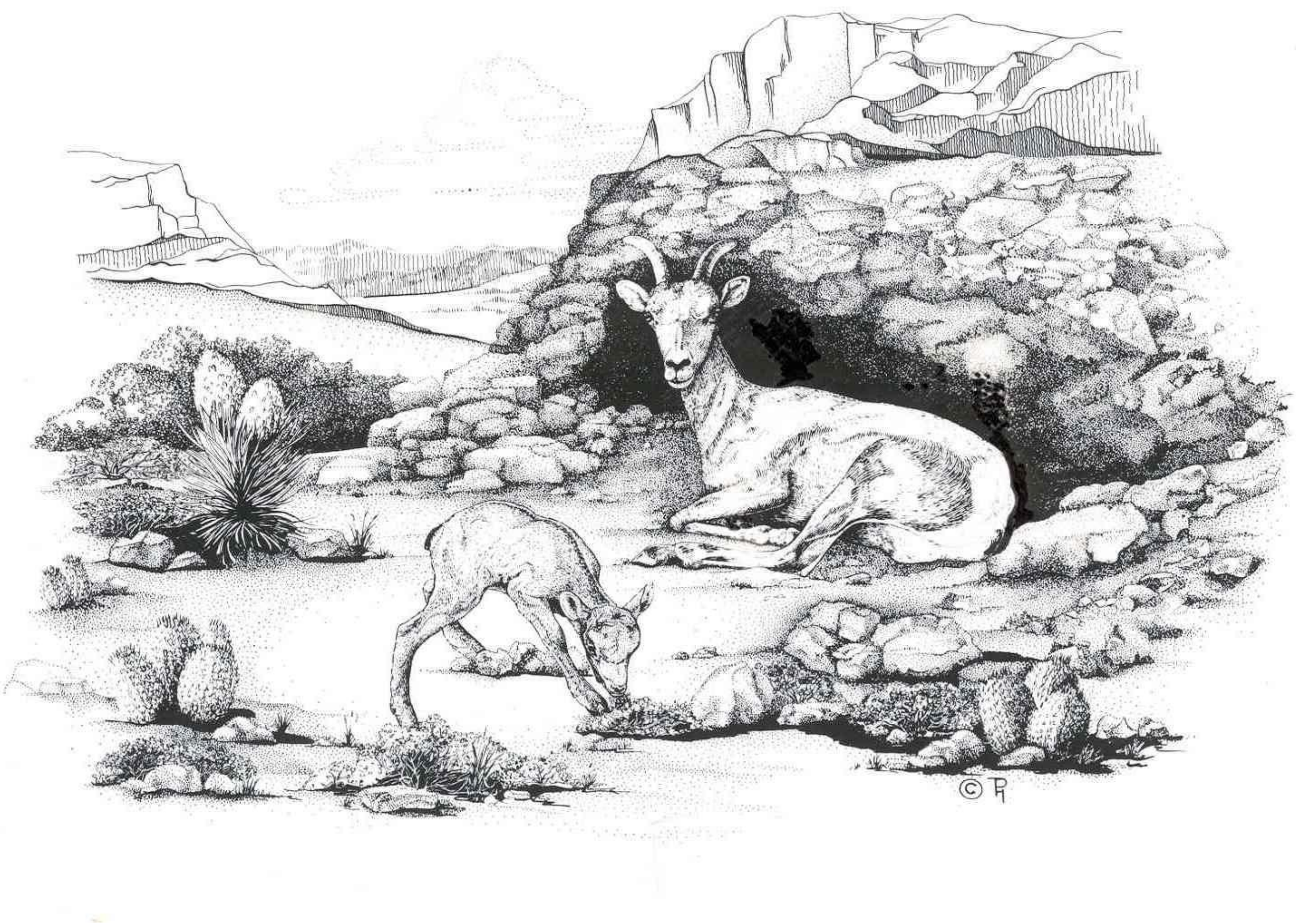
DESERT BIGHORN COUNCIL TRANSACTIONS



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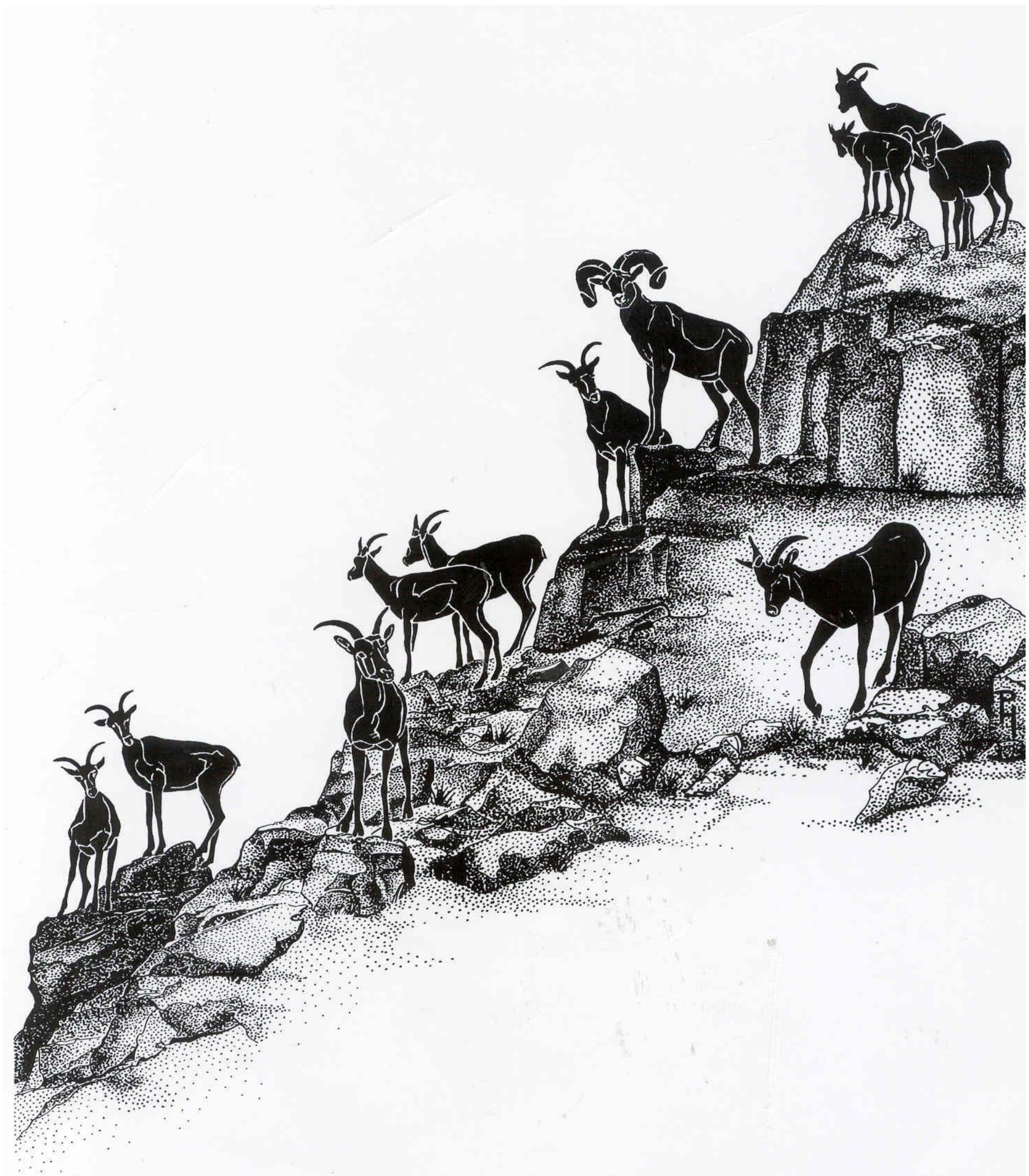

Bighorn sheep habitat and model extrapolation across remote landscapes

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Abstract Determining a species' habitat use is an essential first step in any wildlife conservation action. We described habitat use, animal movements and probable lambing areas in a remote, restricted-access region of the Mojave Desert. Differences in habitat use between sexes was apparent, supporting the often-reported concept of risk-aversion by females. Animals exhibited low variability in distances travelled, although males travelled further and with more variability than females. All females demonstrated what we interpret as lambing behavior during the same 2 ½ month periods over the two years, strongly supporting our inference of lambing sites. Water appeared critical to animal long-range movements, with no animal moving beyond 8.5 km from known sources. Modeling habitat use across the landscape of concern is another necessary step for conservation of species, allowing managers to plan for and predict the outcomes of management actions. In ecology, models are often created within relatively small areas, then extrapolated across larger regions of concern. The ability to extrapolate ecological models may be especially useful across remote areas, where consistent access by wildlife managers may be highly restricted. These restrictions on access require that most data be collected remotely, necessitating the need for extrapolating models developed in other areas. We used data from GPS-collared desert bighorn sheep to describe and model habitat use across the Pintwater Range, located on the Nevada Test and Training Range of southern Nevada, a highly restricted military training ground. We tested the efficacy of habitat model extrapolation by comparing the performance of two models derived from adjacent but independent desert bighorn sheep populations. The predictive power of seasonal habitat models derived from adjacent mountain ranges was lower than those derived from the local population. However, the performance of the extrapolated model suggests it could still be a feasible alternative for estimating general habitat use.

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Key words Desert bighorn sheep, habitat use, lambing, military lands, modeling, water

Before effective management actions can be taken towards ensuring the conservation of a species, fundamental ecological parameters of habitat use, movement, and parturition should be determined (Bleich et al. 1990, Hoglander et al. 2015, Cain et al. 2019). In the deserts of the southwestern U.S., habitat use by desert bighorn sheep (*Ovis canadensis nelsoni*) is affected by many factors such as terrain type (Sappington et al. 2007), vegetation quality and quantity (Creech et al. 2016), water availability (Longshore et al. 2017), and disturbance (Lowrey and Longshore 2017). Comprehensive models that incorporate these factors can be very useful in guiding the management of species (Johnson and Swift 2000) and are an integral part of any conservation plan. Modeling ecological factors and processes allows for spatial prediction and movement of animal distributions to be extrapolated beyond the boundaries of data collection (Austin 2002). Habitat model extrapolation is therefore a critical undertaking, providing the scientific basis for management actions designed to conserve species (Rubin et al. 1998, Hoglander et al. 2015). The ability to extrapolate models across the landscape is especially important in remote and restricted-access areas, where direct data collection is not feasible.

For managers to be confident in the effectiveness of extrapolated habitat models, model performance should be evaluated across independent data sets (Bahn and McGill 2013). Ideally, a desert bighorn sheep habitat model developed in one mountain range could be used in other, similar ranges, reducing the need for expensive and time-consuming animal capture, collaring, and analyses. As distances between mountain ranges increase, however, differences in vegetation, precipitation, elevation, and other factors also increase. Therefore, this type of model extrapolation should be applied conservatively to those areas outside the population in which the data underlying the model were collected.

Desert bighorn sheep habitat use and movement has been documented and modeled in many areas (Bangs et al. 2005, Hoglander et al. 2015). However, understanding habitat use in different mountain ranges may require specific analyses due to variation among ranges in vegetation, water availability, terrain, disturbance levels and other factors to which large mammals respond (Garshelis 2000). The ability to document habitat use in many individual ranges may be limited by access restrictions across the southwestern U.S.

Military training areas cover vast regions in the southwestern U.S. and given the potential for ecological impacts from military activities, research in these areas can be valuable to the conservation of wildlife (Quist et al. 2003). Due to the nature of military training, large areas may remain untouched, while other areas may be heavily disturbed, resulting in some species being heavily impacted and others less affected (Stephenson et al. 1996, Warren et al. 2007, Krausman et al. 2010). In southern Nevada, the Nevada Test and Training Range (NTTR) covers over 11,740 $km^2$and contains many mountain ranges that support bighorn sheep. Access to this area is necessarily restricted due to military security and public safety concerns; however, limited access was granted for this study to better understand the populations and inform management of desert bighorn sheep within the Pintwater Range.

Of the many important components of bighorn sheep habitat, water can be an especially critical resource in the arid desert regions of the southwest (Krausman et al. 2006, Bleich et al. 2010). Although water availability can be most critical during summer, bighorn sheep are known to use water sources year-round (Longshore et al. 2009). Availability of water for desert bighorn sheep has been substantially enhanced in some areas by man-made water catchments and guzzlers provided by wildlife managers (Bleich et al. 2006). These artificial water sources have been shown to increase habitat quality across ranges, creating potential advantages for population persistence (Epps et al. 2004, Bleich et al. 2010). Understanding how specific bighorn sheep populations respond to water sources is therefore a necessary component to any habitat modeling effort.

Understanding the reproductive needs of a population is also important for wildlife managers. Female desert bighorn sheep seek isolated, discreet areas for parturition, and these lambing areas may play an important role in lamb survival (Bangs et al 2005, Karsch et al. 2016). Female ungulates generally seek areas which allow avoidance of predators, even if this results in a trade-off in longer distances from quality forage (Berger 1991, Rachlow and Bower 1998). Females may choose steep, rugged terrain to give birth, decreasing the chance of lamb predation (Bangs et al. 2005). However, parturition areas cannot be identified only by a simple linear relationship of steep, rugged terrain , and many factors need to be considered before lambing habitat can be predicted (Smith et al. 2015, Karsch et al. 2016).

In this study, we use data from GPS-collared desert bighorn sheep to describe and model seasonal habitat use across the Pintwater Range. We also describe animal movements and probable lambing areas to allow evaluation of these parameters relative to non-restricted areas. Additionally, we use established techniques to derive seasonal habitat models for a population of bighorn sheep inhabiting two nearby mountain ranges, the Desert and East Desert ranges, treated as a single range, and extrapolate the spring and summer models across the adjacent Pintwater Range of southern Nevada. We then measure how these extrapolated models perform relative to locally derived models. Finally, we address how these results can be used by managers and researchers to further the conservation goals of desert bighorn sheep on military lands and other restricted-access areas.

STUDY AREA

The NTTR consists of over 2.9 million acres in rural portions of Nye, Lincoln, and Clark Counties, Nevada. The southern portion of the Nevada Test and Training Range (NTTR) is located within the Desert National Wildlife Refuge and covers over 11,740 km^2. The NTTR's mission is to provide aerial battle space to train pilots, and is the largest Air Force airspace in the U.S. Within the NTTR, the Pintwater Range is located 72 km north of Las Vegas in northern Clark and southern Lincoln counties. The Pintwater Range extends approximately 58 km north of Creech Air Force Base and is bounded on the west by Indian Springs Valley, and on the east by Three Lakes Valley. Elevations extend from 1,036 m to 2,145 m. Most of the northern part of the Pintwater Range consists of rolling terrain in excess of 1,676 m elevation with a single steep escarpment along the eastern side. The central and southern sections of the range are composed of rough and broken terrain with an abundance of steep, rocky canyons.

Three major plant communities were found in the mountain range; the creosote community was characterized by creosote (*Larrea tridentata*), burro bush (*Ambrosia dumosa*), and shadscale (*Atriplex confertifolia*). The mid-elevation association was dominated by blackbrush (*Coleogyne ramosissima*) intermixed with Joshua trees (*Yucca brevifolia*), cliffrose (*Cowania mexicana*), Apache plume (*Fallugia paradoxa*), and some sagebrush (*Artemesia* spp.). The cliff-sparse association included barren and sparsely-vegetated cliff faces and rocky outcrops of various types with generally < 10% plant cover.

METHODS

Desert Bighorn Data Collection

Bighorn sheep were captured using a net gun fired from a helicopter, blindfolded, and immobilized with leg hobbles. Physiological measurements (weight, length, eye response to light, etc.) and biological samples (blood, tissue) were obtained from each animal. Nine adult females and ten adult male bighorn sheep were fitted with GPS-satellite collars (Telonics, Mesa, AZ.) and ear tags. Extensive field testing of Telonics collars has shown < 5 m of location error (C. Lowrey, USGS Ecologist, unpublished data). We collected location data over a 20-month period from 11/2016 through 6/2018, and programed collars to collect locations at 4-hour intervals except during the first five days of each month, when they were collected every hour.

Predictor Variables, Seasons, and Correlation between Habitat Variables

We used three vegetation-type categories, ruggedness (index) (Sappington et al. 2007), slope (%), profile curvature (parallel to slope), planform curvature (perpendicular to slope), viewshed (area viewable within a 75 m radius), distance to water sources (m), Normal Differential Vegetation Index (NDVI), and difference in NDVI over a two-week period which measures green-up (positive) or desiccation (negative) as variables in our models. Except for NDVI, which was collected at the 250 m scale, all variables were measured at a 10 m grid-cell resolution. Lowrey et al. 2019 shows the detailed descriptions of habitat variables for this region. We analyzed slope, ruggedness, curvature profile, curvature planform, and viewshed for potential correlation. However, we found no correlations large enough (Pearson's correlation values >0.60 (Zolman 1993)) to justify either omitting the variable(s) or combining them into a latent variable such as a principle component. Season dates were chosen based on bighorn sheep biology and local seasonal conditions: Spring (February-May) was the period of lambing and the greatest vegetation growth; summer (June-September) included high temperatures, plant desiccation, and greatest reliance on water sources; winter (October – January) was the period of greatest precipitation and winter green-up. We split our data set into seasonal time periods before analyses. Although there are benefits to running all data as a single model, we believed the clarity of this approach reduced potential confusion in interpreting multiple three-way interactions necessary in a single-model approach.

Desert Bighorn Sheep Habitat Use within the Pintwater Range

Habitat analyses were split by sex and season. We used findings from previous research and expert opinion to derive candidate models designed to address whether desert bighorn sheep were affected by terrain factors, occurrence of water sources, vegetation types, NDVI, or change in NDVI (Wehausen 1996, Turner et al. 2004, Longshore et al. 2009, Smith et al. 2015, Creech et al. 2016). A binary logistic regression (Menard 2002) and an Akaike Information Criterion (AIC) model selection process was used to derive the highest-rated model (Burnham and Anderson 2002). Application of logistic regression to use-availability data, where availability is determined by random points, produces resource selection function (RSF) values that are proportional to the probability of occurrence and have been shown to yield robust and valid estimates of habitat selection (Johnson et al. 2006). Performance of the highest-rated models was measured with both the area under a Receiver Operating Characteristic curve (ROC), which represents the probability a randomly chosen location is correctly classified (Hanley and McNeil 1982), and Pearson chi-square goodness of fit measures. The contribution of each variable was determined by odds ratios and beta coefficients, which represent the relative contribution of that variable to the total explanatory strength (structural coefficient) of the model (Legendre 2008). This approach allows for a more detailed and specific measure of the relative strength of each variable than would be allowed by AIC methods alone (Cade 2015).

Movement Patterns

We used GIS-measured distances between successive bighorn sheep locations taken at one-hour and four-hour intervals to describe animal movements within the Pintwater Range. One-hour movements were collected only during the first five days of each month during the study period. Distances between time periods greater than four hours, which indicated a missing location, were omitted. We analyzed movement patterns and did not attempt to address specific movement hypotheses which are outside the scope of this paper. We used an ANOVA to address whether there were any differences in movement patterns between sexes and/or seasons.

Lambing Habitat

We identified January through March as the probable lambing period by aging lambs (Monson and Sumner 1981) photographed at two water sources occurring within the northern and southern regions of the Pintwater Range. We did not have access to document actual lambing sites, so we used location data to define these areas. Using GPS locations taken during daylight hours within the probable lambing period, we isolated individual female bighorn sheep occurring in 100 m radius clusters of six or more points during a 72-hour period (Bangs et al. 2005) using an R Animal Site Fidelity program (Mahoney and Young 2017). This algorithm was able to identify at least 8 of 9 lambing sites that were confirmed by vaginal implant for a study in Zion National Park, Utah (Kezia Manlove, pers. comm. Utah State University). We defined those individuals meeting these criteria as engaged in probable lambing behavior (Mahoney and Young 2017), and defined the areas used as probable lambing areas.

Comparison of Habitat Models between the Pintwater Range and the Desert/East Desert Ranges

We compared bighorn sheep habitat models derived from two separate areas to determine whether models developed in one area may be extrapolated to similar mountain ranges in the southwest. The bighorn sheep location data within the Desert and East Desert (D/ED) ranges (combined together), which are directly adjacent to and east of the Pintwater Range, were used for comparison to the Pintwater Range. Habitat-use models in D/ED were derived using the methods described subsequently. These ranges closely resemble the elevation (below 2200 m), terrain, and vegetation conditions found in the Pintwater Range. We believe these similarities in terrain and vegetation (Boyce and McDonald 1999, Miller et al. 2004) as well as the proximity to the Pintwater Range make this an appropriate data source for testing desert bighorn sheep model extrapolation across the region.

Based on elevation and season, we selected 2,050 locations from seven females within the D/ED ranges, which were then separated into the spring and summer seasons. We chose to use females during the spring and summer for this comparison because females tend to significantly alter their habitat use between these time periods due to parturition needs, forage resource changes, the need for water, and other potential factors (Bleich et al. 1997).

To test whether model extrapolation was efficacious, we compared RSF values derived from the highest-ranked models within each of the two ranges during the spring and summer seasons. The two RSF models developed using bighorn sheep locations from the Pintwater Range were:

Spring Pintwater RSF = (1.34) MidVeg + (1.98) CliffVeg + (-0.015) profile + (-0.015) planform + (0.118) ruggedness + (0.439) slope + (-0.93) viewshed + (-0.022) distance to water + (-0.001) NDVI + (0.0008) difference in NDVI + (-0.016) slope*ruggedness.

Summer Pintwater RSF = (1.179) MidVeg + (1.64) CliffVeg + (-0.027) profile + (0.183) ruggedness + (0.426) slope + (-0.947) viewshed + (-0.053) distance to water + (-0.002) NDVI + (0.0004) difference in NDVI + (-0.021) slope*ruggedness.

The two models developed using bighorn sheep locations from the Desert/East Deserts were:

Spring D/ED RSF = (0.118) ruggedness + (0.121) slope + (-0.005) distance to water + (-0.016) slope*ruggedness.

Summer D/ED RSF = (1.204) MidVeg + (1.224) CliffVeg + (2.236) ruggedness + (0.123) slope + (-0.059) distance to water + (-0.046) slope*ruggedness.

We first extrapolated the D/ED bighorn sheep habitat models (RSF values) across the Pintwater Range. We then extrapolated the Pintwater habitat models across the Pintwater Range. Finally, we compared RSF model performance between the D/ED and the Pintwater datasets using ROC and Goodness of Fit measures (Burnham and Anderson 2002).

RESULTS

Habitat Model Selection

Males.–Eight candidate models were evaluated for each sex and season. Using AIC model selection, the model containing all measured variables was the highest-ranked predictor of male occurrence during spring (ROC = 0.743, SE = 0.002, Pearson Chi-square = 0.976). During summer, all variables except difference in NDVI contributed to the highest-ranked model (ROC = 0.774, SE = 0.003, Pearson chi-square = 0.967). All variables except profile curvature contributed to the fall-winter model (ROC = 0.819, SE = 0.003, Pearson chi-square = 1.017; Table 1).

Females.–The candidate model containing all measured variables was the highest-ranked predictor of occurrence for female during the spring (ROC = 0.849, SE = 0.002. Pearson Chi-square = 1.019). During summer, all variables except planform curvature contributed to the highest-ranked model (ROC = 0.864, SE = 0.001, Pearson Chi-square = 0.935). During fall-winter, all variables except planform curvature contributed the highest-ranked model (ROC = 0.864, SE = 0.002, Pearson Chi-square = 1.019; Table 2).

