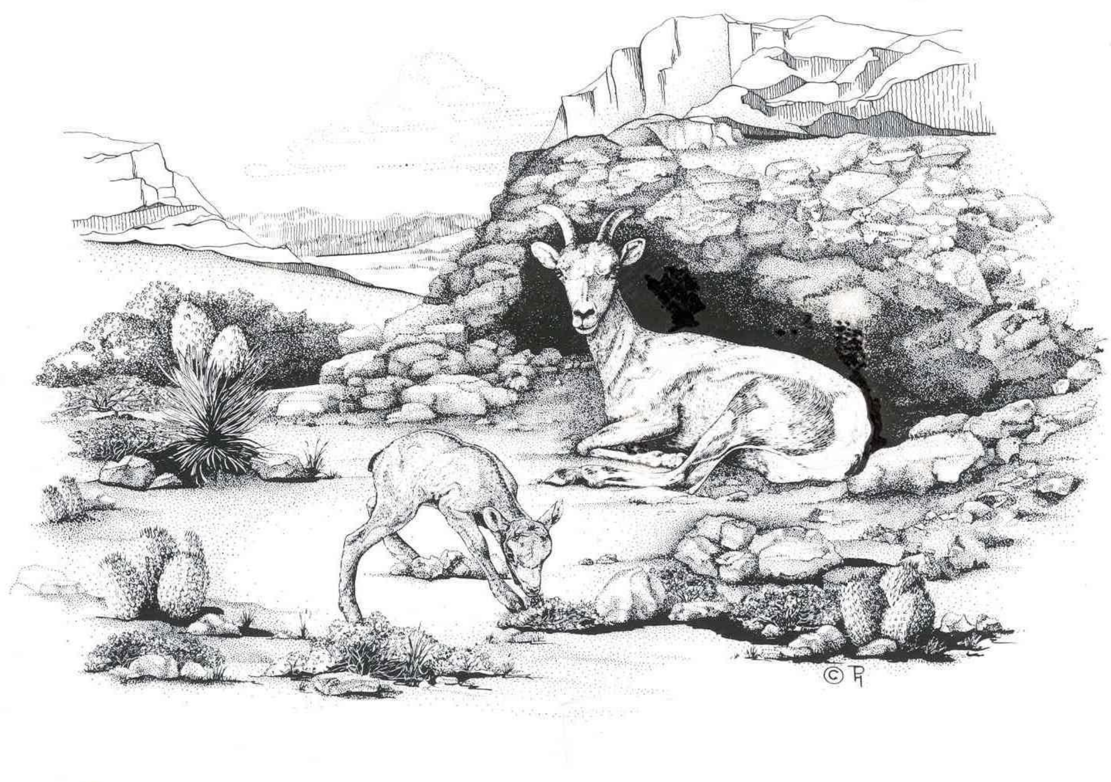

Status of desert bighorn sheep in – Texas, 2013–2014

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Desert Bighorn Council Transactions 53:49–52

Populations

Overall, the Texas bighorn population is on the rise (Figure 1). Yearly bighorn surveys were conducted in August of 2013 and 2014. The 2013 helicopter count resulted in 1,190 bighorns counted with a lamb crop (lambs per 100 ewes) of 36% and 1,235 and a 47% lamb crop for 2014. However, the 2014 helicopter count does not include the 2014 Capote Peak bighorn foot survey. Therefore, the corrected count for 2014 would approximately be at least 1,280 bighorns. There are an estimated 1,500 bighorn sheep statewide.

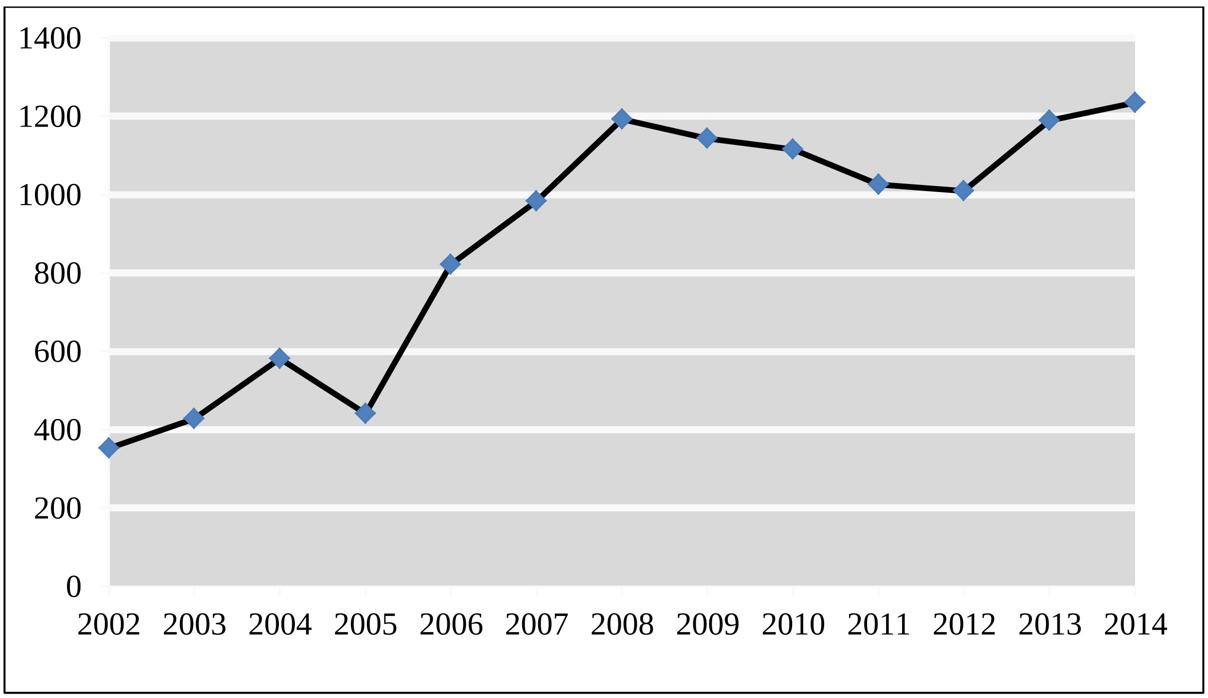


Figure 1. Statewide desert bighorn survey results for Texas. 2002–2014.

Harvest

In the 2013-14 bighorn hunt season, 14 permits were issued, which included 3 Public and 11 private landowner permits. The 2013-14 hunt season resulted in a 100% success rate. For the 2014-15 season, 13 permits were issued. Out of the 13 permits, 9 were issued to private landowners. The remaining 4 were public permits which includes 3 Texas Parks and Wildlife Department (TPWD) and 1 Big Bend National Park (BBNP). There are still 3 outstanding permits which have not been hunted. One of the outstanding 3 permits was issued to BBNP, and consequently won't be hunted. Since bighorn hunting was reinstated in 1987, there have been 188 permits issued. These include 130 private landowners, 56 TPWD and 2 BBNP permits.

Water Development

Five new water guzzlers were constructed in strategic locations which will benefit bighorns as well as other wildlife. This added a potential 12,500 total gallons of water for those 5 guzzlers across the landscape. In addition to the 5 new guzzlers, 5 old guzzlers were rebuilt and updated with new water storage tanks, drinkers, and aprons.

Restoration

From December 2010 to January 2015, over 320 bighorns have been captured and translocated to mountains which have not seen sheep in over 50 years (Table 1.). These ranges include the Bofecillos Mountains of Big Bend Ranch State Park (BBRSP), 9 Point Mesa in southern Brewster County, and most recently to Capote Peak which forms part of the Sierra Vieja Mountains.

Despite extremely dry environmental conditions following the first translocation and initial losses (e.g. predation, natural death), the BBRSP bighorn herd has adjusted well and appears to have stabilized. The last 2 surveys (August 2013 and 2014) have resulted in lamb crops (lambs per 100 ewes) of nearly 80% and 60%, respectively. A total of 56 bighorns were counted in 2013 and 51 in 2014. We are certain we missed several within BBRSP as well as others in Mexico. Some of the BBRSP bighorns have made movements in excess of 30 miles away from the actual release site making use of sheep habitat south of the border into Mexico, as well as to the north out of BBRSP boundary and onto private property. And while there has not been a dramatic increase in bighorn numbers, there has been no noticeable decline either.

The 9 Point bighorns have fared rather well since their release in December 2012. Movements to neighboring Santiago Peak (approximately 13 miles to the north), have been observed in some rams, as expected, but they tend to return to 9 Point. However, some bighorns have gone back to Elephant Mountain (capture site) approximately 26 miles to the north. There have been other bighorns on 9 Point that cannot be accounted for. One potential source is Elephant Mountain. Another source could be the Persimmon Gap area approximately 15 miles west of 9 Point and on the northern end of Big Bend National Park

The Capote Peak bighorns seem to have settled down from their transplant in January 2014 and January 2015 and are making good use of the area. A few bighorns have moved off of the Peak and onto a neighboring Escondido Peak (approximately 10 miles to the south), but still on the Sierra Viejas. Others ventured to small foothills across the flats to the west about 5 miles and spilt their time between foothills and Capote. A foot survey was conducted on Capote in May 2015. Nearly 60 bighorns were counted with a lamb crop of almost 60% (58%).

Research

Out of the 136 translocated bighorns during the 2014-2015, 86 were fitted with radio collars to facilitate post-release monitoring. The collaring of these bighorns also served as research for 2 M.S. projects and 1 Ph.D project. One of the M.S. projects included investigating the survival and habitat utilization of translocated desert bighorn sheep to 9 Point Mesa Mountain. The other M.S. project investigated the movements and survival of translocated bighorns from two distinct herds. The PhD project is investigating the spatial, temporal, and demographic

Table 1. Desert bighorn sheep translocations in Texas, 2010–2015, including source population and release sites.

Year	Source	Release Site	Rams	Ewes	Total	Collared Rams	Collared Ewes
2010	EMWMA[1]	BBRSP[2]	12	34	**46**	10	25
2011	Metapop.[3]	BBRSP	19	76	**95**	14	29
2012	EMWMA	9 Point Mesa	22	22	**44**	18	22
2014	EMWMA	Capote Peak	21	40	**61**	13	23
2015	Metapop.[4]	BBRSP	15	45	**60**	12	30
2015	Sierra Diablo	Capote Peak	2	13	**15**	2	6
		TOTAL	**91**	**230**	**321**	**69**	**135**

[1]EMWMA: Elephant Mountain Wildlife Management Area
[2]BBRSP: Big Bend Ranch State Park
[3]Metapop: Beach, Baylor and Sierra Diablo Mountains
[4]Metapon: Beach and Sierra Diablo Mountains

characteristics of desert bighorn sheep in Texas. These projects are still ongoing and final results are not available at this time. Some of the preliminary results from these projects show that the bighorns from the BBRSP study use an area of almost 1.5 million acres, which includes mountain ranges on both the Texas and Mexico side. Additionally, travel corridors between Texas and Mexico seem to have been identified.

Disease Monitoring

While there have been no noticeable disease outbreak in the Texas herd, the disease monitoring continues to be an important component of the management and restoration of desert bighorn sheep in Texas.

A new position was created which allowed for the addition of a TPWD wildlife veterinarian. Dr. Bob Dittmar comes to TPWD with over 30 years of veterinarian field experience in the private sector.

A few of the things being planned include the standardization of the necropsy protocol, identifying a tissue sampling protocol applicable to Texas, and developing a formal Disease Outbreak Response Plan.

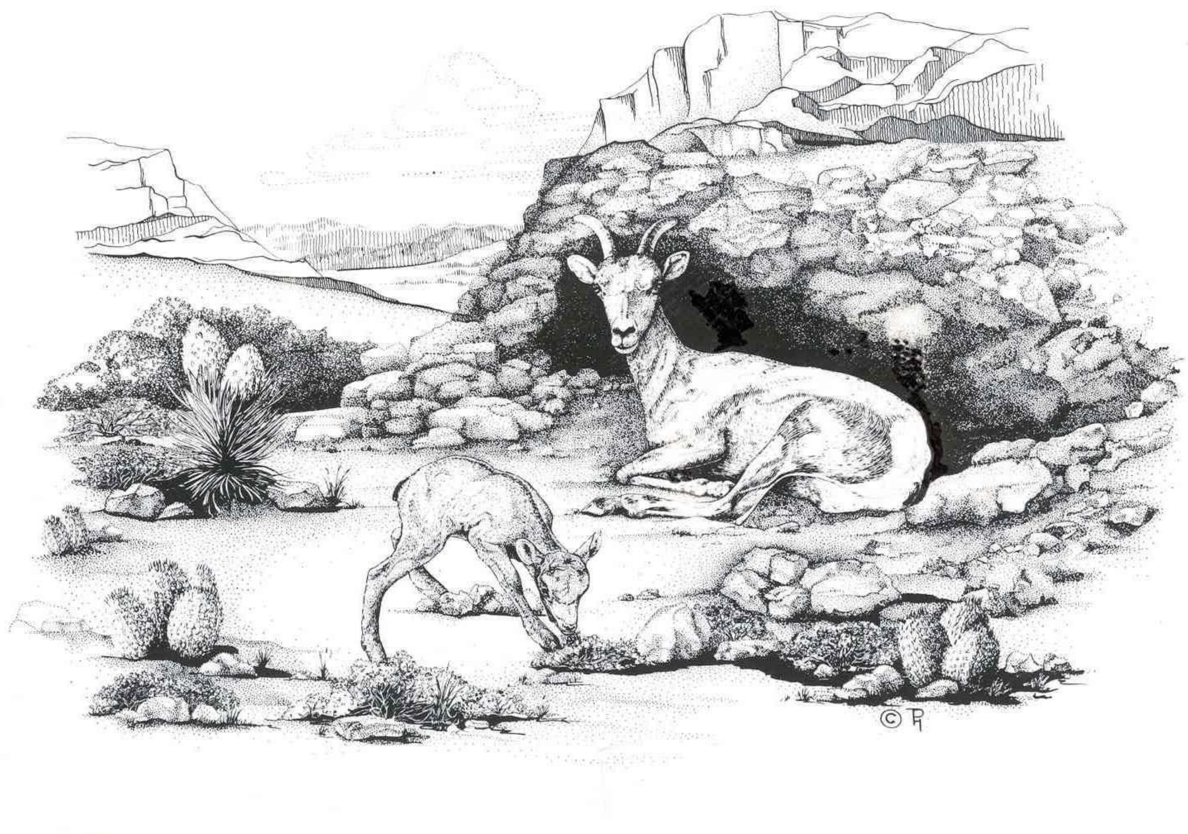
Closing

Since the early stages of desert bighorn restoration efforts in Texas, the Texas Parks and Wildlife Department has had the good fortunate of having conservation partners, hunters and outdoor enthusiasts, dedicated landowners, committed individuals, and loyal volunteers who share the passion for bighorn sheep and all things wild. Without their support, bighorn restoration would have been nearly impossible.

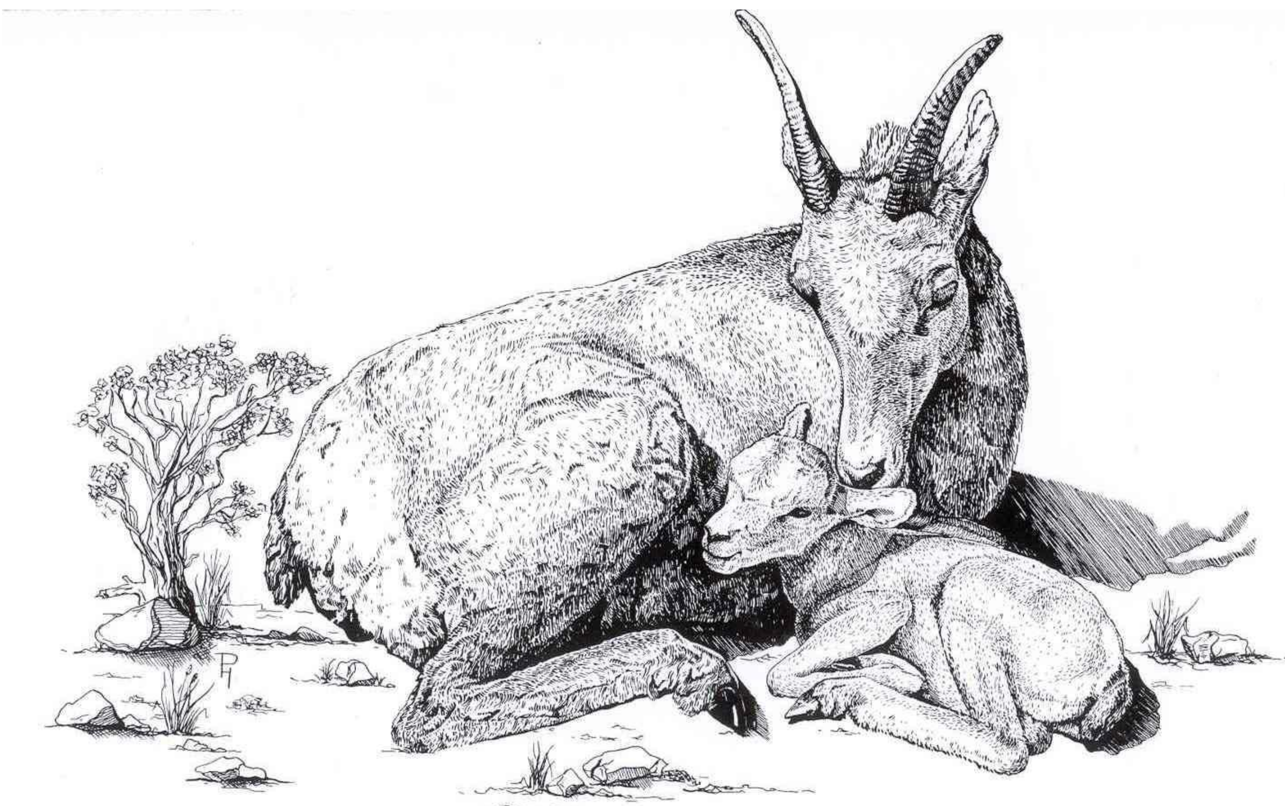
Support and cooperation continues to be a vital part of bighorn restoration. This has been epitomized in the last several years. For without the help of all partners, supporters, volunteers and landowners, captures and transplants would be nearly impossible.