Habitat Use

Over 39,600 female and 46,600 male locations were collected (see Tables 3 and 4 for descriptive statistics). Although models containing similar variables defined habitat use, bighorn sheep responded differently to these variables across sexes and seasons. Collared bighorn sheep exclusively occupied the Pintwater Range, and we found no evidence of travel beyond this region. Two collared sheep, one male and one female (5 months and 2 months after capture, respectively), independently traveled north of the study area to the gap between the Pintwater and Spotted ranges; however, both returned to their respective home ranges within one week (Fig. 1).

Males.–During spring, males were strongly associated with mid-elevation shrub vegetation followed by the cliff-sparse

Table 1. Candidate models and ΔAIC values used for evaluating male desert bighorn sheep habitat use within the Pintwater Range, Nevada. Highest ranking models are indicated by a ΔAIC of zero.

Male bighorn candidate models[1]	Spring[2] ΔAIC	Summer ΔAIC	Fall-winter ΔAIC
Veg + plan + rgd + slope + view + dwtr + ndvi + diffndvi + slope*rgd	10.5	7.7	0
Veg + prof + plan + rgd + slope + view + dwtr	102.4	10.2	48.6
Veg + prof + plan + rgd + slope + view + dwtr +diffndvi	102.1	12.8	31.3
Veg + prof + plan + rgd + slope + view + dwtr + ndvi + slope*rgd	3.1	0	39.7
Veg + prof + plan + rgd + slope + view + dwtr + ndvi + diffndvi + slope*rgd	0	8.2	112.1
Veg + prof + plan + rgd + slope + view + ndvi + diffndvi	150.6	293.8	5.6
Veg + prof + rgd + slope + view + dwtr + ndvi + diffndvi + slope*rgd	4.6	9.5	5.5
Veg + rgd + slope + view + dwtr + ndvi + diffndvi	1510.2	632.1	428.2

[1]Variable notation: Veg = A 3-class vegetation variable of mid-elevation, cliff-sparse vegetation, and lower-elevation. associations (reference category); plan = planform curvature; rgd = vector ruggedness measure; slope in percentage; view = amount of area visible to an animal to a distance of 75m ; dwtr = distance to the nearest water source; ndvi = normalized difference vegetation index; diffndvi = difference between ndvi and ndvi measured 2 weeks earlier at the same location; prof = profile curvature.
[2]Seasons: Spring = Feb. - May, Summer = June – Sept., Fall-winter = Oct. - Jan.

relative to lower-elevation shrub areas. Areas of decreasing viewshed, and increasing slope and ruggedness were used. Within male use of steep, rugged areas, there was significant interaction between slope and ruggedness: ruggedness decreased as use of slope increased. Males selected ridgeline formations over valley areas. The effect of NDVI and difference in NDVI were both marginal. Water sources also had marginal effects on habitat use (Table 5).

During summer, males continued to be

Table 2. Candidate models and ΔAIC values used for evaluating female desert bighorn sheep habitat use within the Pintwater Range, Nevada. Highest ranking models are indicated by a ΔAIC of zero.

Female bighorn candidate models	Spring ΔAIC	Summer ΔAIC	Fall-winter ΔAIC
Veg + plan + rgd + slope + view + dwtr + ndvi + diffndvi + slope*rgd	8.8	12.3	19.8
Veg + prof + plan + rgd + slope + view + dwtr	145	216.9	309.5
Veg + prof + plan + rgd + slope + view + dwtr + diffndvi	74.1	218.2	310.1
Veg + prof + plan + rgd + slope + view + dwtr + ndvi + slope*rgd	127.0	11.5	46.3
Veg + prof + plan + rgd + slope + view + dwtr + ndvi + diffndvi + slope*rgd	0	24.3	26.8
Veg + prof + plan + rgd + slope + view + ndvi + diffndvi	57.4	17.2	10.1
Veg + prof + rgd + slope + view + dwtr + ndvi + diffndvi + slope*rgd	5.7	0	0
Veg + rgd + slope + view + dwtr + ndvi + diffndvi	943.3	337.1	460.8

Variable notation as in Table 1.

most strongly associated with mid-elevation shrub and cliff-sparse vegetation. Areas of decreasing viewshed, increasing slope, and increasing ruggedness were used. Slope and ruggedness continued to negatively interact, and animals selected ridgeline formations over valley areas. The effect of NDVI was again marginal, however, difference in NDVI was not a contributing factor. Males were highly attracted to water especially compared to the other seasons (Table 5). During fall-winter, males were again found in mid-elevation and cliff-sparse vegetation types more often than lower-elevation associations. Areas of increasing slope and ruggedness, decreasing viewshed, and ridgeline formations were used, and slope and ruggedness continued to negatively interact. Although use of ridgelines which are parallel to the fall-line (positive planform) contributed to the overall model fit, the effect was marginal. The effect of NDVI and difference in NDVI was also marginal. Although males were closer to water than would be expected by chance, distance to water was not a strong predictor during fall-winter (Table 5).

Females.–During spring females responded strongly and positively to cliff-sparse and mid-elevation vegetation. Areas of decreasing viewshed were used, and increasing slope and ruggedness were strong predictors. There was a significant, negative interaction between slope and ruggedness.

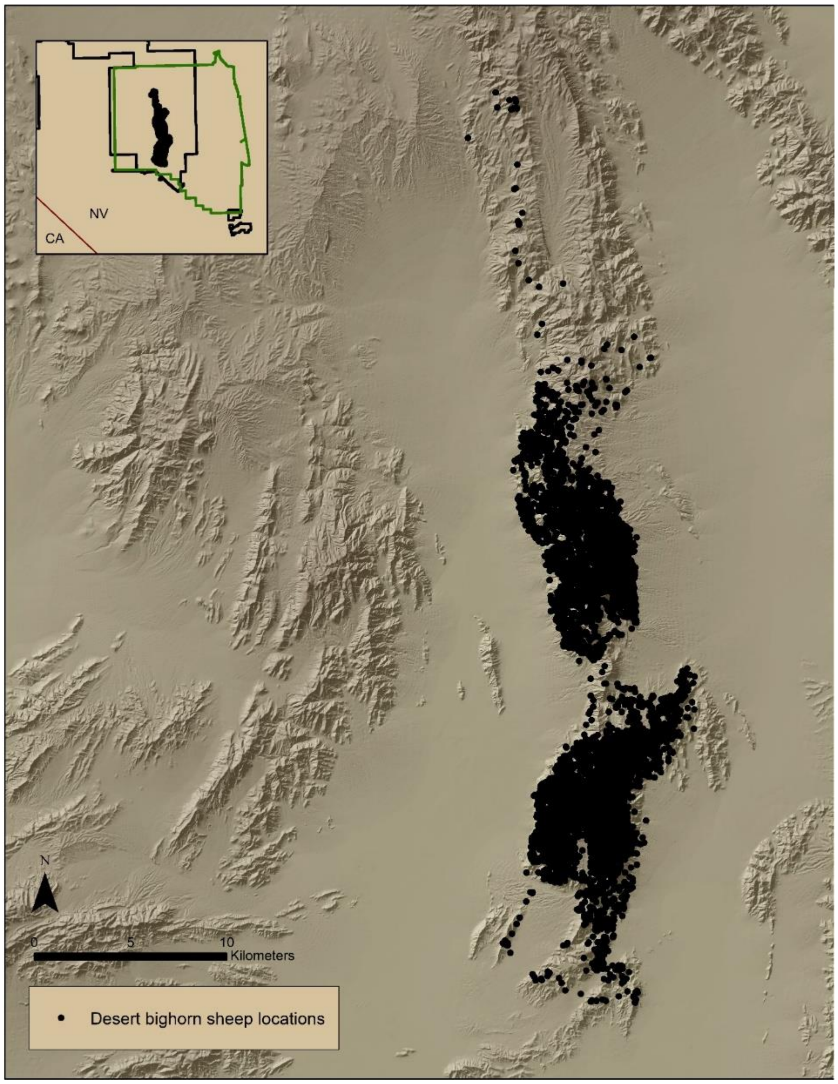

Figure 1. Locations of 19 collared desert bighorn sheep within the Pintwater Range of southern Nevada collected between 2016 and 2018. Green border defines Desert National Wildlife Refuge, black defines Nevada Test and Training Range.

Females selected ridgeline formations over valley areas however, depressions perpendicular to the slope were also used. The effect of NDVI and difference in NDVI was strongest during spring, with females reducing use of areas with greater biomass (relatively heavier shrub) and increasing use of greening vegetation (forbs and grasses). Females were closer to water than would be expected by chance but this effect was not strong (Table 6).

Females during summer were strongly associated with cliff-sparse and mid-elevation vegetation types. Areas of decreasing viewshed were used, and increasing slope and ruggedness were strong predictors. As found previously, slope interacted with ruggedness, and females selected ridgeline formations over valley areas. The effect of NDVI and difference in NDVI was again marginal. Females were closer to both water sources than would be expected by chance, and this effect was great-

Table 3. Desert bighorn sheep male general habitat use variables within the Pintwater Range, Nevada.

Habitat Variable	Spring[a]		Summer		Fall-winter	
	Mean	SD[b]	Mean	SD	Mean	SD
Elevation (m)	1518.7	184.5	1471.6	183.2	1412.2	207.4
Ruggedness (*100)	1.064	1.34	1.237	1.556	1.039	1.329
Slope percentage	50.1	26.1	55.0	28.6	50.5	27.6
Distance to water (m)	2871.2	1339.0	2583.4	1675.1	3418.7	1940.2
Viewshed (m^2)	8096.5	2968.4	7928.1	2865.3	8326.9	3243.7
Profile curvature	-0.124	2.918	-0.018	3.252	0.052	2.95
Planform curvature	0.171	2.33	0.17	2.742	0.058	2.342
NDVI	1380.4	275.5	1209.1	216.9	1268.9	206
Difference in NDVI	14.8	225.1	-30.0	159.3	10.5	194.1

Variable notation as in Table 1

Table 4. Desert bighorn sheep female general habitat use parameters within the Pintwater Range, Nevada.

Habitat Variable	Spring		Summer		Fall-winter	
	Mean	SD	Mean	SD[b]	Mean	SD
Elevation (m)	1446.2	211.3	1352.6	185.3	1429.9	189.7
Ruggedness (*100)	1.629	2.325	1.346	1.596	1.437	1.709
Slope percentage	73.5	42.3	69.0	40.0	65.9	31.7
Distance to water (m)	2479.8	1558.5	2306.8	1838.2	1702.2	1443.1
Viewshed (m^2)	7136.9	2614.9	7440.7	2902.5	7208.3	2696.4
Profile curvature	-0.046	4.797	-0.148	4.304	-0.12	3.974
Planform curvature	-0.108	3.263	0.126	3.191	0.169	3.038
NDVI	1293	259.4	1199	186.6	1132.7	213.8
Difference in NDVI	38.6	210.9	-0.5	153.7	-25.4	173.8

Variable notation as in Table 1

Table 5. Male bighorn sheep seasonal habitat model variable coefficient (beta) and odds ratios within the Pintwater Range of southern Nevada.

	Spring			Summer			October - January		
Variables	β	SE	Odds ratio	β	SE	Odds ratio	β	SE	Odds ratio
Midveg	1.343	0.043	3.831	1.526	0.063	4.60	0.857	0.042	2.355
Cliffveg	0.528	0.051	1.696	1.154	0.071	3.169	0.669	0.05	1.952
Rgd	0.199	0.009	1.22	0.172	0.011	1.188	0.13	0.008	1.139
Slope	0.345	0.012	1.412	0.318	0.016	1.374	0.27	0.012	1.31
Slp*rgd	-0.025	0.001	0.975	-0.02	0.001	0.981	-0.017	0.001	0.983
View	-0.5	0.01	0.587	-0.537	0.062	0.584	-0.416	0.049	0.66
NDVI	0.0005	0.00005	1.0001	0.0002	0.0001	1.000	-0.0004	0.0001	0.998
NDVIdiff	-0.0001	0.0001	0.998	N/A	N/A	N/A	0.0005	0.0001	1.0001
Profile	-0.017	0.005	0.983	-0.006	0.006	0.994	N/A	N/A	N/A
Planform	0.015	0.006	1.015	0.016	0.008	1.016	0.007	0.006	1.007
Dwater	-0.01	0.0008	0.998	-0.016	0.001	0.984	0.007	0.0007	1.007

Variable notation as in Table 1 & 5.

est during summer (Table 6).

Females used cliff-sparse and lower-elevation vegetation types more often than mid-elevation types during the fall-winter. Females used areas of greater slope, ruggedness, and decreasing viewshed, and selected ridgelines over valleys. Slope continued to interact with ruggedness, however, the effect was not strong. The effect of both NDVI and difference in NDVI was marginal, and animals were closer to water than would be expected by chance (Table 6).

Comparison between the Desert/East Desert Ranges and the Pintwater Habitat Models

Our direct comparison of the performance of two models within the Pintwater Range determined that, in this case, the models based on locally-derived data (Pintwater locations) were statistically superior to models derived from more-distant sources (D/ED locations) during both spring and summer. The spring Pintwater model (ROC = 0.907, 95% CI = 0.898-0.916) performed better than the spring D/ED model (ROC = 0.821, 95% CI = 0.808-0.834) (Fig. 2). Similarly, the summer Pintwater model (ROC = 0.922, 95% CI = 0.907-0.937) performed better than the summer D/ED model (ROC = 0.859, 95% CI = 0.837-0.880) (Fig. 3). These differences were significant as indicated by the lack of overlap between the 95% confidence intervals.

Movement Patterns

Males moved farther than females in the spring ($F_{1,23160}$ = 160.1, $P < 0.001$), summer ($F_{1,3248}$ = 115.0, $P < 0.001$), and fall-winter ($F_{1,21301}$ = 74.9, $P < 0.001$). Seasonally within sexes between six-hour periods, females moved farther during the summer than they did during spring and fall-winter ($F_{2,26532}$ = 54.3, $P < 0.001$). However, we found no difference between spring and fall-winter ($F_{2,26532}$, $P = 0.193$).

Males moved in a similar pattern, farthest during summer than the other two seasons ($F_{2,31177}$ = 132.2, $P < 0.001$), with no difference found between spring and fall-

Table 6. Female bighorn sheep seasonal habitat model variable coefficient (beta) and odds ratios within the Pintwater Range of southern Nevada.

	February – May			June - September			October - January		
Variables	β	SE	Odds ratio	β	SE	Odds ratio	β	SE	Odds Ratio
Midveg[c]	1.34	0.071	3.82	1.179	0.092	3.25	-0.459	0.049	0.632
Cliffveg[d]	1.98	0.074	7.246	1.64	0.096	5.157	0.321	0.053	1.379
Rgd[e]	0.118	0.009	1.126	0.183	0.013	1.201	0.079	0.009	1.082
Slope[f]	0.439	0.015	1.551	0.426	0.021	1.531	0.345	0.014	1.412
Slp*rgd[g]	-0.016	0.001	0.984	-0.021	0.002	0.979	-0.009	0.001	0.991
View[h]	-0.93	0.05	0.394	-0.947	0.073	0.388	-0.934	0.055	0.393
NDVI[i]	-0.001	0.0001	0.999	-0.002	0.0001	0.998	-0.001	0.0001	0.999
NDVIdiff[j]	0.0008	0.0001	1.001	0.0004	0.0001	1.0004	0.0007	0.0001	1.001
Profile[k]	-0.015	0.005	0.985	-0.027	0.006	0.973	-0.027	0.005	0.973
Planform[l]	-0.015	0.006	0.985	N/A	N/A	N/A	N/A	N/A	N/A
Dwater[m]	-0.022	0.0009	0.978	-0.053	0.001	0.948	-0.028	0.0008	0.973

Variable notation as in Table 5

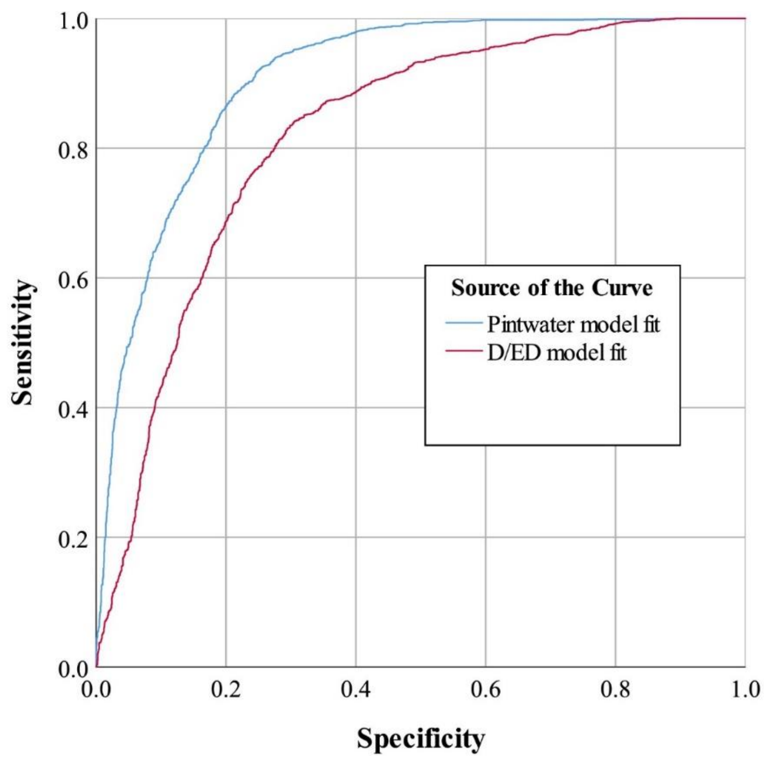

Figure 2. Receiver Operator Curves for desert bighorn sheep probability of occurrence within the Pintwater Range of southern Nevada during spring (Feb. through May). Upper curve indicates greater performance of Pintwater model versus the extrapolated Desert/East Desert Range model (lower curve).

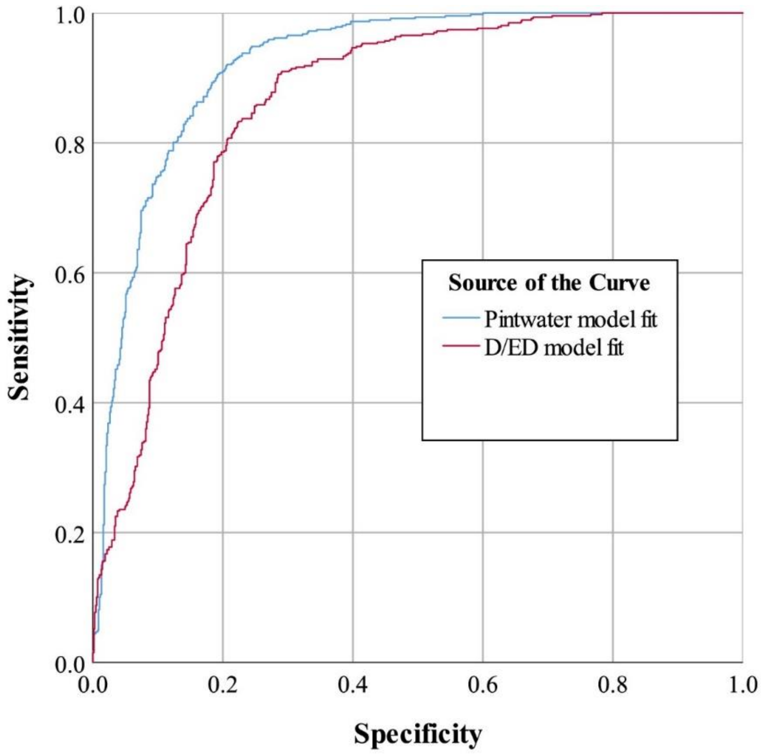

Figure 3. Receiver Operator Curves for desert bighorn sheep probability of occurrence within the Pintwater Range of southern Nevada during summer (June through Sept.). Upper curve indicates greater performance of Pintwater model versus the extrapolated Desert/East Desert Range model (lower curve).

winter ($F_{2,31177}$ = 6.02, P = 0.784; Table 7). Between one-hour periods, males traveled farther than females during the summer ($F_{1,23160}$ = 20.5, P < 0.001), fall-winter ($F_{1,20160}$ = 33.9, P < 0.001), and spring seasons ($F_{1,20160}$ = 26.3, P < 0.001). Seasonally within sex between one-hour periods, females traveled farther during summer than during either spring or fall-winter ($F_{2,12369}$ = 59.0, P < 0.001). Males also travelled farther during summer than spring or fall-winter ($F_{2,12369}$ = 59.1, P < 0.001). We found no difference in one-hour distance moved between spring and fall-winter ($F_{2,12369}$ = 18.03, P = 0.319; Table 7).

Lambing Habitat

We found 382 locations among all nine collared females displaying clustering behavior at 13 separate sites (of potentially 18 sites for 9 females over two years) within the Pintwater Range (Fig. 4). Clustering occurred from January 1st through March 15th of 2017 and 2018. The fact that all nine females demonstrated clustering behavior during the same 2 ½ month period strongly supported our inference that clusters were probable lambing sites. Ten of the 13 sites occurred on the eastern slope of the range. In general, lambing habitat consisted of relatively steep (mean slope = 61.7 %, SD = 24.5) and rugged (mean ruggedness index × 100 = 1.25, SD = 1.83) areas of low visibility. Distance to water was highly variable (mean = 2358 m), with clusters occurring from 330 m to over 7.2 km from known water sources. Mean elevation was 1210 m. Lambing occurred primarily in cliff-sparse vegetation types (91.6% of total cluster locations) but also in mid (3.7%) and lower (4.7%) vegeta-

Table 7. Euclidean distances moved between desert bighorn sheep locations within the Pintwater Range of southern Nevada.

Sex	Season[1]	Dist 6 hour[2]	SD[3]	Max 6 hour[4]	Dist 1 hour	SD	Max 1 hour
Male	Spring	282	369	8158	103	173	3720
Male	Summer	374	553	8162	138	232	2409
Male	Fall-winter	279	402	8638	98	180	2797
Female	Spring	224	322	6618	88	144	2009
Female	Summer	282	399	5309	116	176	2961
Female	Fall-winter	233	353	8219	78	143	2019

[1]Spring = Feb. -May, summer = June – Sept., Fall-winter = Oct. – Jan.
[2]Dist 6-hour = distance between locations taken every 6 hours.
[3]SD = standard deviation around the mean.
[4]Max 6-hour = maximum distance of travel between 6-hour periods.