The future is looking bright. Bighorn populations in various mountain ranges are found in healthy numbers, which presents capture opportunities for further translocations. We hope to be able to continue transplanting bighorns to ranges which have been void of bighorns and continue expanding by stocking their historical range. We also intend to transplant bighorns into existing herds to augment populations as needed.

Desert bighorn restoration in Texas will continue moving forward. And cooperation, support and partnerships will always to be a vital part of the restoration effort and critical to the success of the program.



Abstracts of Presented Papers



THE ROLE OF MYCOPLASMA OVIPNEUMONIAE IN EPIZOOTIC PNEUMONIA OF BIGHORN SHEEP

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The increasing body of evidence that supports a key role for *Mycoplasma ovipneumoniae* (Movi) in the epidemiology and pathophysiology of pneumonia of bighorn sheep will be summarized. A causal role for Movi is supported by a strong statistical association between its detection in a population and the occurrence of the disease (with an odds ratio >40), by observational and experimental evidence satisfying Koch's postulates and by stronger support than competing hypothesized agents under Bradford Hill's criteria. Ongoing studies are investigating the role chronic carrier ewes, animals that survived pneumonia and recovered but continue to shed Movi in nasal secretions. Chronic carriers appear to play a key epidemiologic role in the transmission of Movi to susceptible lambs and the persistence of the agent in the population. Other ongoing studies to be described include 1) comparison of domestic sheep and goats Movi strains as agents of bighorn sheep pneumonia; 2) the impact of introduction of a second Movi strain to a previously Movi-exposed population; and 3) a method to document the specific source of Movi that trigger bighorn sheep pneumonia outbreaks. Finally, differences between desert bighorn sheep and other sub-species that may affect the transmission and persistence of Movi will be discussed.

DEMOGRAPHIC RESPONSES OF BIGHORN SHEEP TO RECREATIONAL ACTIVITIES: A TRIAL OF A TRAIL

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Long-term effects of anthropogenic disturbance to wildlife, and whether such effects have population-level consequences, often are difficult to determine. In 1996, a recreational hiking trail (Maah Daah Hey Trail) was constructed by the U.S. Forest Service through 4 geographic areas, each occupied by a distinct subpopulation of bighorn sheep (*Ovis canadensis*), in western North Dakota, USA. From 2001 to 2012, we monitored distribution, recruitment rates, and abundance of female bighorn sheep to investigate responses to activities associated with unhindered use of that trail and subsequent free access to an important lambing area. To investigate whether demographic consequences occurred, we compared those data to identical information from 3 reference populations of bighorn sheep that were not exposed to unhindered public use of the trail. Female bighorn sheep were displaced from, and eventually abandoned, lambing habitat subjected to intensive, erratic, and unpredictable recreational use. Those females had lower fidelity to lambing areas than the reference populations, all of which realized 100% fidelity. Further, the females exposed to unhindered disturbance achieved lower recruitment of young, exhibited a substantial downward trend in recruitment rate, and a decline in the number of females in that population compared with the others, for which perturbation was less severe and human activities were consistent and predictable, and public use of lambing habitat was not unhindered. Metapopulations of bighorn sheep occurring in fragmented habitat having minimal vertical relief may be especially susceptible to sources of disturbance, which should be a consideration when recreational facilities are developed.

GENETIC POPULATION STRUCTURE OF PENINSULAR BIGHORN SHEEP (OVIS CANADENSIS NELSONI) INDICATES SUBSTANTIAL GENE FLOW ACROSS THE US-MEXICO BORDER

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Within the United States (US), Peninsular bighorn sheep (*Ovis canadensis nelsoni*, PBS) are listed as federally endangered. Despite known metapopulation structure, little is known regarding functional connectivity across the international border with Mexico. Increasing threats to connectivity associated with highway expansion, renewable energy development, and completion of the US-Mexico border fence, led us to conduct a study of genetic variation and spatial structure. Blood and fecal samples were collected (n = 224) on both sides of the border from 1992 to 2013. Genetic data was obtained for 25 microsatellite loci and 515 base pairs of the mitochondrial DNA control region. Microsatellite diversity (observed heterozygosity = 0.56; allelic richness = 4.1; inbreeding coefficient = 0.01) was substantial despite past demographic declines. STRUCTURE analysis indicated the presence of three genetic populations, one of which spanned the international border. This pattern of genetic structure was supported by analysis of molecular variance for both microsatellites and mitochondrial DNA ($P < 0.01$), and low-moderate pairwise fixation indices ($F_{ST} = 0.09$—0.15; $\Phi_{ST} = 0.18$—0.27) indicated substantial gene flow among populations. Migrant detection tests indicated natal dispersal occurred within both sexes, with no evidence of sex bias. Despite the severe reductions in population abundance which led to federal listing in the US, these data suggest PBS have retained substantial genetic variation and show little evidence of a recent genetic bottleneck. Patterns of genetic spatial structure suggest gene flow throughout the ranges is common, and construction of a US-Mexico border fence or wind energy infrastructure would disrupt connectivity of the metapopulation. Future conservation efforts should focus on identifying dispersal corridors and maintaining functional connectivity to facilitate recolonization of unoccupied habitat. *(Buchalski et al. 2015 Biological Conservation).*

RANGE-WIDE POPULATION GENETIC STRUCTURE AND PHYLOGENETICS OF DESERT BIGHORN SHEEP: IMPLICATIONS FOR CONSERVATION

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Though often well characterized at the regional level, few studies have examined the genetic structure or phylogeography of desert bighorn sheep range-wide. We examined genetic variation of 672 desert bighorn sheep (*Ovis canadensis* spp.) across 53 sites throughout their range in the southwestern US and northern Mexico, and an additional 52 Sierra (*O. c. sierrae*) and 70 Rocky Mountain bighorn (*O. c. canadensis*) from adjacent populations. Variation at 39 microsatellites and a 515 bp portion of the mitochondrial D-loop was analyzed. Using microsatellite data, a discriminant analysis of principle components differentiated the three recognized taxa (Sierra, Rocky Mountain, and desert), and provided evidence of substructure (5 groups) within desert bighorn. Genetic differentiation among desert bighorn herds appears largely due to isolation-by-distance, though discrete barriers within the central Mojave and Transverse Ranges were identified. Concordantly, network and maximum-likelihood analysis of the mitochondrial D-loop revealed three distinct clades (≥ 72% bootstrap support) that conformed to the three major groups. Our microsatellite and mitochondrial data suggest strong divergence of desert bighorn from other subspecies in North America, with no statistical support for recognition of multiple subspecies within the taxon. Although desert bighorn appear connected by gene flow as a single evolutionary unit, future analyses are needed to investigate potential for local selection to structure functional genes. Regardless, conservation of localized genetic variation remains necessary for maximizing diversity.