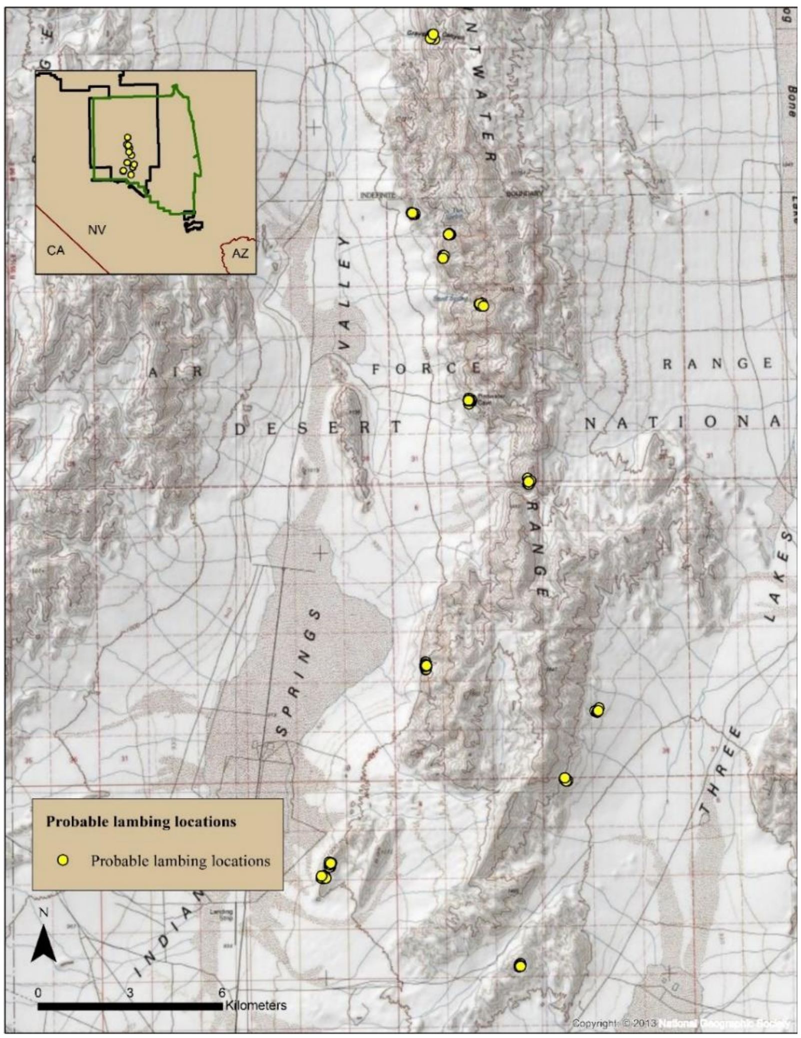

Figure 4. Locations of 19 collared desert bighorn sheep within the Pintwater Range of southern Nevada. Green border defines DNWR, black defines NTTR.

tion associations. Although important data on probable lambing habitat were derived, 13 sites were not sufficient to model lambing habitat on a landscape scale.

DISCUSSION

Here, we discuss habitat use, movement patterns, potential effects of water, and potential lambing habitat of the Pintwater Range, the primary focus of our paper. Habitat use was best described by the inclusion of several variables during all seasons, strongly supporting the premise that desert bighorn sheep use a wide variety of terrain, vegetation type, water, and forage indicators to select habitat (Monson and Sumner 1981, McKinney et al. 2006, Karsch et al. 2016). Differences in habitat selection between sexes were apparent during spring, as males used the potentially better forage of the mid-elevation vegetation type while females concentrated within the cliff-sparse vegetation areas. This corresponds with a recognized strategy of males accessing greater quality forage despite a potential increase in predation risk (Bleich 1999, Altendorf et al. 2001, Atwood et al. 2009). Interestingly, both males and females increased their use of cliff-sparse vegetation during summer, and female presence was positively associated with greening vegetation. These findings suggest that remnant patches of greening forage available in these steep, rugged areas may be attracting bighorn sheep.

Our spring season data corresponded to the documented risk-averse strategy in which females use very steep, rugged areas during parturition (Bleich et al. 1997, although see Karsch et al. 2016). Both males and females responded similarly to terrain curvature, using ridge formations on both the parallel and perpendicular axis to the fall line. Animals may be using ridge formations to increase their viewshed, which is necessarily reduced in steep, rugged areas (K. Longshore, USGS, unpublished data). Use of areas with increasing growth of vegetation (positive difference in NDVI) was indicated for females across all seasons though especially during spring. Males, however, demonstrated no common association with NDVI. This may be a function of males greater use of the mid-elevation type of vegetation, which may be more homogenous than the cliff-type selected by females.

In general, animals exhibited low variability in distances travelled over the study period, however, there were differences in movement patterns. As measured during both 1-hour and 4-hour intervals, males moved farther and with greater variability than females during all seasons (Tables 3, 4). Both sexes moved farther in summer relative to other seasons, suggesting a shift to more browse-type forage from forbs and grasses (Monson and Sumner 1981) and/or reflects increasing scarcity of quality forage as temperatures rise. Alternatively, increased visitation to distant water sources may also affect summer movement (Longshore et al. 2009). Males experience the rut during summer months, which may also explain an increase in distances travelled as they pursue females (Bleich et al. 1997). Additionally, males spent up to 80% of their time in mid-elevation vegetation, which allows easier movement than the cliff-vegetation types females preferred. This suggests that males trade-off of safety to access quality forage is also a driver of sex-based differences in movement patterns (Zollner and Lima 1999, Schick et al. 2008). Although there were statistical differences between seasons and sex in terms of distances travelled, the total average differences were less than 80 m between 4-hour intervals and less than 50 m between 1-hour intervals. These are relatively minor distances for a bighorn sheep to travel (Monson and Sumner 1981), and it is unknown whether this might represent a significant energetic demand. Interestingly, although 19 animals were collared for up to 20 months, no animals moved beyond the Pintwater Range.

The availability of water sources is recognized as an important factor in predicting desert bighorn sheep habitat (Rosenstock et al.1999, Longshore et al. 2009, Bleich et al. 2010), and our analysis confirmed the importance of water sources for bighorn sheep in the Pintwater Range. Water appeared well-dispersed throughout the study area, and no water source was more than 13 km away from another within the Pintwater Range. Bighorn sheep maintained a closer average distance from water during summer, and females were farthest from known water sources during spring, when greener vegetation and ephemeral water sources are more likely to be available (McKee et al. 2015). Both sexes maintained an average distance of approximately 2.5 km from water sources, which is similar to other studies (Longshore et al. 2009, Bleich et al. 2010). Interestingly, the two collared animals which travelled the farthest north stopped at the last water source available, continued north for approximately 4 km and 7 km, respectively, then returned south to their previous home ranges. We found no animal over 8.5 km from a known water source during the study period.

In general, what we inferred as lambing activity took place in relatively steep, rugged areas (Smith et al. 2015). However, this terrain was not necessarily the steepest or most rugged available, and parturition sites have been shown to be less steep than nursery sites, (Karsch et al. 2016). Females often used sites with ravines and depressions, a behavior likely to reduce predation risk to lambs (Karsch et al. 2016). In contrast, one female did apparently give birth in a low-slope (<10%) environment, an area considered at higher risk for predation (Berger 1991). Over the 2 ½ year study period, all nine females were identified by the cluster program as they greatly constrained their activity during what we infer was the parturition period. This inference was supported by the fact that the clustering behavior only occurred once during the lambing season and occurred for each female (Bangs et al. 2005).

Model extrapolation is a critically important process for remote areas, and our analysis of model performance across two independent mountain ranges provided a robust test rarely afforded researchers and managers of ungulates in the southwest (Bahn and McGill 2013). Due to this rarity, we compared two suitable, adjacent mountain ranges to find if we could use one habitat model to inform the other. Although the Desert/East Desert Range models were suitable for predicting bighorn sheep occurrence within the Pintwater Range, the predictive power was reduced compared to models derived for the population inhabiting the Pintwater Range. This is not entirely unexpected, as ungulate species will modify their use of habitat as the underlying environment changes even in nearby areas (Hoglander et al. 2015). How bighorn sheep might modify their use is indicated by the differences in model selection between ranges, suggesting animals prioritized different aspects of the environment as conditions changed over space. Furthermore, unmeasured variables, such as disease occurrence (Cassirer and Sinclair 2007), or the differences in disturbance regimes between military and refuge areas (Krausman et al. 2010) may also have contributed to habitat use changes. Regardless of cause, this reduced performance indicates that although producing a model feasible for understanding general habitat use across remote or restricted areas, extrapolated models may not be useful for determining specific impacts from local disturbances or events (Stankowich 2008). We acknowledge, however, that one comparison does not necessarily justify or invalidate extrapolating models across the landscape, and we expect a larger scale study to address which variables maintain their correlation with habitat use and which do not.

MANAGEMENT IMPLICATIONS

The use of extrapolated habitat models could greatly reduce costs, time, and other limited resources. Access restrictions, whether due to military requirements, lack of roads, or other constraints, further argue for the use of extrapolated models. Our study suggests managers use extrapolated models to address general habitat concerns but not as tools to address specific responses to local disturbances and events. We further suggest our study may be used by managers as a source for understanding habitat use, movement patterns, and lambing habitat on remote, military lands.

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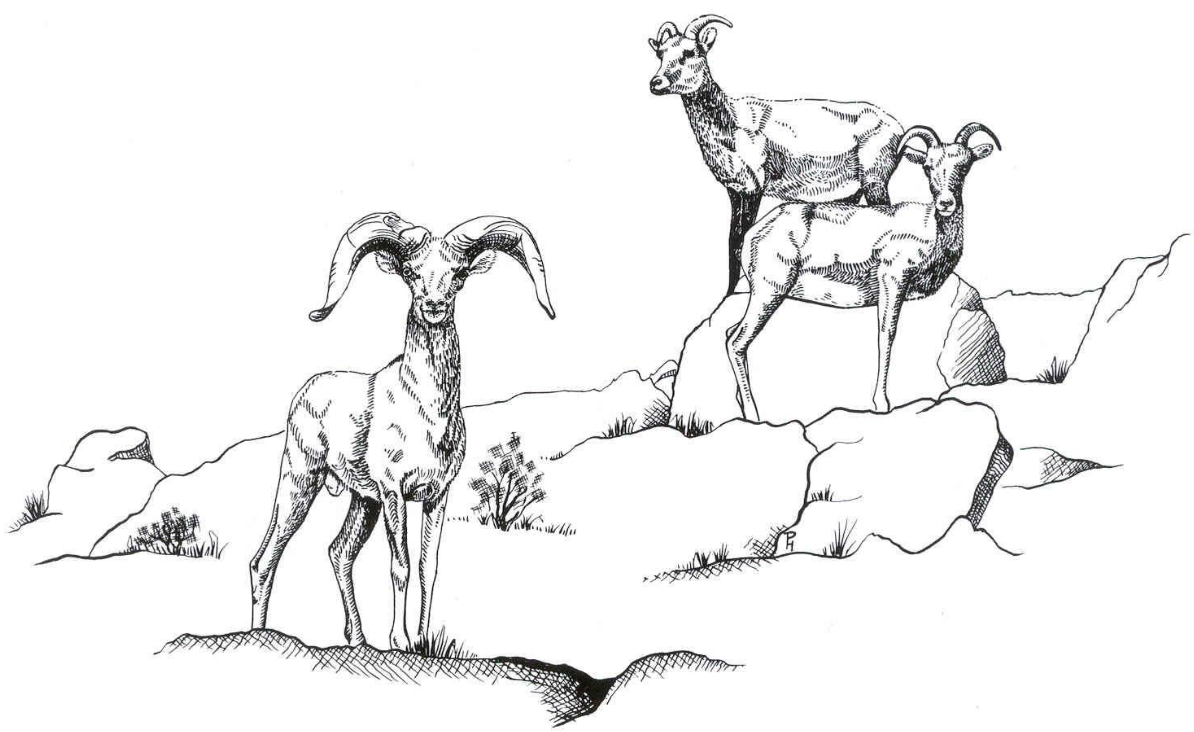

Binational movements of desert bighorn sheep between Texas, USA and Chihuahua, Mexico

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Abstract In the late 1800s, there were >1,000 desert bighorn (*Ovis canadensis*) estimated 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 translocation of desert bighorn from Arizona. Since that time, more than 900 bighorn have been translocated to historically occupied mountain ranges in Texas from in-state and out-of-state translocation efforts. In December of 2010 and 2011, 141 desert bighorn were transplanted to Big Bend Ranch State Park (BBRSP); 78 of which were fitted with GPS collars. 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 may very well be the first free-ranging population (consisting of both males and females) documented in Chihuahua since their extirpation in the 1980s. The recorded movements and range sizes ultimately show that our restoration undertakings are on a scale grander than previously imagined. When dealing with a species that requires vast, continuous landscapes, the necessity and benefits of cooperation at the public, private, state, federal, and international levels is exemplified.

Desert Bighorn Council Transactions 55:21–31

Key words Bighorn sheep; border; border wall; Chihuahua, Mexico; international cooperation; *Ovis canadensis*; restoration; Texas, USA; translocation

Desert bighorn sheep (*Ovis canadensis* ssp.) once occupied mountain ranges from western Canada to northwestern Mexico and Baja California (Valdez and Krausman 1999). Carson (1941) believed there to be 1,000–1,500 desert bighorn (*O. c. mexicana*) living in 16 mountains ranges (Bailey 1905, Davis and Taylor 1939) in the Trans-Pecos region of Texas in the late 1800s. By the early 1960s, Texas lost the last of its native desert bighorn (Kilpatric 1990). Like many other states with declining or extirpated populations, the reasons for decline were not completely understood, but were believed to be associated with a combination of unregulated hunting, competition and disease transmission from domestic sheep and goats, habitat fragmentation, and potentially other unknown causes (Davis and Taylor 1939, Buechner 1960).

Beginning in 1957, the Texas Game and Fish Commission (now Texas Parks and Wildlife Department [TPWD]) translocated desert bighorn from Arizona to a captive breeding facility to initiate a bighorn restoration process (Kilpatric 1990). Over the next 4 decades, 146 desert bighorn were transplanted to Texas facilities from Nevada (*n* = 107), Arizona (*n* = 31), Mexico (*n* = 6), and Utah (*n* = 2; Brewer and Hobson 2000). As bighorn populations grew within the captive breeding facilities, individuals were captured and released into historically occupied mountain ranges (Cook 1994). As free-ranging bighorn numbers increased, the need for captive breeding facilities and out-of-state augmentations diminished (Cook 1994). By 1997, 237 desert bighorn had been captured from re-established Texas bighorn populations and released into other Texas mountain ranges (Cook 1994, Brewer and Hobson 2000). In 2000, <50 years after bighorn restoration efforts began, Pittman et al. (2001) reported observing 381 free-ranging desert bighorn during annual helicopter surveys in 7 mountain ranges.

Similar to Texas, the native desert bighorn of Chihuahua, Mexico (*O. c. mexicana*) were believed to be extirpated by the early 1980s (Heffelfinger and Marquez-Muñoz 2005). Beginning in 2000, reintroduction efforts occurred with 4 desert bighorn (1 M, 3 F) being transplanted to a captive breeding facility on the La Guarida Ranch in northeastern Chihuahua from the state of Sonora, Mexico (Uranga-Thomas 2001). By 2012, Uranga-Thomas and Valdez (2011) reported that there were approximately 400 desert bighorn within 4 captive breeding facilities in the state of Chihuahua. Heffelfinger and Marquez-Muñoz (2005) reported up to 5 males being harvested in the northern part of Chihuahua, just south of New Mexico from 1995–2005. Pelz-Serrano et al. (2006) also reported 1 desert bighorn male being hunted and another male being spotted in 1995 and 2002, respectively, in northwestern Chihuahua. Heffelfinger and Marquez-Muñoz (2005) and Pelz-Serrano et al. (2006) believed these males presumably traveled from the Big Hatchet Mountains in New Mexico; one being confirmed by a Telonics (Mesa, AZ) radio collar. Even with these reports on males and success of the captive breeding facilities, there were not any indications of free-ranging desert bighorn populations, or even females, in the state of Chihuahua as of the time of this study.

Despite a successful restoration program in Texas, there has been limited work (Locke 2003) on documenting the movements and survival of translocated desert bighorn within the state, and no published data on international bighorn movements from Texas. The Bofecillos Mountains had been void of bighorn ≥50 years (F. Hernández, TPWD, unpublished report). Our objectives were to translocate bighorn from 2 source populations within Texas to the Bofecillos Mountains, monitor their survival and movements via radio collars, and determine if, and to what extent, desert bighorn made international movements to Chihuahua, Mexico.

STUDY AREA

Big Bend Ranch State Park (BBRSP) was located in the southern part of the Big Bend region of Texas along the Texas, USA and Chihuahua, Mexico border (Fig. 1). At the time of our study, BBRSP encompassed approximately 1,254 km^2 with private in-holdings located throughout the park (TPWD 2014). The park was bordered to the south and west by the Rio Grande; to the east by Lajitas, Big Bend National Park, and private lands; and to the north by private lands. Elevations ranged from approximately 700 m along the Rio Grande at Lajitas to 1,565 m at Oso Mountain (TPWD 2014). The primary geographic features of BBRSP included the Bofecillos Mountains, the Solitario (a collapsed volcanic dome), and mountain

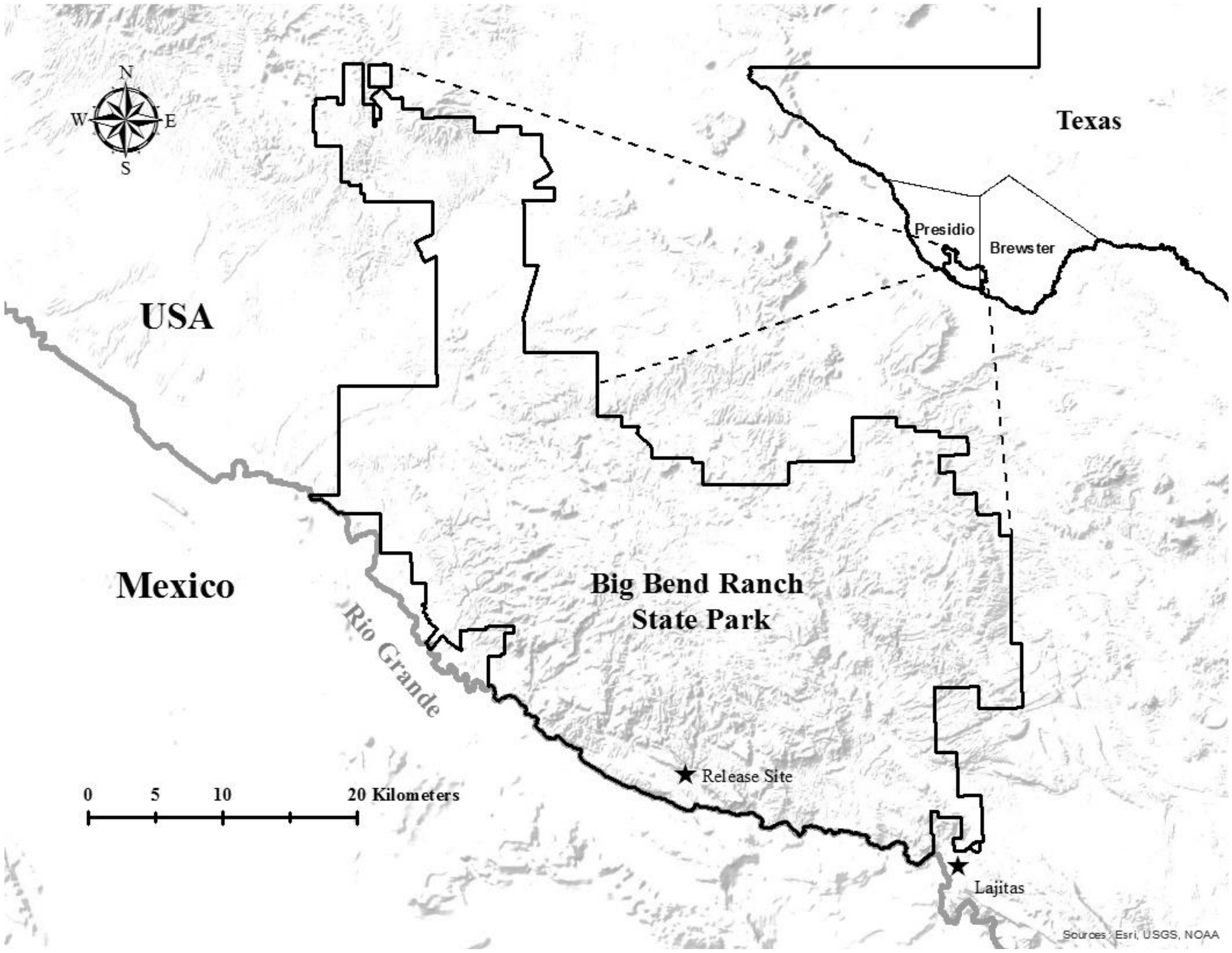

Figure 1. Location of Big Bend Ranch State Park in Presidio and Brewster counties, Texas, along the USA and Mexico border.

ridges formed by alluvial fans from the volcano (TPWD 2014).

Ing et al. (1996) classified BBRSP as a hot desert with mountains, canyons, uplands, basins, and riparian zones throughout. More than 100 natural springs, streams, and seeps had been documented in BBRSP (Yancey 1996, TPWD 2014). Climate had been characterized as semiarid to arid (Hanselka 1976*a*, *b*; Schmidly 1977). Annual precipitation averaged 30–36 cm (USDA 2013), with most occurring during the late summer monsoonal season (Hanselka 1976*a*, *b*).

Ecological sites were characterized mostly as Limestone Hill and Mountain Desert Grasslands; Limestone Hill and Mountain, Hot Desert Shrublands; and Igneous Hill and Mountain, Desert Grasslands (USDA 2013). Deeper soils were more common in lower elevations (draws and canyons; Milner 2003) and included a higher floral diversity (Powell 1988). Ocotillo (*Fourquieria splendens*), lechuguilla (*Agave lechuguilla*), sotol (*Dasylirion wheeleri*), cacti (*Opuntia* spp.), creosote (*Larrea tridentata*), and chino grama (*Bouteloua ramosa*) were the prominent vegetation throughout BBRSP (Powell 1988). Large mammalian species included javelina (*Pecari tajacu*), mule deer (*Odocoileus hemionus*), aoudad (*Ammotragus lervia*), *bobcats* (*Lynx* *rufus*), coyotes (*Canis latrans*), and mountain lions (*Puma concolor;* Yancey 1996).

METHODS

Capture

In December 2010 and December 2011, we captured 141 desert bighorn (31 M, 110 F) using the helicopter and net-gun method (Krausman et al. 1985; Scientific Research Permit 0592-525) from the Elephant Mountain Wildlife Management Area (EMWMA [*n* = 46]) and Sierra Diablo Metapopulation (SDMP [*n* = 95]; Table 1). Upon capture, the helicopter crew secured and blindfolded the sheep, then aerially transported the bighorn to a designated staging area. At the staging area, we collected the following data for each individual: sex, age, body condition, fecal and hair samples, nasal and ear swabs, and whether females were lactating. We determined the sheep's ages by horn growth rings (Geist 1966, Hansen and Deming 1980) and tooth wear and replacement (Hansen and Deming 1980). Of the 141 sheep captured, we fitted 78 (24 M, 54 F) with global positioning system (GPS) radio collars (either Lotek [Newmarket, Ontario, Canada], Advanced Telemetry Systems G2110D [Isanti, MN], or North Star NSG-D1 [King George, VA]). The collars were programmed to collect GPS locations every 3-5 hours (depending on collar type) for ≥24 months. All collars had VHFs (very high frequencies) that assisted in locating the radio-collared sheep. We kept our handling time to a minimum and monitored each of the animal's temperatures throughout the process. Veterinary personnel tended to notable injuries. After collaring and processing the sheep, we placed the females in modified livestock trailers and loaded the males into wildlife crates modified for transportation. Once captures were completed for the day, we transported and released the bighorn at BBRSP (29.320683° N, -103.975433° E; Fig. 1).

International Movements

Upon finding a collar, either after the host died or the collar successfully dropped off, we retrieved the data using each brand's respective software. We uploaded all files into ArcGIS® 10.1 (Environmental Systems Research Institute [ESRI], Redlands, CA) and analyzed them in the North American Datum 1983 Universal Transverse Mercator (UTM) Zone 13N coordinate system. After removing GPS locations collected prior to the animal's release (data collected before collaring the host, or while in transport to the release site), as well as any post-movement data (after the collar dropped off or the host died), we created new Microsoft Excel files for each individual's dataset (Janke 2015).