PNEUMONIA IN BIGHORN SHEEP: TESTING THE SUPER-SPREADER HYPOTHESIS

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Following introduction of pneumonia, disease can persist in bighorn sheep (*Ovis canadensis*) populations for decades as annual or sporadic pneumonia epidemics in lambs. Recurring years of depressed recruitment due to high rates of pneumonia-induced mortality in juveniles is a major obstacle to population recovery. Management strategies for resolving this problem have so far been elusive. We are investigating the feasibility of removing individual "super-spreaders" to improve lamb survival. Individual variation in infection and transmission is well documented in human diseases (e.g. "Typhoid Mary"). We are testing the hypothesis that pneumonia epidemics in lambs are initiated by transmission of pathogens from a few "chronic-shedder" ewes. We have completed the first year of a 5-year project in the Hells Canyon region of Idaho, Oregon, and Washington, and in a captive population at South Dakota State University. Through repeated testing of free-ranging individuals in Hells Canyon, we have identified individual differences in shedding of *Mycoplasma ovipneumoniae*, a primary pathogen in the bighorn sheep respiratory disease complex. We also found that when penned separately in captivity, lambs of ewes that consistently tested positive (chronic shedders) were infected and died of pneumonia, whereas lambs born to ewes from an infected population that tested negative (non-shedders), were not infected and survived. Over the next 4 years we plan to 1) continue and expand testing of free-ranging and captive animals, 2) determine whether removal of chronic-shedder ewes improves lamb survival in free-ranging populations, 3) expand and replicate chronic-shedder commingling experiments in captivity, and 4) establish and monitor a new population founded with non-shedders from an infected population.

DESERT LION MOVEMENT RATES AND UNGULATE KILL RATES RELATED TO AMBIENT TEMPERATURE

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We examined movement rates of mountain lions (*Puma concolor*) in an arid landscape of west-central Arizona in relation to ambient temperature and season. Seventeen lions were fitted with Global Positioning System (GPS) collars during 2009-2014 for multiple monitoring and research purposes, and collars were programmed to obtain locational fixes at least 4 times per day. We calculated mean hourly movement rates and tested for correlation with ambient high temperature, and compared movement rates among seasons. We also tested if increased movement rates resulted in a corresponding expansion of home range size. We identified GPS-clusters using an automated algorithm, ground-truthed a subset of the identified clusters with field investigations, and estimated ungulate kill rates by season for each lion. Finally, we examined potential relationships between kill rates, ambient temperature, and movement rates. Results of these analyses will be discussed in relation to potential implications to lion predation on desert bighorn sheep (*Ovis canadensis*).

ADAPTIVE MANAGEMENT OF BIGHORN HERDS AT RISK TO DISEASE TRANSMISSION

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In Nevada, the core mission of our bighorn management program for decades focused on restoration of sheep through translocations and water developments; in essence "putting sheep on the mountain". Unprecedented success (3,000 wild sheep in 1980 to 11,000 in 2013) fostered a cavalier attitude toward disease risks which was supported by disease surveillance of growing source stock herds showing most harbored "bugs", specifically *Mannheimia hemolytica*, which should have caused deadly die-offs. After successfully creating metapopulations of interconnected herds, we experienced disease events of varying severity. The confidence and excitement of herd expansions and high lambdas turned to concern over reports of sick sheep and poor lamb recruitment. Improved pathogen diagnostics, realization of how rapid the spread of disease can occur between herds, the unknown severity of the next disease event, and variation in herd responses to disease led to a paradigm shift of increasing emphasis on "keeping sheep on the mountain". Several new tenets to Nevada's bighorn management program are:

- Don't cause a disease event through management actions; make informed decisions;
- Polymicrobial pneumonia may cause severe and long-lasting herd impacts;
- Public land sheep allotments and private flocks should be mapped and monitored;
- Pathogens spread by bighorns are equally as devastating as the initial transmission from domestics;
- Conduct active and passive disease surveillance on all herds but prioritize healthy herds at high risk to exposure;
- Attempt to define lamb mortality caused by drought vs. disease;
- Presample source and recipient herds prior to translocations;
- Conduct low risk translocations but commit to intensive monitoring as if they were experiments;
- Collaborate to stratify and replicate the varying conditions that bighorns are exposed to in understanding the variable population responses to pathogens;
- Educate NGO's, sportsmen, wildlife commissions, policy makers, and general public.

A DESERT BIGHORN POPULATION'S STRUGGLE AND RECOVERY AT AN URBAN INTERFACE

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Peninsular bighorn sheep (*Ovis canadensis nelsoni*) in the northern Santa Rosa Mountains (NSRM) of southern California regularly utilized residential and urban areas that were constructed within their habitat beginning in the early 1950s. In 1998, bighorn sheep in the Peninsular Ranges were federally listed as endangered. From 1985-2002, the NSRM population averaged 34 adult bighorn with 19 adult ewes and the herd experienced chronic low lamb recruitment averaging 14 lambs/100 ewes. We conducted cause-specific mortality studies of adult radio-collared bighorn from 1991-1996 and of radio-collared lambs from 1998-2001. We found that urbanization accounted for 34% of the adult bighorn deaths and 43% of the lamb deaths during these studies with 56% of the adult and 93% of the lamb mortalities within 300 meters of the urban interface. Urban deaths included auto collisions, ingestion of toxic, non-native plants and drowning in swimming pools. As a result of these findings, a 4 mile, 8 feet high exclusionary fence was constructed around the NSRM urban interface in Rancho Mirage, California and was completed in 2002. The bighorn exclusion fence has completely eliminated urban-related bighorn deaths in the NSRM. Post-fence (2003-2014) the NSRM population has averaged 58 adult bighorn and 31 adult ewes and lamb recruitment has averaged 26 lambs/100 ewes. Within 2 years of the completion of the bighorn exclusion fence, the NSRM ewe group reached its recovery goal of 25 adult ewes.

DESERT BIGHORN SHEEP IMMUNITY DURING A MYCOPLASMA OVIPNEUMONIAE OUTBREAK

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Infectious diseases have been suggested to be key drivers in the extinction vortex of small, isolated wildlife populations due to the loss of immunogenetic variability. In 2013 an epizootic of *Mycoplasma ovipneumoniae* caused high mortality in desert bighorn sheep (DBH) at Old Dad Peak in the Mojave National Preserve and spread to neighboring populations. Genetic diversity is known to vary widely among populations in this system, including genetic diversity of microsatellite loci linked to immune-system genes, but the consequences of that variation in diversity during an epizootic are unclear. We used blood samples (n=72) from DBH subsequently captured in 9 populations in this region to measure individual DBH immunity using a variety of immunoassays (hematology, bacterial killing, lymphocyte proliferation, and mRNA isolation). We evaluated whether those measures of individual immune function were correlated with individual characteristics (e.g. disease status) or population-level characteristics such as population connectivity and genetic diversity at neutral or adaptive-linked markers. At the population level, decreased genetic diversity of microsatellites linked to immune genes was correlated with increased disease prevalence, although interpretation is complicated by the spatial progression of the disease. Also, individual immune measures appeared to vary geographically. Finally, using next generation sequencing technologies, we have identified a subset of DQB MHC class II genes expressed in DBH.

PRELIMINARY ESTIMATION OF CHANGES IN GENETIC STRUCTURE OF A DESERT BIGHORN SHEEP METAPOPULATION OVER TWO GENERATIONS

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Investigations of genetic structure within a metapopulation of desert bighorn sheep in the central Mojave Desert of California conducted from 2000-2004 revealed a highly fragmented system where genetic structure was strongly influenced by connectivity and isolation, barriers such as interstate highways, and habitat. Genetic structure also appeared to be influenced by extinction-colonization dynamics, which are often obscure. Since that time, several apparent recolonizations of little-used habitat patches have been observed. Moreover, a recent outbreak of respiratory disease within the system apparently spread rapidly among populations, even across barriers such as Interstate 40, suggesting that gene flow and genetic structure may have changed significantly. We present a preliminary recharacterization of genetic structure within this system using samples collected approximately two generations (12 years) after the first systematic genetic sampling, using 14-16 putatively neutral microsatellite loci. We observed dramatic changes in genetic structure, including shifts in genetic diversity and genetic distance across barriers. The most significant changes appear to have resulted from establishment of inter-population connectivity following natural recolonization or population expansion in previously underutilized habitat patches. Overall levels of connectivity and gene flow in the system appear higher than observed previously, likely due to increases in population size and occupied areas. Thus, potential for disease spread among populations may have increased as well. Overall, genetic structure within this metapopulation of desert bighorn sheep appears to be more dynamic than previously assumed.

RESOURCE SELECTION FUNCTIONS IN CONSERVATION PLANNING FOR ENDANGERED SIERRA NEVADA BIGHORN SHEEP

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Species distribution models (SDMs) provide a measure of the importance of ecological variables that correlate with species occurrence. These models can provide a framework in which to implement adaptive management in the recovery of federally endangered Sierra Nevada bighorn sheep (*Ovis canadensis sierra; SNBS)* and reoccupy historic habitat. Model results can be applied to spatial data to produce maps representing the likelihood of species occurrence. We use one type of SDM, a resource selection function (RSF), generated by logistic regression to examine how species rarity affects model predictions of the likelihood of occurrence. We present RSFs constructed with a use-availability design based on summer ewe occurrences or ram locations between May and December. Using k-fold cross validation and leave-one-out validation which includes locations from newly reintroduced bighorn, we show that a ewe summer RSF has higher predictive power interpolating between than extrapolating outside of patches of occupied habitat. This model and a winter RSF that accounts for altitudinal migration identified two large patches of bighorn habitat unrecognized by the Recovery Plan in remote geographic areas where there is a paucity of historic occurrence data. We combined an RSF based on ram occurrences with a cost distance analysis to quantify the proximity of domestic sheep grazing relative to bighorn sheep core home range. We ask how robust this model is to the expanding distribution of SNBS. By quantifying habitat quality and disease risk, these models will directly inform translocation efforts, allowing managers to identify suitable areas for future Sierra sheep reintroductions.

GPS COLLARS – HOW MUCH DATA IS ENOUGH?

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With the use of modern high fix-rate GPS collars, it is now possible to perform a wide variety of analyses that were formerly difficult. In deploying GPS collars, a critical question is: "What fix-rate is suitable to investigate our particular question?" Since battery life is a trade-off with study duration and sampling rate, ideally researchers would collect the minimum amount of data needed per unit time in order to maximize the study duration while minimizing the use of scarce resources. We analyze GPS data collected from Sierra Nevada bighorn sheep to explore how much information is contained in various fix rates and times with respect to a number of different analytic parameters: home-range size, slope, elevation, aspect, forage and cover type. We use high fix-rate data collected at 1 point per hour as the standard for comparison. We compare the high fix-rate data to the permutations of data collected at lower rates using subsampling, looking at all of the time and fix-rate permutations. We compare the values of each subsample to the true values to determine what minimum fix-rate substantially describes the target parameter. The results suggest that researchers can employ relatively low fix-rates (<<24/day) and still adequately assess many spatial variables. Our analysis may help reduce oversampling of spatial data. However, since the list of variables we analyzed is not exhaustive, it is possible that other variables may be more nuanced and require higher fix-rates so some caution in implementation is advised.

RESPIRATORY DISEASE AND *MYCOPLASMA OVIPNEUMONIAE* IN DESERT BIGHORN SHEEP OF CALIFORNIA, NEVADA, AND UTAH

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Respiratory disease is one of the most important factors limiting the recovery of bighorn sheep (*Ovis canadensis*). In 2013, a pneumonia outbreak with high mortality occurred in desert bighorn sheep (*Ovis canadensis nelsoni*) populations in the Mojave Desert of California. *Mycoplasma ovipneumoniae*, which is considered a primary pathogen in the bighorn sheep respiratory disease complex, was detected with ELISA and PCR from the Mojave bighorn sheep populations. Concurrent disease surveys in neighboring Nevada identified one identical and one distinct strain of *Mycoplasma ovipneumoniae*. In 2014, additional disease surveys were conducted across a wider area, and populations as far as the Orocopia Mountains were found seropositive and PCR positive. We report findings from the 2013 disease outbreak and 2014 disease surveys and provide an overview of historical and current data on the distribution of *Mycoplasma ovipneumoniae* in desert bighorn sheep populations in California, Nevada and Utah.

SURVIVAL ASSESSMENT OF DESERT BIGHORN TRANSLOCATIONS IN TEXAS.

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Beginning in 1959, translocation efforts initiated in Texas to restore desert bighorn (*Ovis canadensis mexicana*) to their historic habitats. Partnering with the Texas Parks and Wildlife Department, the Borderlands Research Institute has been at the forefront of desert bighorn sheep research in Texas. Since 2010, 172 bighorn (63 rams and 109 ewes), of 246 captured and released, have been fitted with GPS radio collars for research purposes. So far, we have recovered more than 100 collars from our study, producing nearly 200,000 GPS points for our analyses. Over the last 4 years, we have investigated 53 bighorn mortalities in the Big Bend area and Mexico. Of those mortalities, 19 were killed by mountain lions, 1 fell from a cliff, 1 was poached in Mexico, 2 died in a pila, 1 ewe died from birth complications, 1 ram died from eating toxic vegetation, 1 ram died from a fight injury, and 21 deaths were from unknown causes. There were also 6 documented mortalities of bighorn rams with skin conditions that we believe to be associated with the parapox virus. Five of the 6 cases consisted of mature rams and we are in the process of trying to determine why this virus is primarily being found on mature rams. The knowledge gained will continue bettering our understanding of bighorn restoration and conservation efforts in Texas, and in the Chihuahuan Desert. Without collaborative conservation, the desert bighorn sheep restoration program would not be where it is today.

CHANGES IN GENETIC VARIATION OVER TIME AND MERGING DESERT BIGHORN POPULATIONS

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Measuring the amount of genetic change over generations provides a way to evaluate past management and the theoretical effect of management provides an approach to predict future genetic variation. Founder effects and genetic bottlenecks in general can lead to low levels of genetic diversity, which can influence the persistence of populations. We examined genetic variation in two captive populations of desert bighorn sheep (*Ovis canadensis*) to measure change over time and evaluate the impact of introducing individuals from one into the other. Over about three generations, the amount of genetic variation in the Red Rock, New Mexico population increased. In contrast, over about two generations the amount of genetic variation in the Pilares, Coahuila population decreased significantly compared to its ancestral Tiburon Island, Sonora population. In addition, although both populations have low genetic variation, it is predicted that the introduction of Pilares rams into the Red Rock population in 2011 might increase the amount of genetic variation in the Red Rock population.

INTERNATIONAL COOPERATION VITAL TO BIGHORN RESTORATION

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In the late 1800s, there were believed to be 1,500 desert bighorn roaming throughout 16 mountain ranges in the Trans-Pecos region of Texas. By the early 1960s, the last of the native bighorn were believed to be extirpated from the state. Just across the border, Chihuahua, Mexico, also lost the last of their native bighorn around the same time. Starting in 1957, restoration efforts began in Texas with the capture and transport of desert bighorn from Arizona back into Texas. Since that time, more than 700 bighorn have been captured and transplanted to historic mountain ranges in Texas from in-state and out-of-state translocation efforts. In Decembers of 2010 and 2011, 141 desert bighorn were transplanted to Big Bend Ranch State Park (BBRSP). Data from 54 collared bighorn have produced >100,000 GPS points for analysis. Movements have been documented in all directions of the release site at BBRSP. More than 1.25 million acres of habitat were explored and used by the translocated bighorn. Forty percent of the collared bighorn were documented crossing into Chihuahua, Mexico. The natural movements of the bighorn from BBRSP/Texas into Mexico are the first instance of bighorn ranging freely in the mountains of Chihuahua. The recorded movements and range sizes ultimately show that our restoration undertakings are on a scale more grand than previously imagined. When dealing with a species that requires vast, continuous landscapes, the necessity and benefits of cooperation on all levels: public, private, state, federal, and international, is exemplified.

DESERT BIGHORN LAMBING HABITAT REVISITED: ENVIRONMENTAL CHARACTERISTICS AT FEMALE PARTURITION SITES, AND LAMB NURSERY AND PREDATION SITES

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Habitat characteristics at parturition sites may play an influential role in desert bighorn lamb survival, yet little is known about bighorn parturition sites because pregnant females isolate themselves prior to parturition and give birth in seclusion, making them difficult to find. Our goal was to examine habitat characteristics at parturition sites, and lamb nursery group and predation sites. We evaluated elevation, slope, terrain ruggedness and adult female visibility at parturition, nursery, and lamb predation sites by comparing them to paired random sites using conditional logistic regression, and used binary logistic regression to compare parturition sites to nursery sites, and predation sites to nursery sites. When compared to randomly available sites, odds of sites being parturition or nursery sites increased with increasing elevation, slope and ruggedness, but decreased with increasing visibility. Odds of a site being a predation site did not change with elevation, but increased with increasing slope and ruggedness, and decreased with increasing visibility. When compared to nursery sites, odds of a site being a parturition site decreased with increasing elevation, slope and ruggedness, but visibility was similar between the two. Odds of a site being a predation site increased with increasing elevation, slope and ruggedness, but decreased with increasing visibility when compared to nursery sites. Understanding factors that affect female parturition site selection, and how habitat characteristics at

these sites differ from those at predation and nursery sites, can provide insight into strategies female bighorn employ both during and after parturition to promote lamb survival.