If we discovered any GPS location points in Mexico from our radio collar datasets, we delineated the areas crossed, the

Table 1. Number of desert bighorn sheep captured, radio-collared, and translocated to Big Bend Ranch State Park, Texas, USA from Elephant Mountain Wildlife Management Area (December 2010) and Sierra Diablo metapopulation (December 2011)

	Elephant Mountain Wildlife Management Area		Sierra Diablo Metapopulation		Total	
	Captured	Collared	Captured	Collared	Captured	Collared
Males	12	10	19	14	31	24
Females	34	25	76	29	110	54
Totals	46	35	95	43	141	78

duration of time spent in Mexico, and the number of times each individual ventured back and forth between the two countries. We recorded the dates and times of international crossing locations for each individual. We determined 'visit' durations by calculating time differences made between successive crossing occurrences (i.e., going to and returning from Mexico).

RESULTS

Data Recovery

Data was recovered from 54 (13 M, 41 F) of the 78 GPS radio collars deployed, resulting in 100,734 GPS points. The 24 collars (11 M, 13 F) unaccounted for had technical issues (most stopped transmitting VHF signals) and were unable to be recovered. After the recovered collar data was screened in Microsoft Excel and program R (T-LoCoH package), 97,806 locations were available for analyses (Janke 2015).

International Movements

Twenty-one (39%) of the 54 collared desert bighorn crossed into Chihuahua, Mexico ≥1 time from BBRSP. Of the 97,806 GPS locations analyzed during our study, 6,490 (7%) were collected in Mexico (Fig. 2). More SDMP individuals (6 M, 11 F) traveled internationally than EMWMA bighorn (1 M, 3 F). Most (17; 81%) animals ventured into Mexico ≤3 times, with 10 bighorn only visiting 1 time. A SDMP female visited Mexico the most (n = 17), but only stayed in the country ≤1 day each visit. The majority (59%) of all crossings lasted ≤1 day in Mexico; 70% lasted ≤1 week (7 days); and only 23% resulted in bighorn remaining there >1 month (30 days). The longest single visit (242 days) was by a SDMP female. The average duration any bighorn stayed in Mexico (accumulation of all visits) was 68.9 days (SE = 24.7 days). The greatest amount of time spent in Mexico by 1 individual (427 days) was by a SDMP male over the course of 8 visits.

The furthest any individual bighorn traversed south of the Rio Grande was >35 km (Fig. 2). Most of the bighorn stayed within Sierra Mataderos just south of BBRSP, between the Rio Grande and Highway 200, but ≥3 crossed Highway 200 and made it to Sierra Rica. A higher percentage of desert bighorn translocated from SDMP (46%; 17 of 37 collars) crossed into Mexico than sheep translocated from EMWMA (24%; 4 of 17 collars). Bighorn from SDMP, tended to have greater seasonal and annual utilization distribution sizes than EMWMA bighorn (Janke 2015), which may be related to the increased frequency of trans-boundary movements. Males also showed a higher tendency (54%; 7 of 13 collars) to go to Mexico from BBRSP than females (34%; 14 of 41 collars). This is consistent with findings from other studies (Hoglander et al. 2015, Janke 2015, Cross 2016) reporting desert bighorn sheep males having larger utilization distributions than females.

The Rio Grande was crossed 115 times by bighorn from BBRSP. Sixty-one crossings were from individuals traversing from the BBRSP-USA into Chihuahua, Mexico, and 54 crossings were from those individuals returning. Seven collars were recovered in Mexico, thus accounting for the difference in crossing directions. Most (95 of 115) of the crossings occurred within a 10 km strip of river ≤6 km of the release site (Fig. 3). Data from each individual's international travels can be found in Table 2.

DISCUSSION

With nearly 40% (21 of 54) of the collared desert bighorn sheep translocated to the BBRSP crossing into Mexico ≥1 time during the study, Chihuahua now had free-ranging

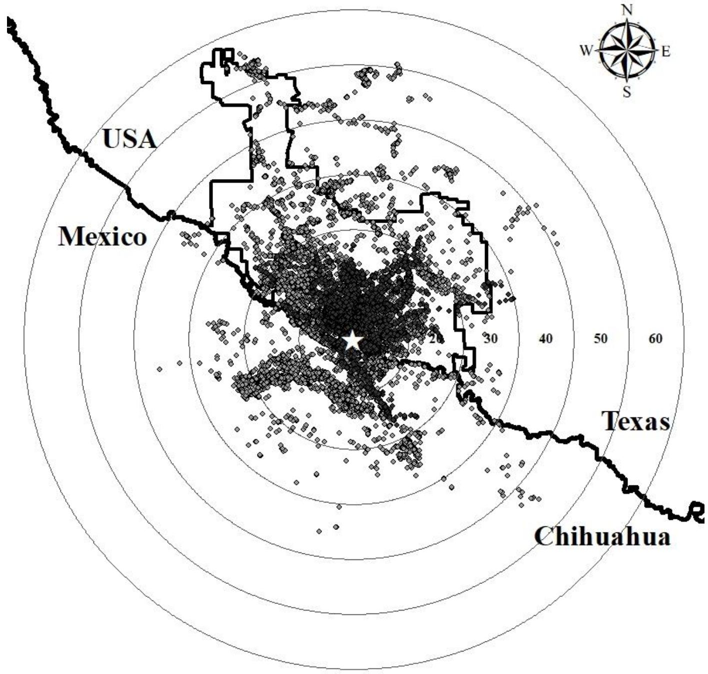

Figure 2. GPS locations (n = 97,806) of translocated desert bighorn sheep released in Big Bend Ranch State Park, Texas, USA, Dec 2010–Jan 2014. Twenty-one individuals crossed into Chihuahua, Mexico. Black and gray dots represent the Elephant Mountain Wildlife Management Area and Sierra Diablo metapopulation individuals, respectively. Rings are in 10 km increments from release site (white star).

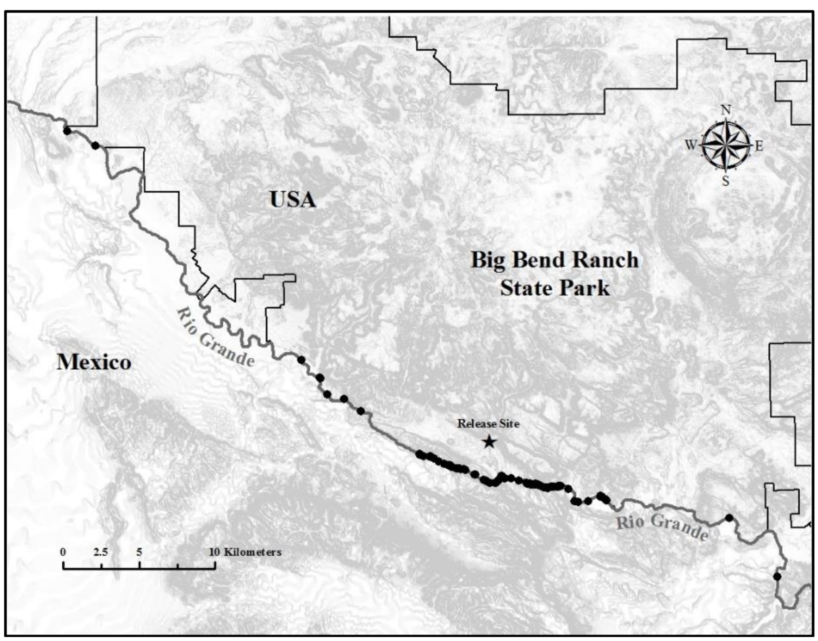

Figure 3. Black dots represent locations (n = 115) of river crossings from translocated desert bighorn sheep released in Big Bend Ranch State Park, Texas, USA, Dec 2010—Jan 2014. The Rio Grande is the international border between the USA and Mexico along the Texas, USA and Chihuahua, Mexico boundary.

Table 2. International movement information for desert bighorn sheep translocated to Big Bend Ranch State Park, Texas, USA from Elephant Mountain Wildlife Management Area (EMWMA) and Sierra Diablo metapopulation (SDMP) that traversed the Rio Grande back and forth into Chihuahua, Mexico, Dec 2010—Jan 2014. Twenty-one bighorn (7 M, 14 F) crossed the river 115 times (61 into Mexico, 54 returning from Mexico), collecting 6,490 GPS locations over the course of 1,447 calendar days in Mexico.

				Time in Mexico		
ID #	Sex	Source	Crossings	Visits	Days	Locations
149.154	M	SDMP	1	1	49	175
149.266	M	SDMP	2	1	1	1
149.335	F	SDMP	1	1	5	20
150.001	F	SDMP	3	2	4	9
150.010	F	SDMP	3	2	78	360
150.030	F	SDMP	2	1	1	1
150.050	F	SDMP	2	1	242	1,145
150.130	F	SDMP	1	1	154	717
150.200	F	SDMP	34	17	17	17
150.220	F	SDMP	1	1	1	3
150.251	F	SDMP	2	1	5	19
150.311	F	SDMP	10	5	5	5
150.380	F	SDMP	6	3	3	3
150.450	M	SDMP	1	1	54	240
150.590	M	SDMP	2	1	67	311
150.611	M	SDMP	6	3	271	1,161
150.650	M	SDMP	16	8	427	1,922
151.220	F	EMWMA	8	4	4	4
151.340	F	EMWMA	6	3	23	144
151.390	M	EMWMA	4	2	28	186
151.680	F	EMWMA	4	2	8	47

desert bighorn roaming its mountains for the first time since their extirpation. Though our data did not indicate any permanent immigration by desert bighorn into Chihuahua, Mexico from Texas (all collars were recovered in the USA or from dead desert bighorn in Mexico), it did suggest that there were resources (Wilson et al. 1980, Cunningham 1989, Wakeling and Miller 1990) available on both sides of the border for the bighorn to freely choose from and utilize for extended time periods (38% of the translocated desert bighorn from BBRSP that traveled into Chihuahua remained there ≥30 days). Unlike Arizona and California (Cheney 2007), Texas bighorn were not limited by a border fence between the USA and Mexico at this time. Influence of such barriers can be detrimental to wildlife populations (List 2007). The lack of border fencing allowed bighorn populations in Texas, and in the bordering mountains of Mexico, to have greater chances of growth and survival. Just as TPWD has had success in restoring Texas' viable historic mountain ranges with desert bighorn from free-ranging and captive populations (originally from other states; Kilpatric 1990, Cook 1994, Brewer and Hobson 2000), Chihuahua, Mexico may one day be restoring its historic ranges (Heffelfinger and Marquez-Muñoz 2005) with desert bighorn that freely cross over from BBRSP.

MANAGEMENT IMPLICATIONS

Our data suggested that desert bighorn, like many other species, are not bound by political boundaries (public, private, state, or international) when given the opportunity (Janke 2015). Recent concerns regarding impacts of a border fence/wall (Flesch et al. 2010, Trouwborst et al. 2016, Greenwald et al. 2017, Fowler et al. 2018) are warranted, as our data shows a free-flow of movement of desert bighorn sheep across the United States–Mexico border. Additionally we were able to identify high-use areas (i.e., corridors) that may be critical in connecting and conserving desert bighorn sheep habitat across the 2 countries.

In order to improve the desert bighorn population as a whole (potentially also affecting many other species in a positive manner), resources need to be managed and conserved on a landscape-scale. This starts with educating the people and communities on both sides of the border (Hernández 2012). Protection and conservation of areas such as the 10 km strip of Rio Grande that the bighorn crossed the majority (83%) of the time need to be prioritized. Ultimately, by working with the country and people of Mexico, Texas is helping its desert bighorn population have a better chance of persistence.

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Repatriated desert bighorn sheep population on the Nevada National Security Site

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Abstract Ecological studies have been conducted on the Nevada National Security Site (NNSS) since the 1960s. Desert bighorn sheep (*Ovis canadensis nelsoni*) were considered rare visitors on the NNSS, with only 9 recorded observations between 1963 and 2009, all of which were males. Females and young were not documented definitively until winter 2011, when several were killed by a radio-collared female mountain lion (*Puma concolor*). Following these observations, we initiated a study of desert bighorn sheep on the NNSS to better understand their movements/interactions with other populations, prevalence of disease, population size, origin, radionuclide burdens and potential radiological dose to humans that may consume harvested animals away from the NNSS. We captured and radio-collared 6 sheep (2 females, 4 males) in November 2015, and 15 (7 females, 8 males) in November 2016. We sampled blood for genetic and disease testing and collected nasal swabs for respiratory disease testing. Sheep from the NNSS spent most of their time around Shoshone Mountain, Fortymile Canyon, and Yucca Mountain but also moved to Bare Mountain, Thirsty Canyon, and Black Mountain. Females greatly expanded their core and overall home ranges during spring, whereas males expanded their home ranges during summer. Of 18 sheep sampled for disease, 12 showed an immune response to *Mycoplasma ovipneumoniae*, and 5 had the bacteria present. Genetic testing revealed that the ancestry of NNSS sheep is from the Bare Mountain (1991-1995, within 24 km of our study area), Specter Range (1990-1995, within 32 km of our study area), and Stonewall Mountain (1975-1983, within 72 km of our study area) reintroduced populations. Radionuclide burden in NNSS sheep was minimal with no significant difference from sheep captured on the Nevada Test and Training Range and northern Nevada. One marked adult male was legally harvested off the NNSS north of Bare Mountain. This recently colonized reproducing population of sheep on the NNSS warrants further monitoring, protection, and inclusion in resource management plans.

Desert Bighorn Council Transactions 55:32–53

Key words Colonization, Desert bighorn sheep, home range, Nevada National Security Site, *Ovis canadensis nelsoni*, radionuclides, repatriation.

Prior to European colonization, desert bighorn sheep (*Ovis canadensis nelsoni*; hereafter referred to as sheep), were thought to have occurred in most, if not all, mountain ranges in southern and central Nevada, including the Nevada National Security Site

(NNSS) (formerly the Nevada Test Site [NTS]; Brewer et al. 2014). Most of these populations were extirpated by the mid-1900s, with respiratory disease from domestic sheep and goats thought to be a major contributor (Buechner 1960; Graham 1980; McCutchen 1995). Ranching and open-range grazing of cattle and sheep on the NNSS and surrounding areas began in the late 1800s (Fehner and Gosling 2000). In the early 1900s, several homesteads and mining camps with livestock were located on the NNSS, primarily at major perennial water sources such as Cane Spring, Twin Spring, Topopah Spring, Tippipah Spring, and Whiterock Spring.

Ecological studies have been conducted on the NNSS since 1960. In 1963, sheep or their sign were documented in the Spotted Range and low hills east of Frenchman Lake just southeast of the NNSS boundary (Jorgensen and Hayward 1965; Fig. 1). O'Farrell and Emery (1976) stated, "There are no authenticated sight records for bighorn sheep on NTS, but they are relatively abundant in mountain ranges to the east and they could easily wander onto NTS." Yucca Mountain Site characterization activities occurred throughout the 1980s and 1990s with no documented sheep sightings. Wills and Ostler (2001) reported that sheep were thought to be rare visitors on the site with a few observations near Mercury and did not appear to reside permanently anywhere on the NNSS. In fact, between 1964 and 2009, only 9 recorded sheep observations were made, and all but 1 were found in the southern part of the NNSS around Mercury, Rock Valley, Skull Mountain, and Topopah Spring. All observed sheep were male. Based on these sighting locations it was assumed that these males were from the translocated populations released in the Spotted Range (50 total in 1993 and 1996) and the Specter Range (44 total in 1990, 1993, and 1995). Evidence of a reproducing population on the NNSS was found during winter 2011, when a radio-collared female mountain lion (*Puma concolor*) killed and ate several females and young. This evidence was assumed to represent a repatriation of a viable sheep population back to the NNSS.

In response to this evidence, we initiated a collaborative effort involving the U.S. Geological Survey Western Ecological Research Center (USGS), Mission Support and Test Services (MSTS) (formerly National Security Technologies, LLC), and the Nevada Department of Wildlife (NDOW) to better understand this newly found population. Basic questions included its origin, home range, habitat use, population size, and health status given large-scale die-offs due to respiratory disease in sheep populations surrounding the NNSS. Other important information regarding the potential for sheep to contribute a radiological dose to humans via hunter harvest and potential radiological dose to the sheep was also required to comply with U.S. Department of Energy regulations (U.S. Department of Energy Order DOE O 458.1, Radiation Protection of the Public and the Environment). Between 1951 and 1992, over 900 nuclear tests were conducted on the NNSS and surrounding locations, resulting in some radiologically contaminated areas that pose a potential threat to wildlife and humans that may consume them. Sheep hunting occurs along the NNSS and Nevada Test and Training Range (NTTR) boundaries and on some portions of the NTTR well away from any contaminated areas, but animals have the potential to access some contaminated areas. This creates a potential, albeit low, risk of a radiologically contaminated sheep being consumed by members of the public.

Specific study objectives included: 1) determine home range sizes and movement patterns, 2) investigate the prevalence of pneumonia-causing bacteria, 3) estimate the minimum number of sheep in the study area,

4) identify the source(s) of the new population, and 5) conduct radiological analyses to quantify the radionuclide burden in sheep and estimate the potential radiological dose to humans via hunter harvest.

STUDY AREA

The NNSS is a 3,561-km^2 secure facility managed by the U.S. Department of Energy and located in south-central Nevada, about 105 km northwest of Las Vegas (Fig. 1). The site is in an area of southern Nevada that lies between the Great Basin Desert and the Mojave Desert as defined by Jaeger (1957). Transitional areas between the 2 deserts are present, having been created by gradients in precipitation, elevation, temperature, and soils. Unique combinations of physical site conditions have resulted in several different vegetation associations (Ostler et al. 2000). Based on these associations, 3 distinct vegetation regions occur on the NNSS: Great Basin Desert, Mojave Desert, and Transition regions. The Great Basin Desert region is a cold desert, dominant plant species consisted of sagebrush species (*Artemisia* spp.), singleleaf pinyon (*Pinus monophylla*), and

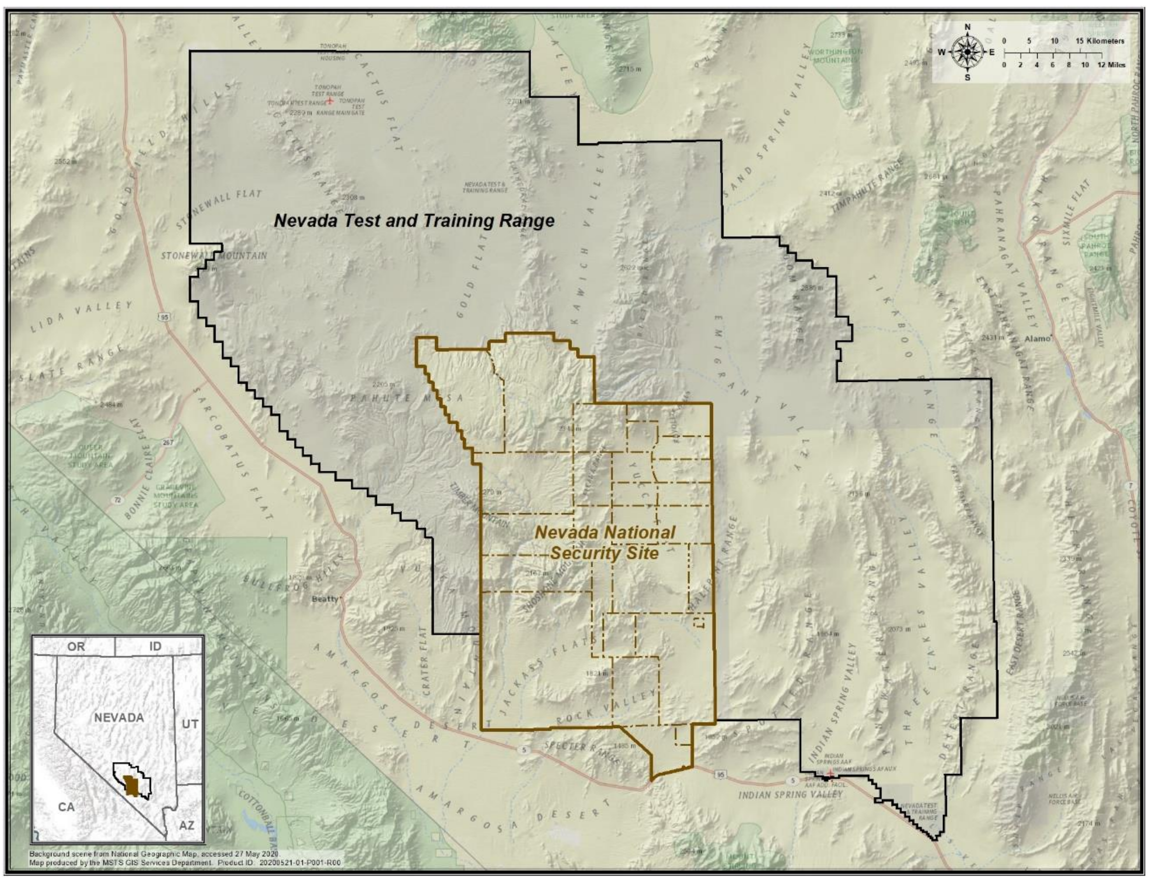

Figure 1. Nevada National Security Site (brown outline) and Nevada Test and Training Range (black outline) and surrounding mountain ranges.

Utah juniper (*Juniperus osteosperma*). The Mojave Desert region is a hot desert with dominant plant species of creosote bush (*Larrea tridentata*) and white bursage (*Ambrosia dumosa*). The Transition Zone is transitional between the Great Basin and Mojave Desert regions. Dominant plant species were blackbrush (*Coleogyne ramosissima*), Nevada jointfir (*Ephedra nevadensis*), and burrobrush (*Hymenoclea salsola;* Ostler et al. 2000). Elevation ranged from less than 1,000 m to 2,340 m. Mean maximum temperatures ranged from 32 to 38° C in the summer and from 10 to 16° C in the winter. Mean minimum temperatures ranged from 13 to 25° C in the summer and -7 to 2° C in the winter. At higher elevations, mostly in the northern NNSS, temperatures were 6 to 8° C cooler. Mean annual precipitation is 13 cm at the lower elevations and 33 cm at the higher elevations with nearly 50% of that falling between December and March in the form of rain or snow (Soule' 2006).

Land use and disturbance at the NNSS included several buildings at a few primary activity complexes, paved and dirt roads, and power infrastructure. Numerous craters, other disturbances, and some radiologically contaminated sites created from historic nuclear weapons testing activities. There has been no public access since the 1940s and less than 10% of the NNSS has been disturbed, leaving the remaining 90% in relatively pristine condition. Other ungulates present include mule deer (*Odocoileus hemionus*), elk (*Cervus elaphus*), pronghorn (*Antilocapra americana*), feral horses (*Equus caballus*), and feral burros (*Equus asinus*). Predators of sheep included mountain lions (*Puma concolor*), bobcats (*Lynx rufus*), coyotes (*Canis latrans*) and golden eagles (*Aquila chrysaetos*).

METHODS

Captures and Movements

We captured sheep in November 2015 and 2016 using a net-gun fired from a helicopter. We blindfolded, physically restrained, and fitted captured animals with Global Positioning System (GPS) collars with Iridium satellite uplink capability. Collars included a VHF radio transmitter, motion sensor, and auto-release mechanism. We programmed GPS collars to record 4 locations/day at 6-hour intervals, as well as at 1-hour intervals for the first 5 days of each month to obtain more fine-scale information on habitat use and movements. We ear-tagged sheep with unique color and alpha-numeric ear tag combinations to be able to identify individual sheep.

We also tested captured sheep for *Mycoplasma ovipneumoniae* (*M. ovi*), a pathogen associated with respiratory disease (Besser et al. 2012, Besser et al. 2014). We collected blood samples and nasopharyngeal swabs during capture and sent them to the Washington Animal Disease Diagnostic Lab (WADDL) using protocols established by WADDL. Tests to detect *M. ovi* included polymerase chain reaction (PCR) for presence of *M. ovi* (McAuliffe et al. 2003, Lawrence et al. 2010) and ELISA testing for current and past exposure to *M. ovi*. (Herrmann et al. 2003, Besser et al. 2012, Ziegler et al. 2014).

Core Use and Home Range Areas

We quantified relative intensity of space use by sheep using a utilization distribution (UD) calculated using kernel density estimation (KDE). We estimated both the core use and home range areas of each animal using a 50% and 90% (respectively) Gaussian KDE that was based on locations of collared sheep (Worton 1989). We calculated bandwidth for the KDE using smoothed cross-validation with a 10-m resolution grid to produce the home range extent (Geospatial Modeling

Environment 7.2.1). To make comparisons of core use areas between sexes and seasons over the same time period, we used animal locations obtained from February 2017 through January 2018. This provided movement data for 6 males and 6 females that were captured in November 2016 for analysis. One male died in April 2017 and data from this animal was not included in the core use or home range analysis. For overall home ranges we used data from November 2015 through April 2016 and November 2016 through April 2018. This included data for 8 females and 9 males captured in 2015 and 2016. For both core and overall home range areas, we analyzed differences between sexes within respective seasons and between seasons within sex. We used a repeated-measures ANOVA to address whether there were any differences in either core or overall home range use between seasons or between sexes within each respective season (Zolman 1993). We defined seasons as spring (February-May), summer (June-September), and fall-winter (October-January).

Probable Lambing Sites

We identified the potential lambing period on the NNSS as January through March based on aging lambs from photographs taken at water sources in the Pintwater Range located about 68 km east of our study area (K. Longshore, U.S. Geological Survey. unpublished data). Within this timeframe, we identified females on the NNSS that remained (> 5 locations) within a 100-m radius during a 72-hour period (Bangs et al. 2005). We defined individuals meeting these criteria as those exhibiting probable lambing behavior (Mahoney and Young 2017) and described the overall habitat at these sites (i.e., vegetation type, elevation, slope, topography, distance to water (m), and viewshed (ha)) using a GIS (ArcMap/ArcInfo 10.4). The parturition site identification procedure was validated using known parturition timing information from 9 female sheep from Zion National Park that were collared and fitted with vaginal implant transmitters (VITs) by the Utah Division of Wildlife Resources in the winter of 2018-2019. Parturition events noted by the VITs were then confirmed by a technician on the ground (Utah Division of Wildlife Resources, unpublished data Brianna Johnson, personal communication). The algorithm was able to appropriately identify 8 of these parturition events accurately.

Number of Animals Observed

We estimated the minimum number of sheep observed on the NNSS from digital images taken by camera traps during 2017 and 2018. We set motion-activated cameras at 6 of the known water sources in sheep habitat: Cottonwood Spring (ephemeral), Fortymile Canyon Tanks (ephemeral), Delirium Canyon Tanks (perennial), South Pah Canyon Tanks (ephemeral), Twin Spring (perennial), and Topopah Spring (perennial). Cameras recorded images 24-hours a day with a 1-minute interval minimum between images, and we downloaded images every 3-4 months. We analyzed images for the presence of sheep and, when possible, identified individual sheep using the unique combination of ear tags.

We also counted unmarked sheep, but because they could not be uniquely identified and potentially used >1 water source, we used the maximum number of each sex and age class (female, male, young) observed from any one photo. For example, between 1 and 4 young were observed in many photos from several water sources. We only included 4 in our observations because that was the maximum number in any one photo, even though there may have been more than 4 individuals. We added the maximum number of unmarked animals of each sex and age class to the marked animals.

Population Source

Based on proximity, there are several potential local sources for the sheep population on the NNSS. The closest are populations reintroduced into the Specter Range, Bare Mountain, Spotted Range, and Stonewall Mountain areas. Potential sources further away would be native populations in the Pintwater Range and the Sheep and Desert ranges (Fig. 1).

We investigated potential origins using genotyping data for 18 microsatellite loci from the Sheep, Desert, and Pintwater ranges (see Wehausen and Jaeger 2016 for details). We developed additional genotype data for the same loci for: blood samples from sheep caught in the Yucca Mountain region of NNSS and NTTR and further north and west in the NTTR on Stonewall Mountain and Bare Mountain; from tissue samples from lion-killed sheep on the NNSS in the Fortymile Canyon region (5 samples) and Bare Mountain (2 samples) from 2011; and from sheep fecal samples from the Specter Range. We could not investigate sheep in the Spotted Range as a potential source because they were reintroduced from translocations from the River Mountains, a source of translocations also to the Specter Range, Bare Mountain, and Stonewall Mountain (Table 1). We split the NNSS and NTTR samples geographically into 2 populations for analyses, with 8 northern blood samples from sheep captured near Stonewall Mountain (Thirsty Canyon, Pahute Mesa, Obsidian Butte, and Mount Helen) separated from the more southern blood samples and all the tissue samples (Table 2).

We investigated genetic population structure in 2 ways. First, we developed a matrix of pairwise F_{ST} values from which estimates of gene flow (Nm) were calculated (see Wehausen and Jaeger 2016). F_{ST} is the proportion of the total genetic variance contained in a subpopulation (the S subscript) relative to the total genetic variance (the T subscript). Values can range from 0 to 1. A high F_{ST} value implies an extensive degree of differentiation among populations. This provided a relative picture of which population pairs had more gene flow. Second was the application of the program STRUCTURE (Pritchard et al. 2000), which clusters individual genotypes into varying numbers of populations specified by the user. This Markov Chain Monte Carlo simulation program assigns probabilities for each individual to each of the different clusters as sources of the individual genotypes. The program summarizes results on a population basis. STRUCTURE was run for increasing numbers of burnin and post-burnin generations until 5 repeated runs yielded very similar output patterns indicating good convergence. This was done for 8 clusters (K = 8) matching the number of input populations in the data set (Table 2). We then reran the analysis for declining K values.

Radiological Analyses

We collected blood samples in 2015 from 6 sheep captured on the NNSS and 8 sheep captured on the NTTR (5 from Cactus Range and 3 from Stonewall Mountain) to quantify their radionuclide burden. We collected additional blood samples from 6 California bighorn sheep (*O. c. californiana*) from northern Nevada to use as control samples (no radiologically-contaminated areas) for the NNSS and NTTR samples. We sent samples to commercial laboratories for radiological analyses. Analyses were performed on the 20 samples to determine the presence or absence and quantities of gamma-emitting radionuclides, tritium, Americium (Am)-241, Strontium (Sr)-90, Plutonium (Pu)-238, and Pu-239+240. We reported values that are above the minimum detectable concentration (MDC). This is the concentration at which a sample can be quantitatively distinguished from a blank sample and includes uncertainties from back-

Table 1. Translocation history of desert bighorn sheep populations adjacent to the Nevada National Security Site.

Recipient population	Source population	Year	No. of Sheep
Stonewall Mountain	River Mountains	1975	8
	Corn Creek (Sheep Range)	1975	4
	River Mountains	1977	13
	River Mountains	1983	10
Specter Range	River Mountains	1990	9
	Muddy Mountains	1990	10
	Muddy Mountains	1993	20
	River Mountains	1995	5
Bare Mountain	Black Mountain	1991	20
	Muddy Mountains	1993	18
	River Mountains	1995	5

Table 2. Number of samples used (*n*) by geographic area to assess relatedness in desert bighorn sheep populations throughout southern Nevada.

Population	*n*	Population	*n*
Stonewall Mountain	25	Specter Range	10
NTTR North	8	Pintwater Range	37
NNSS & NTTR South	22	Woody Guzzler & Enclosure Ridge	38
Bare Mountain	21	Cow Camp & Desert Range	48

ground radiation, sample size, counting time, and chemical recovery. We used a one-way ANOVA to determine any significant differences ($P \leq 0.05$) in radionuclide concentrations among the NNSS, NTTR, and northern Nevada samples. We reported dose to humans using the unit of millirem and dose to sheep using the unit of millirad.

We collected 4 additional opportunistic samples from sheep on the NNSS and NTTR for radiological analysis. Three of these were obtained from mountain lion kills on the NTTR during 2013. Only 1 had enough muscle tissue remaining to sample for all the radionuclides listed above, and the other 2 were analyzed for tritium only. We collected another tissue sample from a male that died of unknown natural causes in April 2017 in Fortymile Canyon on the NNSS. This sample was analyzed for all the radionuclides listed above. No statistical analyses were performed on these 4 opportunistic samples.

RESULTS

In the first of 2 capture efforts, 6 sheep (2 females, 4 males) were captured and 5 (2 females, 3 males) were radio collared on the NNSS during November 2015. The females and 2 males were captured near the central-west part of the NNSS near Yucca Mountain and Fortymile Canyon, and the remaining 2 males were captured about 20 km east on

Shoshone Mountain. One male was too young to be fitted with a collar but was ear-tagged. The 5 collared sheep were tracked for < 6 months until a programming error by the manufacturer caused the collar to release in early May 2016. One male was legally harvested off the NNSS, north of Bare Mountain during fall 2016. In November 2016, 15 sheep (8 males and 7 females) were captured. Thirteen animals (7 males, 6 females) were fitted with GPS collars and released on site after processing. One male and 1 female were too young for collars and were fitted with ear tags. One radio-collared male died in early April 2017, and another ear-tagged (not collared) female died in August 2018. The causes of death were unknown, however there was no evidence of predation or scavenging. The remaining collars dropped off between May and September 2018.

Core Use and Home Range Areas

Male core areas were 3.7 times larger than females during summer ($F_{1,10}$ = 5.12, P = 0.047), whereas female core areas were 2.5 times larger than males during spring ($F_{1,10}$ = 9.01, P = 0.013; Table 3). Core area range size did not differ between males and females during fall-winter ($F_{1,10}$ = 3.27, P = 0.10). Female core areas were respectively 3.4 and 8.4 times larger in spring than during summer and fall-winter ($F_{1,2}$ = 10.19, P <0.001; Table 3). Most of the female summer activity focused around Cottonwood Spring, an ephemeral water source. Males used the largest core areas during summer however, due to high variability among some males, we found no difference among seasons ($F_{1,2}$ = 3.91, P = 0.115; Table 3).

Our analysis of overall home ranges yielded similar results: male home ranges were 3.3 times larger than females during summer ($F_{1,10}$ = 8.50, P = 0.012), and female home ranges were 1.8 times larger than males during spring ($F_{1,10}$ = 7.50, P = 0.021; Table 3). No difference was found between males and females in fall-winter ($F_{1,10}$ = 0.95, P = 0.353). Female home ranges were 1.9 and 2.5 times larger in spring than during summer and fall-winter, respectively (overall: $F_{1,2}$ = 16.35, P <0.001). Male home ranges did not significantly differ between seasons, again likely due to the high variability among individuals ($F_{1,2}$ = 3.08, P = 0.154; Table 3).

Probable Lambing Sites

Among collared females, clustering occurred in January or February of all 3 years. We found 69 GPS locations among all 8 females displaying potential lambing (parturition) behavior at 10 separate cluster sites. Seven sites were within the NNSS and the remaining 3 were along the western border of the NTTR and NNSS. All 8 females exhibited clustering behavior only once during a particular lambing season. However, two cluster locations were used by females in multiple lambing seasons.

Our sample size was too small to construct a model of lambing habitat on a landscape scale, so we provide summary data to describe terrain characteristics at lambing sites. In general, probable lambing sites consisted of relatively steep and rugged areas of low visibility (Table 4). Average percent slope was 73.1 (± 31 SD); only two females were in locations with slope values below 48% (47.9 and 25.8, respectively). The average ruggedness index, 1.29 ± 1.531 SD, (x 100) was high, but variable, especially due to one female who had a maximum value of 7.41 (range among all eight was 7.36). Elevation ranged from 1,344 m to 1,788 m. Probable lambing sites were in 4 of the 5 vegetation classes including upper elevation associations (46.4% of total cluster locations), lower elevation shrub (23.2%), cliff-sparse (21.7%), and sagebrush associations (8.7%). Distance to water was less <200 m to > 8.8 km from water sources

Table 3. Seasonal core use (50% probability) (February 2017 through January 2018) and overall home range (90% probability) (December 2015 through April 2016 and December 2016 through April 2018) areas (km^2) for female and male desert bighorn sheep within the Nevada National Security Site.

Sex	*n*	Season	Mean	SD[1]	Min	Max
Female (50%)	6	Spring[2]	43.5	15.4	19.3	59.1
Female (90%)	8	Spring	128.4	26.2	86.7	156.7
Female (50%)	6	Summer[3]	12.9	12.8	2.1	31.1
Female (90%)	8	Summer	67.1	28.5	23.9	98.7
Female (50%)	6	Fall-Winter[4]	5.2	2.1	1.9	7.8
Female (90%)	8	Fall-Winter	50.7	8.9	23.9	98.6
Male (50%)	6	Spring	17.5	14.5	2.8	36.8
Male (90%)	9	Spring	70.7	44.3	15.3	137.7
Male (50%)	6	Summer	47.1	34.6	9.5	105.9
Male (90%)	9	Summer	221.1	126.7	101.5	459.5
Male (50%)	6	Fall-Winter	11.5	8.4	2.4	24.7
Male (90%)	9	Fall-Winter	70.9	50.1	25.2	160.6

[1]SD = standard deviation around the mean.
[2]Spring = Feb through May
[3]Summer = Jun through Sep.
[4]Fall-Winter = Oct through Jan.

Table 4. Habitat characteristics at 8 probable lambing sites located within the Nevada National Security Site, 2016–2018.

Habitat Variable	Minimum	Maximum	Mean	SD
Elevation (m)	1343.9	1788.3	1541.0	131.7
Slope (percentage)	12.1	181.4	73.1	31.0
Profile curvature	-16.362	25.924	0.083	7.498
Planform curvature	-5.671	17.632	1.134	4.325
Ruggedness (index)	0.046	7.409	1.297	1.531
Distance to water (m)	191.0	8842.0	3119.9	2628.3
Viewshed (hectare)	0.16	1.37	0.685	0.265

Disease

Disease testing revealed that a majority of NNSS sheep either had *M. ovi* present or had been exposed to the bacteria. Of 18 sheep sampled for disease on the NNSS during 2015 and 2016, 12 had an immune response to *M. ovi*, indicating that they had been exposed to the bacteria, and 5 of the 9 sheep sampled in 2016 had the bacteria present.

Number of Animals Observed

A camera trap was set at Twin Spring (perennial water) in May 2011, but sheep were not detected until October 2014. A camera trap was set at Cottonwood Spring (ephemeral water) in July 2013, but sheep were not detected until summer 2016. A camera trap was set at Topopah Spring in December 2008 and sheep were detected in June 2009. Only males have been detected at this spring in most years since 2009. Camera traps were set at Delirium Canyon Tanks and South Pah Canyon Tanks in March 2014, and sheep were detected in April and June 2014, respectively. A camera trap was set at Fortymile Canyon Tanks in October 2017, and sheep were detected in February 2018.

Thirteen radio-collared or ear-tagged sheep were detected with camera traps in 2017, including 8 females and 5 males. In addition, at least 7 unmarked sheep (3 female, 2 male, and 2 young) were detected yielding a minimum of 20 sheep detected during 2017. Camera traps also detected 13 marked sheep (8 female and 5 male) during 2018. At least an additional 11 unmarked sheep (4 female, 3 male and 4 young) were detected during 2018. Consequently, we estimated a minimum of 20 (11 female, 7 male, 2 young) and 24 (12 female, 8 male, 4 young) sheep were found on the NNSS in 2017 and 2018, respectively.

Population Source

F_{ST} values suggested differences between the northern and southern NNSS and NTTR samples in sources of microsatellite alleles. The northern sample exhibited a strong connection with the adjacent Stonewall Mountain sample with gene flow between those 2 populations estimated at about 4 times that as between the northern NTTR sample and Bare Mountain or Specter Range samples. Gene flow estimates between the northern NTTR sample and the more distant samples from the Pintwater, Desert, and Sheep ranges were similarly low compared with Stonewall Mountain (Table 5).

In contrast, the highest estimated gene flow for the southern sample was with Bare Mountain, followed by the Specter Range, then Stonewall Mountain. It is noteworthy that estimated gene flow between the northern and southern samples was equivalent to that between the southern sample and the Specter Range, while those between the southern sample and samples from the Pintwater, Desert, and Sheep ranges were lowest (Table 5).

Runs of program STRUCTURE met convergence criteria for 50,000 generations burnin and 250,000 generations post burnin. Results for K = 8 clusters corroborated the estimated gene flow patterns from pairwise F_{ST} values: the northern NTTR sample clustered most with the Stonewall Mountain sample (cluster 2), while the southern sample clustered most with the Bare and Specter range samples (cluster 1; Table 6).

Clusters 1 and 2 included consistently very low probabilities of membership for samples from the Pintwater, Desert, and Sheep ranges (Table 6). This reflects an earlier finding that gene flow estimates from F_{ST} values of about 2 and lower may actually represent such low gene flow that they can be regarded as essentially zero (Jaeger and Wehausen 2012). Cluster 1 similarly suggested a lack of gene flow between the southern sample and Stonewall Mountain. In contrast, clusters 1 and 2 corroborate the F_{ST} results that indicate considerable gene flow

Table 5. Pairwise F_{ST} and gene flow values (F_{ST} / Nm) between Nevada National Security Site samples and potential local sources of gene migration. Gene flow estimates calculated from F_{ST} values are bidirectional in units of migrants per generation. Woody Guzzler and Enclosure Ridge represent sheep at the northern end of the Sheep Range. Cow Camp and the Desert Range represent sheep at the southern end of the Sheep Range.

Population	NNSS & NTTR South	NTTR North
NTTR North	0.0531 / 4.4	
Bare Mountain	0.0388 / 6.2	0.1237 / 1.8
Stonewall Mountain	0.0693 / 3.4	0.0292 / 8.3
Specter Range	0.0542 / 4.4	0.1030 / 2.2
Woody Guzzler & Enclosure Ridge	0.1147 / 1.9	0.1044 / 2.1
Cow Camp & Desert Range	0.1163 / 1.9	0.0820 / 2.8
Pintwater Range	0.1248 / 1.8	0.1365 / 1.6

Table 6. STRUCTURE results for K = 8 clusters. Values are average probabilities for each sample of belonging to each cluster, and values across each row add to 1.0.

	CLUSTER							
Sample	1	2	3	4	5	6	7	8
South	0.750	0.198	0.006	0.011	0.008	0.010	0.008	0.009
North	0.049	0.873	0.008	0.009	0.016	0.017	0.012	0.015
Bare	0.937	0.021	0.006	0.007	0.006	0.012	0.006	0.006
Stonewall	0.013	0.954	0.005	0.006	0.006	0.004	0.006	0.006
Specter	0.810	0.089	0.010	0.017	0.017	0.021	0.024	0.012
WG&ER[1]	0.011	0.007	0.020	0.456	0.278	0.017	0.036	0.175
CC&DR[2]	0.009	0.017	0.067	0.028	0.024	0.165	0.476	0.214
Pintwater	0.009	0.029	0.880	0.016	0.014	0.011	0.019	0.023

1WG&ER = Woody Guzzler and Enclosure Ridge
[2]CC&DR = Cow Camp and Desert Range

between the northern and southern samples.

When a STRUCTURE analysis was run for K = 7 clusters, the northern and southern samples clustered together along with the Stonewall, Bare, and Specter samples, but the 2 samples from the Sheep and Desert ranges did not cluster together (Table 7). This indicates that gene flow between the northern and southern samples is greater than between the 2 samples from the Sheep and Desert ranges.

Radiological Analyses

Only 2 human-made radionuclides were detected in the 20 samples, Pu-238 and Pu-239+240, albeit at extremely low levels (Appendix 1). There was no significant difference among Pu concentrations in sheep

Table 7. STRUCTURE results for K = 7 clusters. Values are average probabilities for each sample belonging to each cluster, and values across each row add to 1.0.

	CLUSTER						
Sample	1	2	3	4	5	6	7
South	0.949	0.006	0.007	0.010	0.008	0.011	0.008
North	0.889	0.007	0.028	0.019	0.016	0.010	0.030
Bare	0.957	0.006	0.005	0.013	0.005	0.008	0.005
Stonewall	0.946	0.007	0.012	0.007	0.011	0.007	0.010
Specter	0.905	0.010	0.018	0.016	0.019	0.022	0.011
WG&ER[1]	0.010	0.021	0.277	0.017	0.038	0.456	0.181
CC&DR[2]	0.012	0.066	0.023	0.173	0.483	0.026	0.217
Pintwater	0.027	0.891	0.014	0.011	0.020	0.016	0.023

[1]WG&ER = Woody Guzzler and Enclosure Ridge
[2]CC&DR = Cow Camp and Desert Range

from northern Nevada, NTTR, or NNSS (Pu-238, $F_{2, 17} = 2.80$, $P = 0.09$; Pu-239+240, $F_{2, 17} = 1.23$, $P = 0.32$). Differences in Pu-238 concentrations approached significance between NTTR and northern Nevada samples. Regarding the four opportunistic samples, no radionuclides were detected above MDC (Warren and McMahon 2014) in the 3 sheep from the NTTR, but Pu-238, Pu-239+240, and Am-241 were detected in the male found dead in Fortymile Canyon, albeit in very low concentrations.

DISCUSSION

Although it is difficult to know the repatriation history of sheep on the NNSS, our collection of data from genetic analysis, historical observations, mountain lion study, camera traps, and sheep observations provided insight into the potential timing of sheep colonization and expansion on the NNSS. Observational data suggest that males from transplanted populations on Bare Mountain (within 24 km of our study area), Specter Range (within 32 km of our study area), Stonewall Mountain (within 72 km of our study area), and possibly the Spotted Range (within 53 km of our study area) were the first to colonize the NNSS from about the mid-1990s to 2009. Timing of the arrival of females and young is unknown but occurred no later than winter 2011. Genetic data identified the source of the new population to be sheep moving from Bare Mountain, the Specter Range, and Stonewall Mountain into the western portion of the NNSS. Although camera trap data and helicopter searches conducted during capture efforts indicated a relatively small population before 2014, there appeared to be a pulse of new individuals arriving on the NNSS between 2015 and 2016. By 2018, there was a growing, reproductive population of a minimum of 24 sheep inhabiting the NNSS, primarily occupying Shoshone Mountain, Yucca Mountain, and Fortymile Canyon, with a few sheep also found on the southern flank of Pahute Mesa on the western edge of the NNSS. Observational and genetic results suggest this increase in population from 2009 to 2018 was likely supported by the earlier translocation efforts within the surrounding mountain ranges. Radio-collared females and some males occupied Shoshone Mountain, Yucca Mountain, and Fortymile Canyon, while a few males ranged farther to Bare

Mountain, Thirsty Canyon, Quartz Mountain, and Black Mountain.

Until recently, bighorn sheep were thought to be poor colonizers of new habitat (Geist 1971, McQuivey 1978; Bleich et al. 1996). Males, and occasionally females, were known to make exploratory forays, but these were typically into contiguous habitat already occupied by bighorn sheep (Geist 1971, Holl and Bleich 1983, Festa-Bianchet 1986, Bleich et al. 1996, Singer et al. 2000). More recently however, genetic analyses have made colonization events easier to identify (Epps et al. 2004, Epps et al. 2010). Unaided colonization of unoccupied habitat patches is now well-documented for desert bighorn sheep in California (Bleich et al. 1996, Epps et al. 2004, Epps et al. 2010), although recolonization has not been well-documented in Nevada. In response to the loss of sheep populations in Nevada, most historical habitat has been repopulated through reintroductions or translocations (Jahner et al. 2019). The translocation of bighorn sheep into surrounding habitat has allowed for exploration and successful colonization of unoccupied habitat in the NNSS.