DISENTANGLING POPULATION DRIVERS TO UNDERSTAND CAUSES OF THE BIGHORN SHEEP DECLINE IN THE DESERT NATIONAL WILDLIFE REFUGE

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In the late 1980s, bighorn sheep on the Desert National Wildlife Range experienced a severe population decline. Actual causes of the decline were unknown, but it was hypothesized that drought conditions triggered the initial decline in 1987. Additionally, ensuing low recruitment rates in 1988 and 1989 (fall lamb to ewe ratio 12/100) were believed to have been precipitating factors at the onset of the decline. Telemetry data and other observations strongly indicated that mountain lion (*Puma concolor*) predation may have been a significant cause of adult mortality. Other potential causes for the decline e.g. disease and poor habitat conditions, were less well understood. Our goal was to assess factors currently affecting sheep demography in order to elucidate those that may have caused the original decline. Specifically, we evaluated population parameters including survivorship, levels of mountain lion predation, and measures of disease. We deployed 5 collars on cougars (4F, 1M), 30 GPS collars on bighorn sheep (15 M, 15 F), and obtained blood and tissue samples for disease testing. Survivorship of radio-collared adult sheep was high (92.9 ± 4.9%, Kaplan-Meier estimate). Mountain lions primarily killed mule deer *(Odocoileus hemionus,* 65.5%), and less often bighorn sheep (29.3%) and small mammals (4.3%). Based on Elisa testing >90% of bighorn tested had been exposed to *Mycoplasma ovipneumoniae*. It appears that the initial population decline in the 1980's was likely due to disease but drought and predation may have had a synergistic effect.

DESERT BIGHORN ESCAPE TERRAIN: NOVEL APPROACH TO DETERMINING THE IMPORTANCE OF SLOPE AND RUGGEDNESS WITHIN AND ACROSS MOUNTAIN RANGES

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For desert bighorn sheep, occurrence of escape terrain, usually defined as steepness of slope and ruggedness of terrain, has been demonstrated to be the most important predictor of probability of occurrence. The degree that slope and ruggedness are correlated within a mountain range can vary among ranges due to differences in their physiography. Correlation between slope and ruggedness make it difficult to determine how each variable contributes to animal presence. Many studies use slope and ruggedness as independent variables, which may or may not be a valid approach. This fact may impede managers and scientist alike in their quest to predict the likelihood of animals to occur, cross over into adjoining ranges, or predict areas of critical habitat. In a novel approach, we use principle components analysis, regression residuals, and logistic regression to separate the contributions of slope and ruggedness within bighorn sheep escape terrain. We use female locations during the lambing season in three different mountain ranges as an example to determine how different physiographic regions can alter interpretations of escape terrain for bighorn sheep.

SPATIALLY EXPLICIT POPULATION STRUCTURE ANALYSES REVEAL BARRIERS TO GENE FLOW AMONG MOUNTAIN LIONS IN SOUTHWESTERN UNITED STATES

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Natural and anthropogenic landscape features that restrict movement of wide-ranging terrestrial species can potentially restrict gene flow among their populations, which may ultimately be detrimental to the persistence of the species and its habitat. We used spatially explicit Bayesian clustering models to investigate contemporary population genetic structure of mountain lions (*Puma concolor*) in southwestern U.S., and to explore the potential impact of landscape features such as rivers and interstate highways. We performed spatial genetic analyses on 401 DNA samples genotyped at 11 well-utilized *Felis catus* (FCA) microsatellite loci. Our analyses revealed a substantial level of genetic structuring among mountain lions with maximum statistical support for the occurrence of four subpopulations. Geographic visualization of the four subpopulations identified based on these data suggested that major highways, specifically Interstate-10 west of the metropolitan area of Phoenix, Interstate-40, and Interstate-17, may be barriers restricting gene flow among mountain lions. We comment on the possibility of combined effects of natural and anthropogenic barriers, and isolation-by-distance, being the underlying cause of observed population genetic structure. These data reveal potential consequences of anthropogenic impacts on mountain lions and their habitat. Wildlife managers, stakeholders, and conservation planners can use this information in guiding management decisions for mountain lion populations, and in prioritizing corridors that may restore habitat connectivity and gene flow for wildlife.

THE PARADOX OF NORTH AMERICAN UNGULATE DENSITY IN PREDATOR-FREE ENCLOSURES AND ON PREDATOR-FREE ISLANDS

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Abstract: Many species of North American ungulates have been introduced into predator-free enclosures or onto predator-free islands and allowed to increase in the absence of predation. I have looked at maximum ungulate density in these environs ranging in size from 2.6 km^2 to ~8,000 km^2. Paradoxically, in all systems, maximum densities stabilize between ~20 and 40 deer-size ungulates/km^2 regardless of the ecosystem or size of the predator-free habitat. Excluding the most severe North American ecosystems, e.g., Mojave Desert or sub-arctic islands, maximum ungulate density varies less than 2-fold in ecosystems as diverse as the Chihuahuan Desert in New Mexico and mixed-hardwood forests in Michigan. This includes desert bighorn densities of 24/km^2 in Red Rock, NM and desert mule deer densities of 34/km^2 in Three-bar, AZ. However, more interesting is the fact that these densities are generally 20-100 times higher than those documented in adjacent habitats with top carnivores. Density-dependent induced decline in fecundity and density-dependent associated 'drag' on other physiological variables are reported as these predator-free populations increase; however, the asymptote of population growth curves invariably occur at densities almost never observed in populations subjected to predation. Densities of 68 and 105 deer-size ungulates/km^2 have been used in experimental research to assess density-dependence. These densities are substantially higher than maximum densities from predator-free populations. I therefore hypothesize, that western North American ungulates rarely, if ever, approach true resource limited carrying capacity while under predation pressure by sympatric carnivores. Recognition of this paradox is fundamental to the understanding of the relationship between ungulate population density and carrying capacity.

PNEUMONIA IN BIGHORN SHEEP

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Pneumonia is the primary disease that has been responsible for the drastic decline of bighorn sheep (BHS) populations in North America. Several die-offs of BHS have been attributed to pneumonia following contact with domestic sheep (DS). Experimental commingling of BHS and DS also results in death of BHS. *Mannheimia haemolytica* and *Mycoplasma ovipneumoniae* are important pathogens of BHS pneumonia. Studies in our laboratory with green fluorescent protein-tagged *M. haemolytica* irrefutably proved transmission of this bacterium from DS to BHS. DS can also transmit *M. ovipneumoniae* which predisposes BHS to infection by *M. haemolytica* and other pathogens. *M. haemolytica* produces a toxin known as leukotoxin that kills the white blood cells, causes lung damage, and death of BHS. Our earlier studies in BHS with *M. haemolytica* wild-type and leukotoxin-deletion mutant have revealed that leukotoxin-deletion mutant causes only mild lesions, but does not cause death of BHS. Studies conducted by our laboratory involving transmission of passive immunity from ewes to lambs, bacterial clearance from the lungs, and experimental immunization, have clearly indicated that if BHS develop antibodies against leukotoxin and surface antigens of *M. haemolyica*, they will be protected against pneumonia caused by this organism. Needle immunization of wildlife is not easy. Administering booster doses is even more difficult. Therefore, it is logical to develop a vaccine that does not require needle-inoculation and booster doses. This vaccine can be easily administered to BHS prior to transplanting them to a new habitat. Progress with the development of such a vaccine will be discussed.

LINKING NUTRITIONAL CONDITION TO POPULATION PERFORMANCE IN BIGHORN SHEEP: APPROACHING THE HOLY GRAIL

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We developed a unique approach to quantify nutritional status in free-ranging ungulates that establishes a direct link between populations and their habitats. Body fat integrates caloric gain and loss as determined by factors such as forage supply, competition for food among conspecifics, winter severity, and reproductive costs. Consequently, body fat in free-ranging animals is an integrated measure of nutritional status and represents how animals balance the energetics of their environment. Energy from forage and fat, in conjunction with protein, is the currency that ultimately underpins growth and reproduction in animals. We present data from bighorn sheep that couples life-history traits with nutrition. We used ultrasonography and a palpation score to estimate body fat. We then analyzed relationships between body condition and vital rates estimated from radio-collared individuals. We also estimated population size and the finite rate of population growth (λ). The physiological limits of total body fat varied between 0.5 and 26%. Mean pre-winter body fat among 8 herds was 8.2 – 15.1% and 14.8 – 23.7% for lactating and non-lactating females, respectively. Mean body fat of females in late winter ranged from 10.1 – 13.6%. Nutritional condition of adult females was positively related to survival and pregnancy. Population growth rate varied between 0.6 and 1.3 and was positive for populations that exhibited mean body fat for lactating females >10.4% in October. The relationship between body fat and population growth rate supports the notion that nutritional status can represent the proximity of a population to animal-indicated nutritional carrying capacity.

RESPONSES BY BIGHORN SHEEP TO RISK OF PREDATION: ARE MOVEMENTS PROPORTIONAL TO RISK AND REWARD?

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We are investigating how Sierra Nevada bighorn sheep (*Ovis canadensis sierrae*) responded to risk of predation by mountain lions (*Puma concolor*), by evaluating data collected during winters 2002–2007, in the Sierra Nevada, California, USA. We hypothesized that those endangered ungulates would respond to risk of predation by exhibiting fine-scale movements to areas that mitigated risk. Comparisons of movements by bighorn sheep on days when a mountain lion was active within winter range of bighorn sheep, with movements on days when no mountain lion was known to be present, demonstrated responses by female, but not male bighorn sheep. Female bighorn sheep moved to higher elevations ($\bar{x}$ = 123 m), and to areas where an index to mountain lion activity was significantly less than the average for areas used by bighorn sheep on that date, whereas males demonstrated no significant movements in response to proximity of a mountain lion. During above-average precipitation years, both sexes demonstrated use of significantly lower elevations, characterized by a higher index of risk compared with those areas used by bighorn sheep in dry years, with males using areas of greater risk than females during wet years. Bighorn sheep used those areas where mountain lions were most active during wet years, likely because mountain lions were most active in those areas of bighorn winter ranges overlapping ranges of mule deer (*Odocoileus hemionus*), where both ungulates accrued forage benefits. We present additional results from an ongoing investigation of temporal and spatial scales of risk avoidance by Sierra Nevada bighorn sheep.

GENETICS AND THE MANAGEMENT OF SIERRA NEVADA BIGHORN SHEEP

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About thirty years ago it became evident that bighorn sheep exist as metapopulations where migration between subpopulations is critical for genetic and demographic integrity. Since then, metapopulation considerations have been incorporated into conservation planning for this species in hopes that resulting gene flow will be sufficient to maintain genetic diversity. Where might it be important to give genetics additional consideration in conservation planning? Bighorn sheep in the southern and central Sierra Nevada appear to be one such situation for multiple reasons. They occur in a separate and largely linear metapopulation in a single mountain range at the western edge of bighorn sheep distribution in the region. Most native subpopulations were extirpated, and the few that survived exhibit a genetic signature of severe past bottlenecks. Consistent with that history, Sierra bighorn have the lowest genetic diversity measured for non-captive bighorn sheep in the desert region. These findings suggest that these sheep could be vulnerable to inbreeding problems and potentially near a genetic tipping point. This talk will present results of some genetic analyses within the Sierra Nevada at metapopulation, subpopulation, and individual sheep levels. There is evidence that gene flow is occurring among many subpopulations in the Sierra, but not all. Subpopulations at the northern end of the current distribution are small with mostly inadequate gene flow. One of those has notably lower genetic diversity and a long history of inconsistent lamb production, which is consistent with the finding of a heterozygosity-fitness correlation throughout the Sierra involving lamb production. That subpopulation recently became the focus of a genetic rescue experiment, but simultaneously experienced an apparent natural genetic rescue. A strategy has been developed for the restoration of subpopulations to vacant habitat that attempts to produce founding gene pools that will produce offspring with higher heterozygosity levels.

DEFINING HERD HEALTH: A KEY FACTOR OF BIGHORN SHEEP MANAGEMENT

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Bacterial pneumonia is recognized as one of the primary challenges facing conservation of bighorn sheep in many areas of the western United States, thus a comprehensive wildlife health plan should be a core component of bighorn sheep management programs. The plan should be based on the management goals identified for each herd or metapopulation and should include establishing baseline herd health status and specific protocols for disease surveillance and investigation. In 2013, a bighorn sheep disease sampling workshop comprised of wildlife health professionals from nine western states and two Canadian provinces was conducted to review and update the testing protocols established in the 2009 WAFWA WHC Sheep Sampling Guidelines for respiratory pathogens of bighorn sheep as well as to standardize sample collection and testing protocols. Products from the workshop include:

- Testing recommendations based on the herd management plan: baseline herd health, source stock or recipient herd, and disease investigation and follow up surveillance and the laboratories that conduct each test.
- Standardized definitions for key terms involving herd health status
- Standardized protocols for sampling for: *Pastuerellaceae spp. and Mycoplasma ovipneumoniae*
- Standardized necropsy protocol

The standardization of testing protocols across agencies allows for consistent data collection and interpretation of results and will support recommendations across agencies for different management practices providing a valuable resource and reference for all wildlife health and management professionals.

Abstracts of Presented Papers and Posters

Abstracts of Presented Posters

WILDERNESS AND WILDLIFE CONSERVATION: WISHFUL THINKING?

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Wilderness management objectives and wildlife conservation objectives often conflict with each other, despite conservation being one of six basic reasons for which wilderness is established. Most wilderness areas appear to have been established as the result of political or societal desires, but in the absence of critical ecological thought. In an era of increasing anthropogenic impacts to wildlife populations and to wildlife habitat outside of wilderness, those ostensibly "pristine" areas in and of themselves will become less and less effective as conservation tools, particularly for large, vagile mammals. Impacts occurring outside of wilderness areas have ramifications for wide-ranging animals that use those areas during one or more portions of their annual cycles, thereby affecting wilderness character. Similarly, impacts occurring inside of designated wilderness also have ramifications for large, vagile mammals that also utilize proximate lands. There is a need to re-ignite the debate over the value of wilderness, both in the context of its societal role, as well as that of a conservation strategy. It is essential that wildlife conservation be elevated to the same level of importance that is accorded solitude and other subjective attributes of wilderness.

MOVEMENTS OF DESERT BIGHORN TRANSLOCATED TO NINE POINT MESA

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Desert bighorn sheep (*Ovis canadensis mexicana*) restoration efforts began in Texas in 1957. A primary tool in these efforts has been translocations of bighorn into viable historic habitat. One of the recent translocations occurred in December 2012 when 44 (22 M, 22 F) bighorn were captured off of the Elephant Mountain Wildlife Management Area and transported to Nine Point Mesa. Forty (18 M, 22 F) bighorn were equipped with Satellite and GPS radio collars to aid in our monitoring and research efforts. After 2 years, data from 36 (90%) of the collars were recovered. Post-release movements and range sizes (core and general use) were analyzed and compared between sexes. The influence of slope on movements and habitat selection was also reviewed. The information gained will aid Texas Parks and Wildlife Department and others in habitat evaluation and restoration efforts.

WATER DRAWDOWN FROM TWO BIGHORN SHEEP WATER DEVELOPMENTS

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Water developments in desert areas are an important wildlife management tool. However, their construction and maintenance on federal lands can lead to controversy due to agency policies concerning natural resource management or legislative laws such as the Wilderness Act. The key to minimizing this controversy rests in identifying the appropriate number and distribution of such developments so as to best benefit wildlife populations and distribution while adhering to the law. In an attempt to resolve this controversy, we monitored two water developments constructed specifically for Desert bighorn sheep (*Ovis canadensis nelsoni*) in the Old Dad/Kelso Mountains in Mojave National Preserve. We tracked water drawdown from storage tanks via remote pressure transducer dataloggers maintained by the Society for the Conservation of Bighorn Sheep and used remote cameras to record bighorn use of the drinker box from 2012 through 2014. Overall, water consumption varied temporally and spatially. Maximum water drawdown and wildlife use occurred from June through September while very little use occurred during the winter months of December through February. Maximum water drawdown exceeded 70 gallons per day and certain periods averaged over 40 gallons per day during summer months. Is this a sufficient number of developments to support these bighorn?