Five of the 8 clusters denoted as probable lamb parturition sites of our radio-collared female sheep were actually located on the NNSS. Although we were not able to visit these sites, we feel that our methods for examining female movements provides information to suggest that parturition is occurring on the NNSS. All clusters denoted as probable lamb parturition sites faced south, although each had its own details of terrain. Terrain variables are comparable to those described by Bangs et al. (2005) and Karsch et al. (2016). All 8 sites were less than 100 m from either a steeper and/or a more rugged terrain available for escape. Given the position of the clusters, we speculate that these locations were chosen based on difficulty of terrain for predators and ease of sight for the mother (Karsch et al. 2016). However, we did not speculate what the predation rate might have been (Cain et al. 2019).

Camera trap data showed that natural water tanks and springs on the NNSS are providing drinking sources especially during the dry summer months. This use by sheep suggests maintaining these water sources may be important. The differential use of waters by sexes implies waters may be used differently. For example, only males were detected at Topopah and Twin springs. These 2 waters are located on lower slopes that do not provide as much escape terrain as the other water sources we monitored and may not be available to females who are less likely to travel farther from escape terrain (Bleich et al 1997).

The identification of home ranges is an additional indicator that sheep have recolonized the NNSS. Overall, male sheep on the NNSS had much larger home ranges than females, except during spring, when females used larger areas than did males. This difference in overall home range size between sexes is well documented for bighorn sheep (Leslie and Douglas 1979, Krausman et al. 1989, Longshore and Douglas 1995, Bleich et al. 1997). Females used larger core areas (50% utilization) and overall home ranges (90%) during spring than those used during summer and fall-winter. Females may take advantage of the increasing green-up occurring during spring months (Monteith et al. 2011). Core use was relatively restricted during summer for females, with most of the activity focused around Cottonwood Spring during 2017. Males increased home range size during summer, which coincided with the mating season (Bleich et al. 1997). Variability in size of seasonal home range and core use areas has been attributed to differences in resource availability (Leslie and Douglas 1979, Krausman et al. 1989, Bleich et al. 1997, Oehler et al. 2003). Seasonal home range sizes are known to vary among sheep populations across the arid southwest (Leslie and Douglas 1979, Krausman et al. 1989, Longshore and Douglas 1995, Bleich et al. 1997, Oehler et al. 2003). However, without quantitative assessments of resource quality for each population, comparisons among populations is difficult.

Respiratory disease exposure seems prevalent on the NNSS. Nearly 70% of the 18 sheep sampled for *M. ovi.* showed an immune response and several had the bacteria present. Based on movement patterns from radio-collared sheep on the NNSS and NTTR captures (Mike Cox, Nevada Department of Wildlife, personal communication), disease transmission is highly likely among populations from NNSS and Bare Mountain to the Cactus Range on the NTTR among mountain ranges. Genetic analyses and collar data show little movement of sheep from east of the NNSS (e.g., Spotted Range, Pintwater Range, Sheep Range) onto or west of the NNSS. This separation may prevent disease transmission among these populations. Continued monitoring of sheep on the NNSS could provide data to assess impacts of *M. ovi* on this population.

Sheep exposure to human-made radionuclides in our study was limited with only Pu-238 and Pu-239+240 detected. Exposure was similar among samples from NNSS, NTTR, and northern Nevada suggesting the source of radionuclides in the sheep is from global fallout. The major source of plutonium world-wide is attributed to global fallout from atmospheric nuclear weapons tests conducted by both the United States and other countries (former Soviet Union, United Kingdom, France and China) (UNSCEAR 2008). In addition, in 1964, the SNAP-9A navigational satellite accident dispersed roughly 1 kg of Pu-238 across the world (Hardy et al. 1972). This is a small amount distributed over a vast area, but combined with plutonium from atmospheric weapons tests, it is detectable even to very low levels. Thus, it is not surprising to find low concentrations of plutonium in samples from all areas including the northern Nevada control samples.

Sheep from NNSS or NTTR have radionuclide concentrations that are barely detectable and do not pose a hazard to anyone consuming them or to the sheep. If each sheep yields 35.4 kg of boneless meat, and 1 person consumed the entire amount with the maximum observed concentration, the dose received would be 0.06 millirem (mrem). If a person ate all 20 sheep they would receive an accumulated dose of about 1.1 mrem. These doses are orders of magnitude less than the 100 mrem/year radiation dose limit set to protect members of the general public from all possible pathways from NNSS activities (U.S. Department of Energy Order DOE O 458.1, Radiation Protection of the Public and the Environment). In addition, a radiological dose limit for terrestrial animals has been set at 100 mrad/day by U.S. Department of Energy's Biota Dose Assessment Committee (U.S. Department of Energy 2019). The estimated dose for the male that died in Fortymile Canyon for all 3 detected radionuclides combined was only 0.0002 mrad/day, well below the dose limit of 100mrad/day considered harmful to sheep and other biota (Warren and Smith 2018). Further, few radiologically-contaminated sites occur in sheep habitat, and based on the sheep locations from radio-collared sheep, they spend little time at contaminated sites (Fig. 2). One unmarked male was photographed using a contaminated sump in Area 20 of the NNSS but only for a short time (Hall and Perry 2018). This is the only detection of a sheep using a contaminated sump. Thus, the risk of sheep receiving large doses of harmful radiation is very low. Brown et al. (1976) studied radionuclide burden in sheep from southern Nevada and the Desert National Wildlife Refuge in the

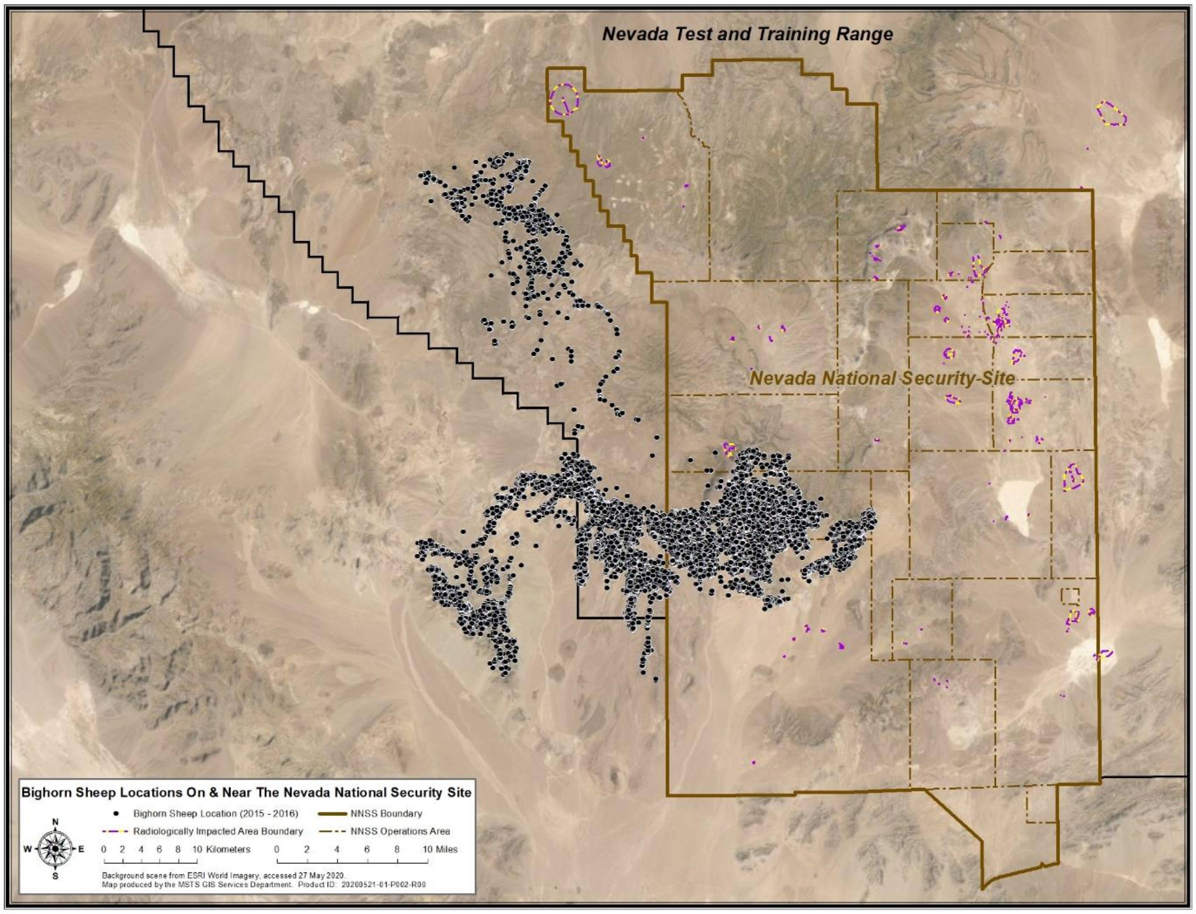

Figure 2. Desert bighorn sheep locations from telemetry data in relation to known contamination areas on the NNSS**.**

early 1970s from hunter harvested sheep using bone, liver, kidney and lung tissue rather than blood. They detected tritium, Sr-90, Pu-238, and Pu 239+240 in low concentrations, and similar to our results, concluded that the consumption of these animals poses little hazard to the public and that insufficient data were available to draw any conclusions on effects to the sheep. No pathological lesions were found at necropsy that could be attributed to ionizing radiation. In our studies, no external evidence of tumors or cancer-related symptoms were observed although detailed necropsies were not conducted. Other NNSS studies of radiation effects on wildlife have yielded similar results with doses well below the 100 mrad/day limit considered to be harmful (Warren et al. 2014, Hall et al. 2017, Warren and Smith 2018, Warren and Smith 2019).

MANAGEMENT IMPLICATIONS

Sheep are increasing and there are a number of reproducing females on the NNSS. Continued monitoring of this population may be important as the population faces risks. Respiratory disease is prevalent, and mountain lion predation may have a directional effect on the small population. This small population may play an important role in other conservation decisions.

To conserve this sheep population, land management decisions may become more important. Maintenance of existing waters and possible increased provisioning may be important. Knowledge of this newly discovered reproductive population of sheep on the NNSS and their habitat use can inform land managers' decisions so they could protect critical areas such as lambing sites and water sources from future development and include sheep and their habitat needs in resource management planning and decision-making.

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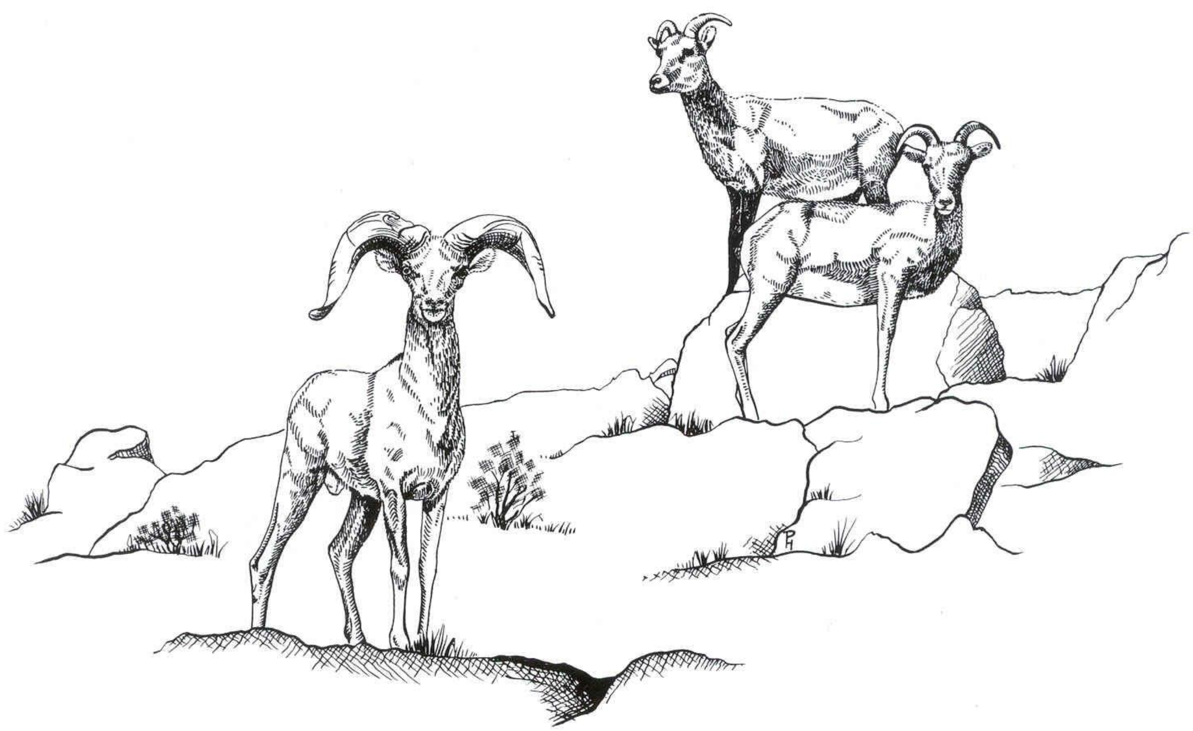


Appendix 1. Results of radiological analyses from blood samples taken from 20 bighorn sheep from northern Nevada, Nevada National Security Site, and Nevada Test and Training Range, 2015 (bold font indicates detectable levels; pCi/g = picocuries/gram).

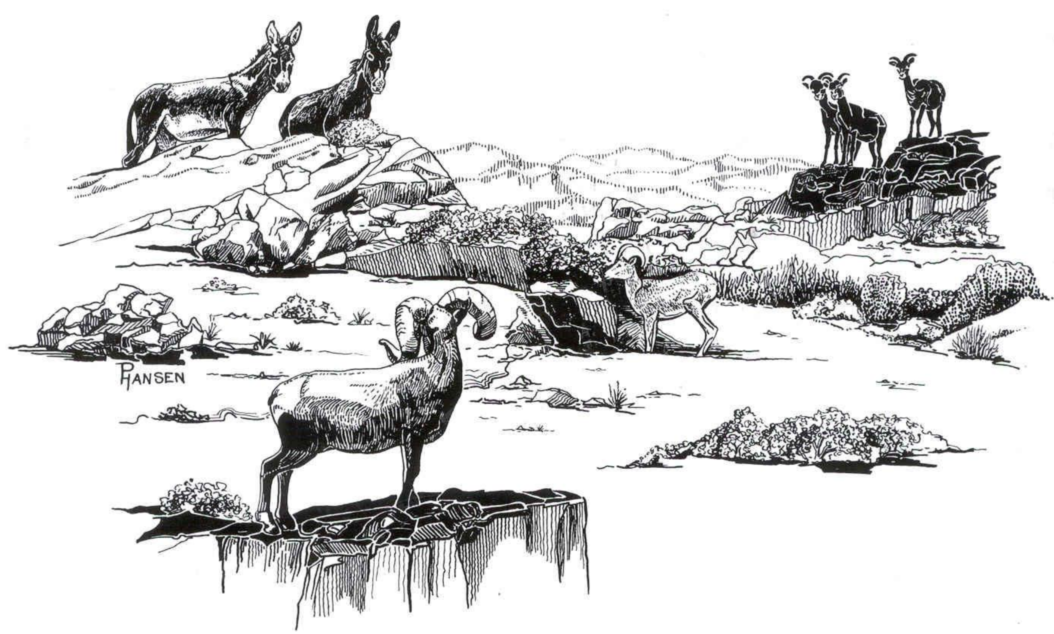
				^{238}Pu (pCi/g)[a]			$^{239+240}$Pu (pCi/g)[a]		
AREA	Capture Date	SAMPLE ID	NDOW Tag Number	Result	Uncertainty[b]	MDC[c]	Result	Uncertainty[b]	MDC[c]
Northern Nevada (Snowstorm Mts.)	12/1/2015	EM25569	3734	0.00051	0.00054	0.00073	0.00039	0.00049	0.00073
Northern Nevada (Trout Creek Mts.)	12/1/2015	EM25570	10191	0.00042	0.00046	0.00068	**0.00061**	**0.00047**	**0.00024**
Northern Nevada (Montana Mts.)	12/1/2015	EM25571	10192	**0.00055**	**0.00045**	**0.00025**	0.00049	0.00047	0.00057
Northern Nevada (Montana Mts.)	12/1/2015	EM25572	10193	**0.00050**	**0.00045**	**0.00027**	0.00018	0.00040	0.00078
Northern Nevada (Montana Mts.)	12/1/2015	EM25573	10194	0.00015	0.00035	0.00067	0.00034	0.00035	0.00023
Northern Nevada (Santa Rosa Range)	12/1/2015	EM25568	10196	0.00000	0.00054	0.00133	0.00042	0.00052	0.00078
NNSS (Area 25)	11/17/2015	EM25448	NNSS10171	0.00052	0.00050	0.00070	0.00011	0.00036	0.00080
NNSS (Area 25)	11/17/2015	EM25449	NNSS10172	0.00011	0.00225	0.00498	**0.00445**	**0.00322**	**0.00151**
NNSS (Area 29)	11/18/2015	EM25450	NNSS10174	0.00027	0.00042	0.00076	**0.00063**	**0.00050**	**0.00054**
NNSS (Area 25)	11/17/2015	EM25451	NNSS10175	0.00108	0.00088	0.00108	0.00047	0.00058	0.00087
NNSS (Area 25)	11/17/2015	EM25452	NNSS10177	0.00000	0.00039	0.00026	0.00039	0.00039	0.00026
NNSS (Area 25)	11/17/2015	EM25453	NNSS10179	0.00023	0.00035	0.00063	0.00032	0.00033	0.00022
NTTR (Cactus Range)	11/14/2015	EM25440	NTTR10071	0.00049	0.00062	0.00103	**0.00316**	**0.00132**	**0.00073**
NTTR (Cactus Range)	11/14/2015	EM25441	NTTR10072	0.00064	0.00125	0.00244	**0.00123**	**0.00112**	**0.00067**
NTTR (Cactus Range)	11/14/2015	EM25442	NTTR10073	0.00107	0.00180	0.00281	0.00240	0.00227	0.00280
NTTR (Cactus Range)	11/14/2015	EM25443	NTTR10074	**0.00157**	**0.00142**	**0.00085**	0.00244	0.00199	0.00244
NTTR (Cactus Range)	11/14/2015	EM25444	NTTR10076	**0.00073**	**0.00058**	**0.00062**	0.00002	0.00040	0.00088

NTTR (Stonewall Mt.)	11/14/2015	EM25445	NTTR10079	0.00035	0.00177	0.00341	0.00079	0.00177	0.00341
NTTR (Stonewall Mt.)	11/14/2015	EM25446	NTTR10080	0.00045	0.00048	0.00064	0.00039	0.00049	0.00079
NTTR (Stonewall Mt.)	11/14/2015	EM25447	NTTR10086	0.00066	0.00058	0.00076	**0.00068**	**0.00052**	**0.00026**

[a] picocuries per gram wet-weight of blood

[b] Uncertainty = 2 standard deviations of analytical uncertainty

[c] minimum detectable concentration. This is the concentration at which a sample can be quantitatively distinguished from a blank sample (includes uncertainties from background radiation, sample size, counting time, and chemical recovery).



Suspected occurrence of caseous lymphadenitis in a desert bighorn sheep

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Abstract The fresh carcass of a free-ranging desert bighorn sheep was discovered in the Palen Range, Riverside County, California. Gross examination revealed a voluminous, purulent discharge from the area of the thoracic inlet and yielded a tentative, albeit unconfirmed, diagnosis of caseous lymphadenitis. This bacterial disease is common in domestic sheep and other small ruminants. Caseous lymphadenitis recently was described in a Rocky Mountain bighorn sheep from Utah but, to the best of my knowledge, has not been reported in desert bighorn sheep. Discovery of this desert bighorn sheep exhibiting clinical signs consistent with a diagnosis of caseous lymphadenitis raises several questions worthy of further consideration.

Desert Bighorn Council Transactions 55:54–59

Key words bighorn sheep, California, caseous lymphadenitis, *Corynebacterium pseudotuberculosis*, disease, domestic sheep, mineral deficiency, *Ovis canadensis*

Caseous lymphadenitis is an important bacterial disease of small ruminants in general (Biberstein 1990), and especially of domestic sheep (Davis 1990). The probable causal organism (*Corynebacterium pseudotuberculosis*) is a facultatively anaerobic wound contaminant that may survive for long periods in the soil, even when exposed to direct sunlight (Davis 1990, Spier et al. 2012). The organism enters the body through an opening in the skin (Biberstein 1990, Davis 1990), but arthropods might also be vectors (Biberstein 1990, Barba et al. 2015). In small ruminants, the condition manifests as abscessation of peripheral lymph nodes and, in some cases, abscesses in the lungs, liver, kidneys, and spleen also are observed (Williamson 2001).

There have been reports of caseous lymphadenitis from native North American bovids, antilocaprids, and cervids, as well as other taxa of wild ruminants or tylopods around the globe (Seghetti and McKenney 1941, Clark et al. 1972, Stauber et al. 1973, Muller et al. 2011, Wernery and Kinne 2016, Morales et al. 2017, Kelly et al. 2018). The disease is not rare in wildlife, and may be endemic in some populations of small ruminants (Colom-Cadena et al. 2014). Origins of such infections remain uncertain, however, and in wild settings have the potential to threaten population persistence (Pepin and Paton 2009, Morales et al. 2017).

In western North America, caseous lymphadenitis is not likely to be transmitted to bighorn sheep (*Ovis canadensis*) in the absence of grazing by domestic sheep (Spraker and Adrian 1990). Indeed, the only incident of which I am aware occurred in a Rocky Mountain bighorn sheep (*O. c. canadensis*) from Utah (Kelly et al. 2018). In this note I describe the suspected occurrence of caseous lymphadenitis in a wild, free-ranging desert bighorn sheep (*O. c. nelsoni*), discuss the ramifications of that observation in the context of ecology and population persistence, and raise some questions worthy of further consideration.

I received a report from H.J. Holshuh, DVM (*in litt.*) describing the carcass of a female bighorn sheep that he encountered in the Palen Range (33°48' N, 115°04' W), Riverside County, California, on 17 January 1988. Post-mortem autolysis was minimal, and a large, open wound on the animal's chest secreted a voluminous thick, purulent, and greenish exudate (Fig. 1); aside from abrasions on the right shoulder, no other external evidence of trauma or disease was apparent. Holshuh estimated the animal to weigh 40 kg, and the presence of deciduous canines indicated it was 3 years-of-age (Deming 1952). Body weight was substantially less than that of mature female desert bighorn sheep from Nevada ($\bar{x}$ = 44.0 kg), Arizona ($\bar{x}$ = 54.0 kg), or elsewhere in California ($\bar{x}$ = 47.9 kg) (Blood et al. 1970, Bleich et al. 1997), suggesting its fat reserves had been exhausted (Riney 1960). Holshuh came upon the carcass in a remote area while on a recreational outing during inclement weather and neither necropsy nor bacteriological sampling was possible, but he suspected caseous lymphadenitis as contributing to the death (Holshuh *in litt.*)

Figure 1. Carcass of a desert bighorn sheep exhibiting clinical signs consistent with a diagnosis of caseous lymphadenitis. Palen Range, Riverside County, California, January 1988. Photograph by H. J. Holshuh II.

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Results of the external examination are consistent with symptoms of caseous lymphadenitis as manifested in domestic sheep (Davis 1990), although copious exudates can be associated with other species of bacteria. The large mass and abscess on the brisket (Fig. 1) resembled those caused by *C. pseudotuberculosis* in equids and that manifest frequently as external abscesses in the pectoral region or along the ventral midline of the abdomen (Pratt et al. 2005, Britz et al. 2014). Absent observation of internal lesions frequently associated with the disease (Williamson 2001) or culture of *C. pseudotuberculosis*, however, the tentative diagnosis of caseous lymphadenitis in this bighorn sheep remains unconfirmed. Nevertheless, this observation is noteworthy because caseous lymphadenitis is not likely to occur in free-ranging bighorn sheep, especially in the absence of exposure to domestic sheep, which had not grazed ephemeral allotments in this remote area of California for ≥8 years (BLM 1991).

Kelly et al. (2018) described a Rocky Mountain bighorn sheep diagnosed with caseous lymphadenitis as 'emaciated', and found it to be severely copper deficient, a condition of malnutrition that can affect growth and reproduction (Abba et al. 2000), and also lead to immunosuppression (Suttle 2010). Kelly et al. (2018) postulated that copper deficiency contributed to immune suppression and the severe bacterial infection and abscessation they reported. The animal described in this paper appeared to be in poor condition, perhaps the result of the severe bacterial infection. In California, nearly 10 percent (8/83) of bighorn sheep sampled in the South Mojave Metapopulation, which includes the Palen Range (Epps et al. 2003), exhibited insufficient levels of copper (Poppenga et al. 2012). No samples were available from the Palen Range, however, and whether copper deficiency contributed to the condition of the animal described herein is not known.

It is probable that fewer than 25 bighorn sheep have occupied the Palen Range over the past 80 years (Weaver and Vernoy 1956, Wehausen 1999, Abella et al. 2011). It is a low-elevation (<1,200 m) mountain range, and is hot and arid with precipitation averaging ~9 cm annually (WRCC 2019). The few bighorn sheep occupying the range likely contribute to gene flow among subpopulations of sheep in the Coxcomb, Granite, Little Maria and McCoy mountains, all of which are proximate to the Palen Range (Bleich et al. 1990, BLM 1991). No more than 25 bighorn sheep inhabit any one of these nearby areas (Abella et al. 2011), and populations of bighorn sheep in each of these ranges may be especially prone to extirpation (Berger 1990; but, see Wehausen 1999), particularly if coupled with stochastic events that further limit recruitment or exacerbate adult mortality (Lande 1988).

It is often through observations of unanticipated or unusual events that questions arise (Estes 2016). Even in the absence of necropsy or bacteriology, the discovery a desert bighorn sheep exhibiting clinical signs consistent with caseous lymphadenitis raises several questions worthy of consideration. Individuals experiencing chronic mineral deficiencies may survive over time yet exhibit poorer reproductive potential and increased susceptibility to disease when compared to those with normal levels of micronutrients (Kelly et al. 2018). Has a paucity of copper played a role in the historically poor demographic performance of bighorn sheep inhabiting the Palen Range, or elsewhere in the South Mojave Metapopulation? Desert bighorn sheep inhabiting arid, low-elevation mountain ranges with limited sources of surface water have a high probability of extinction (Epps et al. 2004). Might the near absence of permanent surface water facilitate transmission of this bacterium from one bighorn sheep to another in the Palen Range, or elsewhere in the South Mojave Metapopulation, through more frequent contact at limited water sources? *Corynebacterium pseudotuberculosis* can persist in the soil or in direct sunlight (Davis 1990, Spier et al. 2012). If the tentative diagnosis of caseous lymphadenitis is correct, when and under what conditions did infection occur? The loss of even one mature female can have severe consequences for small populations when annual recruitment barely offsets mortality (Chow 1991). Have other individuals been affected by this disease in the past, and were there demographic consequences associated with those events?

It is likely that we will never have answers to these specific questions but curiosity, as emphasized by Leopold (1933), provides a foundation for further inquiry. Indeed, it is through serendipitous observations that questions sometimes arise, science advances, and our understanding of nature ultimately is enhanced (Estes 2016).

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Drawing reliable inferences from reliable science – in my opinion

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Abstract Wildlife research employs carefully selected field methods, analytical techniques, and scrutiny of results when drawing conclusions subject to appropriate peer review. At times, we collectively draw inappropriate inferences or make inappropriate references despite our efforts at sound science due to unfamiliarity with relevant subject matter or overreaching in our basic assumptions. I use 3 peer-refereed papers to illustrate my concerns where bighorn sheep (*Ovis candensis*) populations are substantially and inaccurately referenced (Kamler et al. 2002), the premise for conducting bighorn sheep surveys is misstated (Conroy et al. 2018), or the effect of a source of mortality on mountain lion (*Puma concolor*) populations may be perceived to be misleading (Andreasen et al. 2018). I offer caution about mischaracterizing or sensationalizing our research findings to appeal to a broader audience when collateral harm that may occur to the wildlife management profession and our efforts towards science-based management.

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Key words credibility, inference, interpretation, science.

Wildlife managers and researchers focus a substantial amount of effort at ensuring objectivity in the work they conduct, regardless of whether the final intent is a peer-refereed publication or implementation of a management recommendation. Recommendations for regulated harvest through hunting seasons are scrutinized by field biologists, supervisors, and staff specialists prior to submission to Commissions for action. Documentation of effects associated with planned actions are evaluated according to the National Environmental Policy Act, along with other regulatory processes mandated by state and federal legislation. Science is the basis to inform decisions, but science is designed to be objective and unbiased. The public trust managers use science to make recommendations, although the public trustees may use other perspectives in setting objectives or making decisions for the benefit of public trust beneficiaries (e.g., Smith 2011).

Advocacy influences our ability, or at least the perception of our ability, to maintain independence and credibility when working within sociopolitical situations and processes (Ruggiero 2010). A relatively extreme example of this lack of independence and credibility was a report prepared by the Humane Society of the United States that examined mountain lion (*Puma concolor*) hunter harvests and concluded that those harvests must cease to preserve the species (Humane Society of the United States 2017). A subsequent review of that report identified several flaws tied to the lack of independence, including using *a priori* assumptions that hunting is detrimental to

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persistence of populations, followed by selecting scientific arguments to support their value-based position (Cain and Mitchell 2018). Although this fairly egregious example was recognized by many in the wildlife profession, I suggest that we often include less obvious errors in our own work.

To illustrate this, I provide a brief review 3 manuscripts published in peer-refereed journals. These manuscripts contain credible and independent scientific conclusions, but there remain aspects within each that may influence a reader's ability to draw a reliable inference from their reliable science.

Example 1 – Translocated Bighorn Sheep Mortality Caused by Mountain Lions

Kamler et al. (2002) examined survival estimates based on radiocollared bighorn sheep (*Ovis canadensis*) that had been translocated within Arizona during 1979–1997. Their basic analyses examined survival among regions of the state during different time frames and indicated that greater mortality occurred over time in the southwest and central portions of the state, attributable primarily to greater predation rates by mountain lions. They conclude that bighorn sheep survival changes may be due to mountain lion shifting prey selection in response to declining mule deer (*Odocoileus hemionus*) populations. Although they suggest habitat differences may play a role, they did not test this assumption. In addition, they imply that mountain lion predation may be a limiting factor for other populations of bighorn sheep as well.

Wakeling and Riddering (2008) analyzed this same data set to determine if habitat quality could be an influential factor in reduced survival over time. Essentially, they tested to see if sheep translocations in into potentially lower quality habitat might be correlated with survival. Wakeling and Riddering (2008) used numerical rankings compiled by Cunningham (1989) and determined that there was not a relationship between habitat quality and survival or mountain lion predation. They postulated that there was likely a threshold below which measured habitat quality would affect survival, which is lower than Cunningham (1989) originally expected. The failure of Kamler et al. (2002) to account for habitat quality had not influenced their findings.

Despite failing to evaluate habitat quality in the analyses conducted by Kamler et al. (2002), their results appear accurate. Yet they introduce several additional inaccuracies in their paper that draws further critique of their work. For instance, they state that Arizona's bighorn sheep population was estimated at 3,200 individuals in 1994, yet the actual population was estimated at >6,500 (Lee 1995). Kamler et al. (2002) also included in their analyses some populations of bighorn sheep that had not received any translocations (e.g., Silver Bells [Wild Sheep Working Group 2015]). Kamler et al. (2002) has been a paper used in many instances (>50 times) to support our understanding of bighorn sheep and mountain lion management. With substantive inaccuracies within the paper, individuals critical of management paradigms (e.g., mountain lion population reductions to benefit bighorn sheep populations) might be critical of other aspects of this study and call management actions into question.

Example 2 – Desert Bighorn Sheep Abundance Surveys

Arizona primarily uses aerial surveys of desert bighorn sheep (*Ovis candensis*) to monitor population status among years. These surveys, based on initial development of detection probabilities (Hervert et al. 1998), were evaluated on multiple occasions (e.g., Conroy et al. 2014, 2015; Conroy et al. 2018). These subsequent evaluations suggested improvements to the initial technique. The suggested improvements included an evaluation of precision and fiscal costs that allow managers to determine how to best implement surveys in a cost-efficient manner.

However, I believe Conroy et al. (2018) opened their introduction with a mischaracterization of the survey. They stated that "These aerial surveys have 2 main objectives: provide accurate point estimates of bighorn sheep abundance at the resolution of Game Management Units (GMUs) and detect trends in bighorn sheep population trajectories in GMUs and regionally…" Although aerial surveys are certainly used to do these things, the primary purpose of aerial surveys for bighorn sheep is to determine the availability of harvestable male bighorn sheep, which does not require either an estimate of population size or trend (Arizona Game and Fish Department 2018).

This mischaracterization does not invalidate the findings of Conroy et al. (2018), yet it does call into question the ability of the Arizona Game and Fish Department to provide correct hunting and harvest recommendations. Those unfamiliar with harvest regulation or those that may challenge it for personal or political reasons may choose to use our statements in scientific articles to challenge our abilities to do so correctly.

Example 3 – Mountain Lion Survival and Foothold Traps

The scientific literature is replete with references to the interrelationships of predators and prey. For managers of bighorn sheep, the relationship between bighorn sheep and mountain lions can be one of the most important and controversial. One of the reasons for the frequent citation of Kamler et al. (2002) is the critical focus on this relationship and the potential influence of mountain lion management.

Our knowledge of mountain lions is understood less completely than for many ungulate species due to its cryptic nature, lower abundance, and fewer tools and resources for monitoring mountain lion populations at meaningful scales (Whittaker 2011). Andreasen et al. (2018) documented that mountain lions may be inadvertently captured in foothold traps and snares set by licensed trappers pursuing other lawful species such as bobcat (*Lynx rufus*). Of note, Andreasen et al. (2018) found nontarget capture of adult female mountain lions could cause injury and significantly reduce survival rates post-release. In the study conducted by Andreasen et al. (2018), anthropogenic mortality accounted for 100% of the female mountain lion mortality, thereby suggesting that any mortality associated with foothold traps should be considered additive. Andreasen et al. (2018) accurately noted that adult female survival is among the most important factors determining growth rates of large mammal populations (Robinson et al. 2014). They did not detect any effect on survival for adult male mountain lions or young animals of either sex.

The challenge associated with the interpretation of Andreasen et al. (2018) results is that a large segment of the study population was initially captured (that is, entered into the study following capture) in foothold traps by licensed trappers. These trappers notified the study team, who subsequently marked and monitored the mountain lions. Of the 26 adult mountain lions marked for their nested survival analysis, 7 were marked at the first nontarget capture incident. Of the remaining 19 mountain lions included in the analysis, only 1 was trapped after first marking (Andreasen et al. 2018: Table 3). Andreasen et al. (2018) acknowledge that this study occurred in an area comprising 11% of the state where 20% of the trapping occurs.

Andreasen et al. (2018) accurately report survival rates for all classes of mountain lions in their study. Yet the perspective they leave is that nontarget capture and related mortality is perhaps more prevalent than their data would indicate. By introducing mountain lions that were first entered into the study following capture in a foothold trap, the study does not accurately reflect the frequency with which this occurs. While capture in a foothold trap may result in a debilitating injury for an adult female mountain lion, only slightly over 5% of the study population that was independently radiocollared was ever captured in a foothold trap in an area with high trapping activity. Individuals that want to challenge the use of foothold traps and limit the use of legitimate management tools may selectively use the reported survival rate, accurately reported, as a population-level effect even though the data in the study indicate it may be a relatively rare event and unlikely to have a population-level effect.

Management Implications

Publishing results of studies or ensuring that our management recommendations are implemented requires that researchers and managers speak a language that resonates with editors, referees, and public trustees. To do this, we often sensationalize (to some degree) our findings or recommendations. When we do this, we can increase the likelihood of acceptance of our manuscript or our recommendation, but at times this same level of sensationalism may come back to haunt us because our statements may be misused, misplaced, or taken out of context entirely. We may be tempted to say that "…this subspecies is the most poorly understood…" when saying "…this subspecies is the least well understood…" would be equally accurate but would convey less confusion about our status of knowledge. Bleich (2018) provided 7 suggestions for maintaining conservation momentum that largely described increased and expanded relationship trust among individuals and organizations. In my opinion, we need to be critical of our writing and speaking so that we establish a position of trust to maintain that momentum. If we mischaracterize or sensationalize our findings or implications, we risk jeopardizing that momentum.

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State Status Reports

Status of Bighorn Sheep in Arizona, 2018

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Desert Bighorn Council Transactions 55:66–69

POPULATIONS

Statewide population estimates of desert bighorn sheep (*Ovis canadensis mexicana* and *O. c. nelsoni*) have remained relatively stable over the past several years. Male:100 females:lamb ratios averaged 57:100:26 in 2018 (n = 2,244). Based on survey data, Arizona currently has an estimated population of 5,000–5,500 desert bighorn sheep.

The desert bighorn sheep population in the Kofa Mountains (Units 45A, 45B, and 45C) in southwestern Arizona is doing well but has not quite fully recovered and is at about 650 animals (the population had been at about 800 in 2000). The Black Mountains (Units 15A, 15B, 15C, and 15D), Arizona experienced a disease outbreak resulting in a 53% decreased in the number of bighorn sheep observed on surveys in 2016 and 2017, with increasing numbers and ratios observed more recently. Even though Unit 15D is somewhat isolated from the rest of the Black Mountains by AZ Highway 68, the disease crossed the highway and impacted that portion of the population as well. In this region, bighorn sheep carcasses of both sexes as well as coughing bighorn sheep were documented in all Black Mountain units. Increased monitoring of this population will continue.

Rocky Mountain bighorn sheep (*O. c. canadensis*) continue to prosper in Arizona. This population is estimated at about 1,200 animals. Male:100 females:lamb ratios averaged 39:100:28 in 2018 (n = 313). For both Rocky Mountain and desert bighorn sheep, Arizona surveys about one third of the populations annually, although some areas of specific concern or recent translocations have been surveyed annually.

RESEARCH

Galiuro FireScape Project

In 2016, the Coronado National Forest-Safford Ranger District, began implementing the Galiuro FireScape, an 8-year plan to treat 137,000 acres of USFS land in the Galiuro Mountains (Units 31/31) with prescribed fire. The long-term goal of the Galiuro Firescape is the return of the historical natural fire regime. The treatment area was divided into 8 burn units, one unit treated each year.

In conjunction with this project, the Department planned to augment populations of desert bighorn sheep in Aravaipa and Redfield canyons and evaluate post-release success of populations and response to the prescribed burns. In November 2016, the Department used helicopter capture methods to capture 31 desert bighorn sheep (6 male, 25 female) from the Silver Bell Mine west of Tucson (Unit 37A), for release in the Galiuro Mountains. Eleven bighorn sheep were released in Aravaipa Canyon (2 males, 9 females) and 20 in Redfield Canyon (4 males, 16 females).

This timeframe allowed for the accumulation of GPS data identifying home ranges and habitat use by bighorns prior to any prescribed burn efforts. Unused desert bighorn sheep habitat and a potential corridor between the 2 existing desert bighorn sheep populations have been identified for treatment with prescribed fire during the implementation of the Galiuro Firescape.

Post-treatment home range data and habitat use will be gathered by the existing collars, thereby allowing for the comparison of pre- and post-treatment habitat use by bighorn sheep in the Galiuro ecosystem.

Currently, Aravaipa and Redfield bighorn sheep movements are still separated by about 30 km. Current and future data collected from the collared animals is helping direct the implementation of the Galiuro Firescape. As the burn units between the 2 populations are treated, it is possible that connections between the herds and an expansion into restored habitat may occur, negating the need for future translocations into the Galiuro Mountains. This study could be developed into a model to predict other areas where prescribed fire may be used to restore bighorn sheep habitat.

In 2019, the Department plans to collar additional bighorn sheep in this area to continue monitoring movement in response to the habitat modifications.

HABITAT

The Department works with private organizations (primarily the Arizona Desert Bighorn Sheep Society (ADBSS) and the Wild Sheep Foundation) and federal agencies to achieve habitat improvements for bighorn sheep. Many of these projects are part of the Department's Habitat Partnership Committee program and are funded with Special Big Game License-Tag funds generated through the sale of 3 bighorn sheep tags.

In 2018, the Department and ADBSS coordinated on projects for over $700,000 USD including building or maintaining water sources, habitat treatments, bighorn sheep survey, and translocations.

In 2018, because of unusually dry conditions, a record-setting efforts were expended in Region 4 to keep water available for wildlife. Regional staff and volunteers hauled 338,092 gallons of water to various catchments; the Department’s Development Branch hauled an additional 94,300 gallons, for a grand total of 432,392 gallons delivered to wildlife waters during the first nine months of 2018. While many of these wildlife waters do not benefit, or solely benefit, bighorn sheep, a significant number of them do. 48,500 gallons alone was delivered by helicopter to bighorn sheep waters. Without considerable support from the Bighorn Sheep Special Tag fund to cover costs of helicopter time, many bighorn sheep waters in Region 4 would have gone dry during the past summer. The Region continues to increase storage and improve collection at many of the critical waters so that future water-hauling needs are reduced.

HARVEST

Bighorn sheep permits remain the most sought after hunting permits in Arizona. In 2018, 18,707 individuals applied for the 114 available desert and Rocky Mountain bighorn sheep permits.

During the 2018 season, 114 hunters participated, harvesting 113 males in 526 days of hunting. Hunt success was 99%. The age of harvested males ranged from 3 to 13 ($\bar{x}$ = 8), with green scores ranging from 98 3/8 to 189 3/8 ($\bar{x}$ = 165 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 2018, with a third tag to the Arizona Big Game Super Raffle (AZBGSR). Each year, ADBSS has traditionally auctioned 1 tag at the Annual Convention of the Wild Sheep Foundation and auctions the second at their fundraising banquet, which raised $615,000 USD in 2018. The third is raffled through

AZBGSR, raising $173,175 USD in 2018. Each year, 100% of the proceeds of all three tags come back to the Arizona Game and Fish Department to fund conservation and management of bighorn sheep in Arizona.

TRANSLOCATIONS

Arizona relocated 83 bighorn sheep through 1 desert bighorn sheep and 2 Rocky Mountain bighorn sheep translocations in 2018. Thirty desert bighorn sheep (in a ratio of about 1 young male:3 females) were captured in the Silver Bell Mountains in Unit 37A using established Department helicopter capture and handling protocols. The bighorn sheep were released in the Picacho Mountains in Unit 37A, in an effort to re-establish bighorn sheep population in that area.

For Rocky Mountain bighorn sheep, 53 bighorns were captured using a combination of helicopter, drop-net and ground immobilization methods during multiple opportunistic capture efforts and one large-scale capture effort. Twenty-three bighorns captured from the Morenci Mine area of Unit 27/28 were released into the northern areas of Unit 27; 30 bighorns captured in the Morenci Mine and Upper Eagle Creek areas of Unit 27/28 in November 2018 were released in the East Clear Creek area of Unit 4A/5A for the first translocation to reestablish Rocky Mountain bighorn sheep into this area. This brings the total of bighorn sheep moved in Arizona to 2,472.

Santa Catalina Mountains Project

The Department conducted aerial surveys for bighorn sheep in the Catalina Mountains in September 2018. Department personnel surveyed about 45 square miles of bighorn habitat in Unit 33 over 5 hours (Table 3). Thirty bighorn sheep were observed, 14 with ear tags and/or collars. While 6 collars were functioning at the time of the survey, it is impossible to know which individual was directly observed because of the missing ear tags. Eight groups were observed, including 1 individual (single male), 1 pair (two females), 2 groups of 3 (2 females and 1 lamb, 2 males and 1 female), 2 groups of 4 (2 males and 2 females, 1 male and 2 females), 1 group of 5 (2 males, 3 females), and 1 group of 8 (2 males, 6 females). Two adult mountain lions were also observed during the survey, both in the same canyon where the only lamb was observed. No yearlings were observed on survey, but ADBSS volunteers reported seeing several throughout the year.

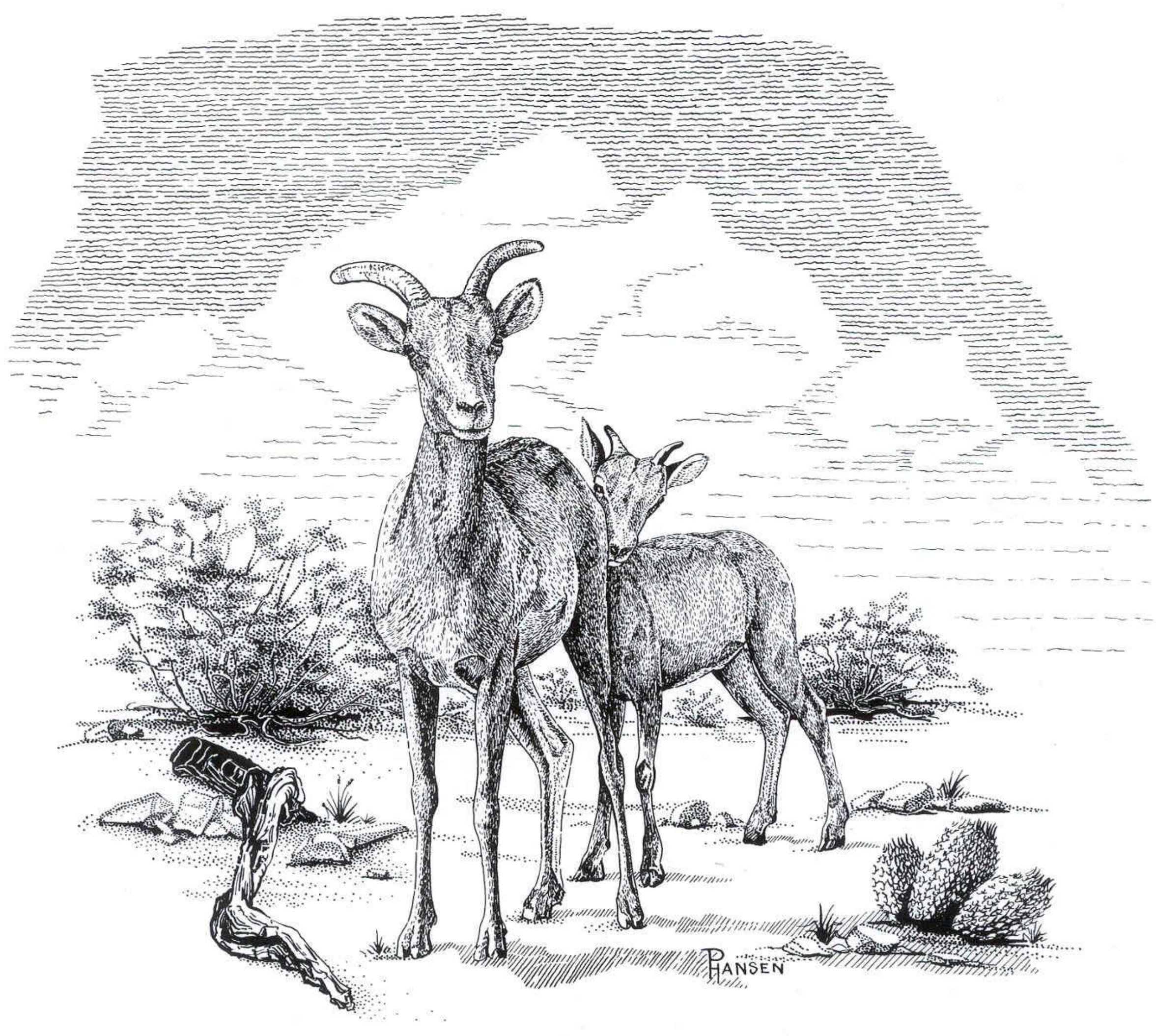
In the past, the Department has used a mark-recapture model to estimate the abundance of bighorn sheep in the Catalina Mountains. The “marked” animals were all animals with working radio collars that were present within the survey area during the survey. Animals were “recaptured” by observing them during the survey flights. Using this method in 2017, it was determined that the minimum population at the time of survey was 66 bighorn sheep. Because we now have both non-functioning collars and unmarked animals wearing collars present in the population, this method is no longer valid.