INTEGRATING RADIO-COLLAR AND CAMERA DATA TO ASSESS IMPACTS OF PNEUMONIA IN THE MOJAVE DESERT: A STUDY DESIGN

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In 2013, a pneumonia outbreak in California led to adult-specific sheep die-offs in the Mojave Desert, where impacts are still being observed. The Mojave Desert system, which is a patchwork of mountain ranges varying in biotic and abiotic complexity, supports a network of bighorn sheep metapopulations that have become increasingly less connected as a result of anthropogenic development. Previously, bighorn sheep in the Mojave were believed to be insulated from the threat of pneumonia, due to reduced connectivity with neighboring systems as well. As of the summer of 2014, outbreak conditions have persisted; lamb recruitment appears extremely low in some ranges, while remaining steady in at least one, attesting to the variability or possible asynchrony in disease patterns between populations within the same system. We propose to analyze range-specific population trends in the Mojave Desert before (prior to 2013) and after (2014-2017) detection of disease to assess apparent differences in severity of impacts. Our objectives are to quantitatively isolate the apparent effects of disease given changes in vital rates and population structure. We will proceed by integrating data from radio-collared animals and camera trap surveys, using a spatially explicit capture-recapture framework for our analysis. We will present our methodology for obtaining and evaluating these data in 5 ecologically distinct mountain ranges to meet our study objectives. Through this investigation, we seek to better understand the dynamics of disease and ultimately extrapolate risk factors based on differences in local environmental factors, which may translate into better management for populations that appear more at risk.

EVALUATING THE FEASIBILITY OF REINTRODUCING DESERT BIGHORN SHEEP INTO THE TAHOE REGION OF THE NORTHERN SIERRA NEVADA MOUNTAIN RANGE, CALIFORNIA

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Habitat suitability and the risk of disease transmission are vital for evaluating a reintroduction site for desert bighorn sheep in California. Bighorn sheep were once part of the northern Sierra Nevada ecosystem in 1848, but were believed to be extirpated due to the gold rush settlers that brought the transmission of disease with domestic sheep and goats, habitat loss and unregulated hunting. In 2007 to 2008, 6 GPS collared California bighorn sheep ewes from the Virginia mountain range in Nevada were tracked crossing into the eastern Sierra Nevada Mmountains of California. Although reintroductions have expanded the historical distribution and population of bighorn sheep in California, a full feasibility is necessary to determine if a bighorn sheep reintroduction could be successful. This study used geographic information system (GIS) habitat suitability models to quantify seasonal home range habitat that could support a viable population of bighorn sheep. A risk analysis was also conducted to evaluate the proximity of active domestic sheep allotments to each potential study plot. Our results found that all six plots exceeded the amount of year round habitat needed to support a herd of 100-125 bighorn sheep. Five out of six plots surpassed 6.25km^2 of snow-free winter habitat in 2003 and 2011, which may indicate the majority of plots could support a bighorn sheep herd in the harshest of winters. The risk analysis was the limiting factor for this feasibility study as it indicated that only two study plots were greater than 23 km away from an active domestic sheep allotment. The results from this study have provided initial insight into monitoring the possible natural recolonization event of wandering ewes and rams occurring near the Nevada-California border. It also supports recommendations to form a California Bighorn Sheep Technical Working Group (CBST) to further reduce domestic sheep risk in order to reintroduce 10-15 collared bighorn sheep for phase II of the reintroduction plan.

RESOURCE SELECTION BY AN ENDANGERED UNGULATE: A TEST OF PREDATOR-INDUCED RANGE ABANDONMENT

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We investigated influences of risk of predation by mountain lions (*Puma concolor*), topographic metrics at multiple scales, and vegetation, land, and snow cover, on resource selection by Sierra Nevada bighorn sheep (*Ovis canadensis sierrae*), an endangered taxon, during winters 2002–2007, in the Sierra Nevada, California, USA. We hypothesized that those mountain ungulates would trade off rewards accrued from using critical low-elevation habitat in winter for the safety of areas with reduced risk of predation. We also tested the prediction that differences in quality of forage at low-elevations versus high-elevations were reduced in years of below-average precipitation than in wet years, yielding a reduced benefit of migration to low-elevations during drought, compared with years of above-average precipitation. Sierra Nevada bighorn sheep did not trade off benefits of forage for reduced risk of predation, but selected areas of high solar radiation, a correlate of vegetation productivity, where risk of predation by mountain lions was greatest, while mitigating indirect risk of predation by selecting for steep, rugged terrain. Bighorn sheep selected more strongly for areas where mountain lions were active, than for low elevation habitat in winter, likely because mountain lions were most active in those areas of bighorn winter ranges overlapping ranges of mule deer (*Odocoileus hemionus*), where both ungulates accrued forage benefits. We demonstrated reduced benefit of migration to low elevation during drought years, providing an alternative explanation to the predator-induced abandonment hypothesis for the disuse of low-elevation winter range observed during drought years.

ALUMINUM BIGHORN TRANSPORT CRATES

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Achievements in restoring desert bighorn sheep (*Ovis canadensis*) populations throughout the western United States and Mexico are associated with our ability to transplant animals to new or historical habitats. We designed an aluminum transport crate after years of capturing desert bighorn with safety, mobility, and expense in mind. Given the remote, rugged nature of desert bighorn habitat, the decision to release animals in roadless areas is often preferred. Thus, many areas with Wilderness designation are also habitat for wild sheep. Moreover, the remote release approach with transport crates is generally the best or only method under the current Minimum Requirements Decision Guide for areas with Wilderness designation. Specifications to the crates were designed so they may be loaded into the back of a pickup, on a trailer, or slung under a helicopter. Spinning issues related to helicopter transport and ventilation were addressed, as was the concern for ambient temperatures inside the crates. Dimensions for the crates can be modified for use with other species such as pronghorn (*Antilocapra americana*). These crates have been successfully used in New Mexico, Nevada, and Utah for transporting desert ungulates.

Abstracts of Presented Papers and Posters

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 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*.

SUBMISSION AND COPY: Electronic submissions as word processing (e.g., word) or PDF files are preferable. However, if for some reason authors are unable to submit electronically, please use good quality white paper 215 × 280 mm (8.5 × 11 inches), or size A4. 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 there are multiple addresses for authors and in tables.

ACKNOWLEDGEMENTS: Include acknowledgements at the end of the paper, before Literature Cited, 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 for unpublished reports are filed parenthetically in the text.

LITERATURE CITED: Use capital and lower case letters for authors' last names, initials for given names. Do not abbreviate titles of serial publications; follow **Guidelines for Authors and Reviewers of *Wildlife Society Bulletin* manuscripts**. Show issue number or month only if pagination is not consecutive throughout the volume.

TABLES: Prepare tables in keeping with the size of the pages. Tables should be self-explanatory and referenced in the text. Short tables with lists of pertinent comments are preferred to long tables. Start each table on a separate page and continue onto 1 or more pages as necessary. Double space throughout. Omit vertical lines. Identify footnotes by roman letters. Do not show percentages within small samples (N or $n < 26$).

ILLUSTRATIONS: Illustrations and drawings must be submitted as an electronic file suitable for no larger than 215 x 280 mm (8.5 x 11 inches) final layout. Make all letters and numbers large enough to be ≥1.5 mm tall when reduced. Lettering size and style when reduced should be the same in all figures. Submit prints of good contrast either as high resolution image files (e.g., jpeg, tif) or as a hard copy on glossy paper. Type captions on a separate page in paragraph form. On the back of each illustration, lightly write the senior author's name, figure number, and "Top."

SUBMISSION AND PROOF: All papers will be reviewed for acceptability by the Editorial Board and 2 outside reviewers. Submit papers to James W. Cain at jwcain@nmsu.edu. If hard copies must be submitted, they should be mailed to James W. Cain, New Mexico Cooperative Fish and Wildlife Research Unit, P.O. Box 30003, MSC 4901, Las Cruces, NM 88003, 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.

TRANSMITTAL LETTER: When the manuscript is submitted, send a letter to the Editor, stating the intent to submit the manuscript exclusively for publication in *The Transactions*. Explain any similarities between information in the manuscript and that in any other publications or concurrent manuscripts by the same author(s), and furnish a copy of such manuscripts or publications.

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DESERT BIGHORN COUNCIL MEETINGS 1957–2015

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 & L. Fountein	Charles Hansen	Charles Hansen
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 R. Pulliam, 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

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Year	Location	Chairperson	Secretary	Treasurer	Transactions Editor
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
2007	Las Vegas, NV	Ross Haley	Esther Rubin	Stacey Ostermann-Kelm	Brian Wakeling
2009	Grand Junction, CO	Scott Wait	Esther Rubin	Kathleen Longshore	Brian Wakeling
2011	Laughlin, NV	Brian Wakeling	Esther Rubin	Kathleen Longshore	Brian Wakeling
2013	Las Cruces, NM	Eric Rominger & Patrick Morrow	Esther Rubin	Kathleen Longshore	Brian Wakeling
2015	Borrego Springs, CA	Ben Gonzales & Regina Abella	Amber Munig	Kathleen Longshore	James W. Cain