Annual post-translocation surveys will continue to be flown every year through 2019, then will follow the triennial survey period used for most other statewide bighorn populations.

To date, 110 bighorns have been released into the Catalina Mountains, 92 of which were collared with satellite GPS collars. No future releases of bighorn are being considered at this time. There have been 62 confirmed mortalities: 30 from predation by mountain lions; 1 from capture myopathy; 5 from (suspected) pneumonia; 1 from possible EHD/Bluetongue; 1 from predation by an unknown felid, likely a bobcat; 2 from collision with vehicles, 2 from falls, and 21 from natural or unknown causes. One additional female is suspected dead based on lack of movement for 3 months, but death has not been confirmed because of the rugged terrain where the collar is located. Eighteen marked animals have been confirmed alive during the past year either through surveys or photographs submitted by the public. An additional 16 unmarked animals were observed on survey in 2018.

BIGHORN SHEEP AND DOMESTIC SHEEP AND GOAT INTERACTIONS

The Department responded to several reports of bighorn sheep and domestic sheep and goat interactions. Reports are not yet available.



Status of Bighorn Sheep in California, 2019

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INTRODUCTION

California Department of Fish & Wildlife (CDFW) manages two subspecies of bighorn sheep: Sierra Nevada bighorn sheep (*Ovis canadensis sierrae*) and desert bighorn sheep (*Ovis canadensis nelsoni*). The latter is divided into Peninsular desert bighorn sheep (PBS), which are geographically isolated, federally listed as endangered, and managed under their own recovery plan; and desert bighorn sheep (DBS), which broadly refers to all non-Peninsular *O.c. nelsoni* populations (Fig. 1). The Sierra Nevada bighorn (SNBS) population is also federally listed as endangered and is managed under its own recovery program. All three programs continue to build on their knowledge of metapopulations to further our understanding of biological implications and to advance the CDFW model of managing bighorn sheep.

Regular status reports are prepared for all three management units and may be referenced for additional information. This report is intended to be an update to previous status reports (Torres et al. 1994, 1996; Epps et al. 2003; Abella et al. 2011) and provides a summary of current population status, research projects, habitat improvement projects, harvest, and other challenges and opportunities.

STATE-WIDE POPULATIONS

The total state-wide estimate of bighorn sheep in California is approximately 5,725, consisting of 884 PBS, 4,240 DBS and 601 SNBS. Refer to Table 1 in the appendix for individual management unit population size class estimates, population status, dates of most recent estimates, and *Mycoplasma ovipneumoniae* (*M. ovi.*) exposure.

Peninsular Bighorn Sheep

Peninsular bighorn sheep were placed on the endangered species list by U. S. Fish and Wildlife Service (USFWS) in 1998 (Fed. Register, Vol. 63, No. 52, 1998). From 1994 to 2010, the PBS metapopulation steadily increased from an estimated 335 to 955 based on biennial helicopter surveys. Helicopter surveys were not conducted in 2012 and 2014 due to a delay in executing a statewide helicopter survey contract. Upon resumption of helicopter surveys in 2016, the PBS metapopulation was estimated at 884 and considered stable. Noteworthy, 2016 was the first survey since listing that > 25 females were counted in the San Jacinto Mountains. Furthermore, a minimum of 25 females were estimated in each of the 9 recovery regions; thus, 2016 marked year 1 of 6 in meeting criterion 1 in section II.B.2 for downlisting PBS from endangered to threatened status (U.S. Fish and Wildlife Service. 2000). Unfortunately, a survey was not conducted in

Figure 1. Distribution of bighorn sheep in California.

2018 and a capture to replenish radio-collars was cancelled in 2019 due to delays in helicopter contracts and lack of funding. The current percentage of radio-collared PBS in the Peninsular Ranges is well below the recommended 25% that is necessary for accurate mark-resight population estimates. A capture is planned for fall 2020 followed by helicopter surveys in 2021—a gap of 5 years between surveys. Without consistent funding for captures and surveys, accurate estimates of population abundance that are used to assess if recovery criteria are being met will not be possible.

Using the best available data at the time of listing, 9 recovery regions within the Peninsular Ranges were established (USFWS 2000*b*), in which a minimum of 8 subpopulations (female groups) were identified (Rubin et al. 1998). Knowledge about female group structure and seasonal movements within and between female groups has greatly increased due to CDFW's efforts to maintain GPS collars on females across all recovery regions from 2009 to present (Colby and Botta 2019).

Currently, 19 female groups have been identified within the Peninsular Ranges. The two largest recovery regions, Carrizo Canyon (866 km^2) and the Vallecito Mountains (706 km^2), have 4 female groups each within their boundaries. In the southern Santa Rosa Mountains (562 km^2), 3 female groups have been identified, however, recent global positioning system (GPS) data from several sheep have indicated that this region is likely inhabited by a fourth female group. In the Central Santa Rosa Mountains (257 km^2), there are 3 distinct patterns of habitat use by females, but all overlap extensively during the first half of lambing season and therefore are categorized as one female group. The core habitat use area of another female group straddles the boundary between the Central and South Santa Rosa Mountains recovery regions and cannot be easily assigned to either recovery region. Coyote Canyon (250 km^2) is the fifth largest recovery region and contains 2 female groups. The remaining 4 recovery regions (San Jacinto, North Santa Rosa, North San Ysidro, and South San Ysidro Mountains) all have areas of less than 200 km^2 and contain one female group each.

There are two female groups within the Carrizo Canyon recovery region that are noteworthy. The In-Ko-Pah female group's core lambing area is an 8 x 2 km area between the west and east-bound lanes of Interstate 8 and it is not uncommon for females to cross the Interstate multiple times per day. The Interstate bisects the seasonal movement pathway of both males and females, and as Interstate traffic continues to increase each year, seasonal movement pathways will eventually be cut off. Most notably, the Jacumba female group's home range is bisected by the U.S.-Mexico Border. This female group is dependent upon resources both within the U.S. and Mexico. A border fence would prohibit movement to, and use of, pre-lambing and lamb-rearing habitat within the U.S. and access to summer water sources in Mexico.

Desert Bighorn Sheep

Desert bighorn sheep, outside of the Peninsular Ranges, have historically occupied over 60 mountain ranges across southeastern California. It is not currently feasible for CDFW to survey DBS ranges each year. Our intent, however, is to survey every range at least once every 7–10 years and to regularly monitor a subset of core ranges. There was a lapse in data collection across the desert following a fatal helicopter crash in 2010—CDFW ceased helicopter surveys until a new contract was finalized in 2015. In 2013, an all-age-class die-off resulting from respiratory disease was reported in the Old Dad Peak population within the Mojave Preserve—this marked the first time that *M. ovi.* was documented in a free-ranging desert bighorn population within the Mojave Desert (Epps et al. 2016). This die-off and the presence of *M. ovi* spurred an emergency capture in several ranges across the central Mojave Desert in the fall of 2013 and subsequently brought about the revitalization of the Desert Bighorn Sheep Program at CDFW (Prentice et al. 2018).

During 2013–2018, CDFW captured 379 desert bighorn (271 females, 108 males) via helicopter net-guning across 20 mountain ranges. Of the animals captured, 369 were collared with both GPS and very high frequency (VHF) collars as well as uniquely identifiable ear tags. All of the 20 ranges where samples were collected had at least one individual exposed to *M. ovi* (Appendix, Table 1). In addition to captures, CDFW utilizes remote game cameras on water sources during the summer months, which provide valuable demographic data, evidence of disease and predators, and in some ranges are used for mark-resight population estimates. The renewed helicopter survey effort in 2015 enabled the DBS program to increase monitoring efforts. Lastly, fecal capture-recapture methods have been tested and proven to be both an efficient and cost-effective method for obtaining population estimates in certain ranges (Pfeiler et al. *in review*). Since 2015, CDFW has surveyed and updated population estimates for ~50% of DBS ranges (Appendix, Table 1).

Sierra Nevada Bighorn Sheep

Sierra bighorn were listed as federally endangered in 1999 (USFWS 2000*a*). In an effort to increase abundance and reintroduce SNBS to their native range, CDFW performed a series of translocations during 1979–1988, in the early 2000s, and again during 2013–2015. In 2013, SNBS were reintroduced to historically occupied habitat at Olancha Peak at the southern end of SNBS historical range. During 2014–2015, SNBS were reintroduced to Big Arroyo and Laurel Creek in Sequoia Kings National Park and to the Cathedral Range in Yosemite National Park. The SNBS Recovery Program continues to use translocations to augment existing herds as needed to increase genetic diversity and maintain viable population sizes.

Based on minimum counts conducted in 2017 and 2018, the SNBS Recovery Program estimated a total population size of 601 Sierra bighorn, including 281 females, 110 lambs, and 210 males (male estimate based on a male to female ratio of 3:4). In 2018, the largest SNBS herds were Mt. Baxter, Sawmill Canyon, and Wheeler Ridge, each with more than 40 females. The mid-sized herds were Mt. Langley, Mt. Gibbs, and Olancha Peak, each with more than 20 females. This represents a significant population decline at Mt. Langley as a result of heavy predation by mountain lions during 2017; previously it was considered one of the largest herds and a source for translocation (Few et al. 2015).

The 2016–17 year was the second wettest year on record for the central Sierra Nevada, which received 73 inches of precipitation (>600 inches of snow in some locations). Although the precipitation was a welcome relief from 4 years of drought, the impact on SNBS was severe. The Recovery Program estimated that 100 SNBS females died during the 2016–17 winter, or roughly 30% of the known female population (Greene et al. 2017). Most mortalities were attributed to winter conditions (e.g., malnutrition or avalanche), but many were mountain lion kills. This year marked the greatest loss of individuals, as well as the greatest range-wide proportional loss that the SNBS Recovery Program has documented in a single year. Despite these losses, survival rates increased in the following year.

The SNBS Recovery Plan specifies downlisting criteria to be 50 females in the Kern recovery unit (RU), 155 females in the Southern RU, 50 females in the Central RU, and 50 females in the Northern RU (USFWS 2007). In 2018, SNBS exceeded the goal for the southern RU, met the goal for the Central RU, and had not achieved the abundance goals for the Northern and Kern RUs. In 2018, SNBS were distributed across 14 herd units (from south to north): Olancha Peak, Laurel Creek, Big Arroyo, Mt. Langley, Mt. Williamson, Mt. Baxter, Sawmill Canyon, Bubbs Creek, Taboose Creek, Wheeler Ridge, Convict Creek, Cathedral Range, Mt. Gibbs, and Mt. Warren. The Recovery Plan stipulates that 12 of the 16 recognized herd units be occupied (Criteria B2), and in 2018 SNBS met this spatial delisting criteria and included one herd unit (Cathedral Range) not identified in the Recovery Plan (USFWS 2007).

RESEARCH

Peninsular Bighorn Sheep

There are currently two M.S. projects focusing on PBS. The first is a project being conducted by Kendall Hines, at California State University San Marcos under advisor Dr. Tracey Brown, focusing on perinatal habitat use. The other project is being led by Joseph Knee out of Washington State University and under advisor Dr. Jeff Manning. This project is focused on predicting the landscape of bighorn sheep predation risk by mountain lions and associated cascading effects on smaller carnivores at kill sites. Furthermore, CDFW continues to study the spatial distribution, seasonal movement patterns, and abundance of bighorn sheep in the Peninsular ranges.

Based on recent genetic research, there is substantial genetic variation and gene flow among bighorn sheep populations within the Peninsular Ranges and across the U.S.-Mexico Border indicating functional connectivity (Buchalski et al. 2015). Data from GPS-collared females support these findings. While most females exhibit a high degree of philopatric behavior, there is a subset of females that make regular seasonal movements between adjacent female groups. The exceptions are between the Central and North Santa Rosa Mountains where female movements across Highway 74 are only documented occasionally, and between the San Jacinto and North Santa Rosa Mountains where female movements between recovery regions are rare. As traffic levels continue to increase, particularly on Highway 74 and Interstate 8, and with completion of the border fence, connectivity will be lost.

Peninsular bighorn sheep are tested for exposure to a range of pathogens as part of the regular monitoring of the population. Of particular concern is polymicrobial, epizootic pneumonia, which has been identified as a source of mortality and decreased lamb survival in PBS throughout their range. The bacteria *Mycoplasma ovipneumoniae* (*M. ovi*) has been identified as a primary pathogen associated with bighorn sheep pneumonia outbreaks across the United States (Besser et al. 2012, Besser et al. 2014, Cassirer et al. 2018), and exposure to *M. ovi* (via enzyme-linked immunosorbent assay) has been identified in PBS since testing began in the early 1990s. Due to the polymicrobial nature of this disease, archived samples from sheep across the Peninsular Range have been tested for multiple potential pathogens, in addition to *M. ovi*. Current investigations by Drs. Jessica N. Sanchez and Christine Kreuder Johnson of University of California Davis, in collaboration with CDFW, focus on describing the spatial and temporal exposure of PBS to multiple pathogens, exploring the role of bighorn sheep habitat use in pathogen transmission and how these dynamics have changed over time as the population has recovered, and estimating the impact of disease on bighorn sheep survival and reproduction across the Peninsular Ranges. Results from this research will be shared with stakeholders involved in bighorn sheep management and submitted for peer-reviewed publication.

Desert Bighorn Sheep

The 2013 die-off at Old Dad Peak and the multi-agency response efforts that followed, resulted in a wave of new research across the Mojave and Sonoran Deserts. Previous research by Epps et al. (2005) had shown Interstates 15 (I-15) & 40 (I-40) to be a barriers to connectivity between ranges on the north and south sides. Further research by Creech et al. (2014) used network theory and genetic information to identify high priority corridors across the interstates, and between ranges, where management should focus restoration efforts. When *M. ovi* strain testing showed the same strain on either side of I-40 it raised the question if the porosity of this barrier changed (Epps et al. 2016). GPS data in conjunction with a follow-up genetic survey by Epps et al. (2018) on either side of I-40 demonstrated that both males and females had found a way to cross. This corridor appears to only be on the northern side of the Marble Mountains (moving towards the Granites and even N. Bristol Mountains) because both the genetic and GPS data have not shown this same change in the neighboring South and North Bristol Mountains to the west.

In 2014, Dr. Clint Epps with Oregon State University (OSU) brought on Daniella Dekelaita as a doctoral candidate. Dekelaita et al. (*2019, in review*) investigated post-outbreak survival of adult female bighorn across 9 populations for 3.5 years in the Mojave Desert and evaluated the relationship between *M.ovi* infection and survival, while testing effects of range factors that could potentially drive differences in adult female survival (i.e., forage quality, winter precipitation, and population abundance). They used survival data from 115 adult females with radio-collars and applied the known-fate model in Program MARK to model survival from November 2013 to March 2017. Annual survival was negatively correlated with positive infection status (determined from PCR-testing at time of capture) but varied across populations with respect to differences in range conditions. Summer and autumn forage quality, as represented by mean summer and autumn NDVI, were positively associated with winter survival, while winter precipitation was negatively correlated with overwinter survival, although the effect was weakly supported. Dekelaita et al. (*2019, in review*) also found that population abundance was negatively correlated with annual survival. Estimated mean annual survival differed by as much as 8% for uninfected individuals and 23% for infected individuals given variation in range conditions across populations. They conclude that higher nutrition in summer and autumn may partially obscure the effect associated with *M. ovi* infection on host survival, and further note that chronic infection may have contributed to lower survival among females that were PCR-positive (i.e., infected with *M. ovi*) at time of capture. In a second publication, the authors will evaluate post-outbreak survival of neonates within these same populations and examine potential effects of climatic variables and population characteristics on neonate survival to understand differences across populations and assess implications of disease on population recovery (Dekelaita et al., *publication expected 2020*). In addition, the authors are also examining potential disease transmission risk within and between populations by analyzing movement trends and estimating probability of intermountain movements with respect to season, sex, age, and infection status at time of capture (Dekelaita et al., *publication expected 2020*).

In the summers of 2016 and 2017, Stephen Pfeiler, a MS student under advisor Dr. Mary Connor at Utah State University, tested the efficacy of the fecal DNA capture-recapture method for population abundance estimates on the Marble Mountain desert bighorn population. He compared his results to ground survey methods conducted by CDFW and did a cost-comparison analysis. Transects for the fecal DNA capture-recapture survey were focused on three water sources during the hottest and driest months (June and July) of the year. The abundance estimates for the fecal DNA capture-recapture were more precise (CV=5.1%–6.5%) than the estimates calculated using June ground surveys (CV = 20.5%–55.6%), and was roughly 28% of the costs (Pfeiler et al. *in review*). In addition to this research, Danielle Glass, under advisor Dr. Oswald Schmitz at Yale University, started her master thesis research during the summer of 2019 on the impact of surface water utilization on desert bighorn movement patterns. Data was collected using remote cameras on water sources and GPS data from collared animals. The data is currently being analyzed and is expected to be published upon completion.

Last but not least, as the result of a National Park Service (NPS) grant Dr. Christina Aiello, a post-doctoral scholar working in the Epps Lab at OSU, is working in collaboration with the NPS and CDFW on a Mojave Desert connectivity project. This research uses both trail cameras and GPS collars to further assess bighorn sheep movement relative to Interstates 15 and 40, and the role of existing underpasses in allowing population connectivity across these structures. At a subset of underpasses, they have installed additional water sources in order to test the resource's influence on movement and learned use of nearby underpasses as crossing points. Additionally, Christina and her team will use sign and track surveys combined with pellet collection and genetic testing to update data on bighorn sheep distributions and connectivity throughout the Mojave region. The results will be analyzed to inform survey methods suitable to assessing bighorn occupancy and tracking extinction/colonization events, and to update regional connectivity models.

Sierra Nevada Bighorn Sheep

We continued to conduct science to inform recovery of Sierra bighorn. Research activities, in collaboration with universities, were designed to improve our understanding of the behavior and demography of this unique taxon and threats to its persistence. Our results illustrate the value of long-term monitoring for establishing the links between a variable environment and population performance. Sierra bighorn exhibited migratory behaviors that include winter alpine residency and variation in the tactics and strategies of migrants (Spitz et al. 2017, 2018). We used our multi-year dataset on nutritional condition of bighorn in an analysis of factors that predict horn size in males and females and found a strong relationship with body fat of females (Monteith et al. 2018). Predation by mountain lions on adult Sierra bighorn was spatially and temporally variable and overlap with mule deer winter ranges was related to predation risk (Johnson et al 2013). Conner et al. (2018) conducted a known fate survival analysis and top models included predation risk, avalanche danger, and forage availability. Forshee (2018) developed resource selection functions and linked those models with lamb survival. Johnson et al. (2011) and Forshee (2018) found conflicting evidence for inbreeding depression. To assess the consequences of contact with domestic sheep, demographic rates were employed in a modeling effort that quantified the potential effects of disease on population viability (Cahn et al. 2011).

HABITAT IMPROVEMENTS IN THE MOJAVE DESERT

CDFW continues to work with volunteers and land management agencies on habitat improvement, primarily through artificial water source projects. The following non-government organizations continue to be instrumental in these efforts: Society for the Conservation of Bighorn Sheep (SCBS), the California Chapter of Wild Sheep Foundation (CA WSF), Desert Drinkers 4 Wildlife (DD4W), and Desert Wildlife Unlimited (DWU). Over the last 7 years, SCBS has collaborated with the 29 Palms Marine Corps Installation to build 7 new big game drinkers across the Bullion Mountain Range. During this time period we also documented collared females moving from the Newberry and Ord Mountains in the northwest, into the Bullion Range during the winter, thereby increasing connectivity between otherwise isolated populations. SCBS also replaced an old wildlife water development (WWD) system with a newer and more efficient collection and storage system in the Cady Mountains. Most recently, in October 2019, the NPS, CDFW, and SCBS collaborated to upgrade and rebuild the Old Dad Peak WWD on Old Dad Mountain within the Mojave National Preserve.

HARVEST OF DESERT BIGHORN SHEEP

Desert bighorn sheep hunting opportunities continue to be a coveted, once-in-a-lifetime experience in California. With the recent addition of a new hunt zone, Newberry, Rodman and Ord Mountains, the 2019/2020 hunt season will have a total of 28 tags across 7 hunt zones (Fig. 2). Zones 2, 5, and 6 are currently closed as a result of disease outbreaks and/or low population sizes. One of the 28 tags is a Governor's, any open-zone, auction tag and another is a Zone 1 or Zone 8 auction tag. All auction and general sales proceeds go to the CDFW Big Game Management Account.

PROBLEMS AND OPPORTUNITIES

Today, bighorn sheep managers across the west are struggling, with what feels like an uphill battle, against disease and especially the introduction of disease from domestic animals to wild populations. In California there are still more questions than answers as to why some bighorn populations react more severely than others to the same strain of *M. ovi*, the overall role of *M. ovi* compared to other pathogens in a system, the inherent disease risks of increasing connectivity balanced with the need for gene flow, and many more. However, the increased monitoring and research efforts that have resulted since discovering *M. ovi* in the Mojave Desert in 2013 have also brought forth new and exciting opportunities. Perhaps the most notable is the number of stakeholders that have come to the table to collaborate and support research efforts. The National Park Service continues to be instrumental in funding research projects, providing staff, and supporting CDFW with our monitoring and management efforts. The Bureau of Land Management (BLM), in collaboration with CDFW, executed a California Desert District Environmental Assessment that supports capture, collaring, and remote camera monitoring of desert bighorn in wilderness and non-wilderness areas. The Department of Defense continues to work with CDFW and other collaborators on habitat improvement projects as well as some population monitoring and potential capture efforts. Overall, CDFW could not conduct all of the aforementioned work in this report without the collaboration of many agencies, organizations, and individuals.

ACKNOWLEDGEMENTS

First and foremost, we'd like to acknowledge the Grandfather of Bighorn Sheep, Mr. Bighorn, the late Dick Weaver—the man that paved the way and built the foundation on which all current and future bighorn sheep work in California is built. There are several other instrumental bighorn biologists that may be "retired" but continue to contribute the bighorn work: John Wehausen, Vern Bleich and Steve Torres to name a few. We'd especially like to acknowledge the career, passion, and dedication of Dr. Ben Gonzales who has not only influenced bighorn work in CA but throughout the western states. A huge thanks to all the hard-working volunteers of the Society of the Conservation of Bighorn Sheep, the Wild Sheep Foundation, the Sierra Nevada Bighorn Sheep Foundation, and many others. Last but not least, thank you to the scientific aids that work on all three bighorn programs—this data collection would not be possible without you.

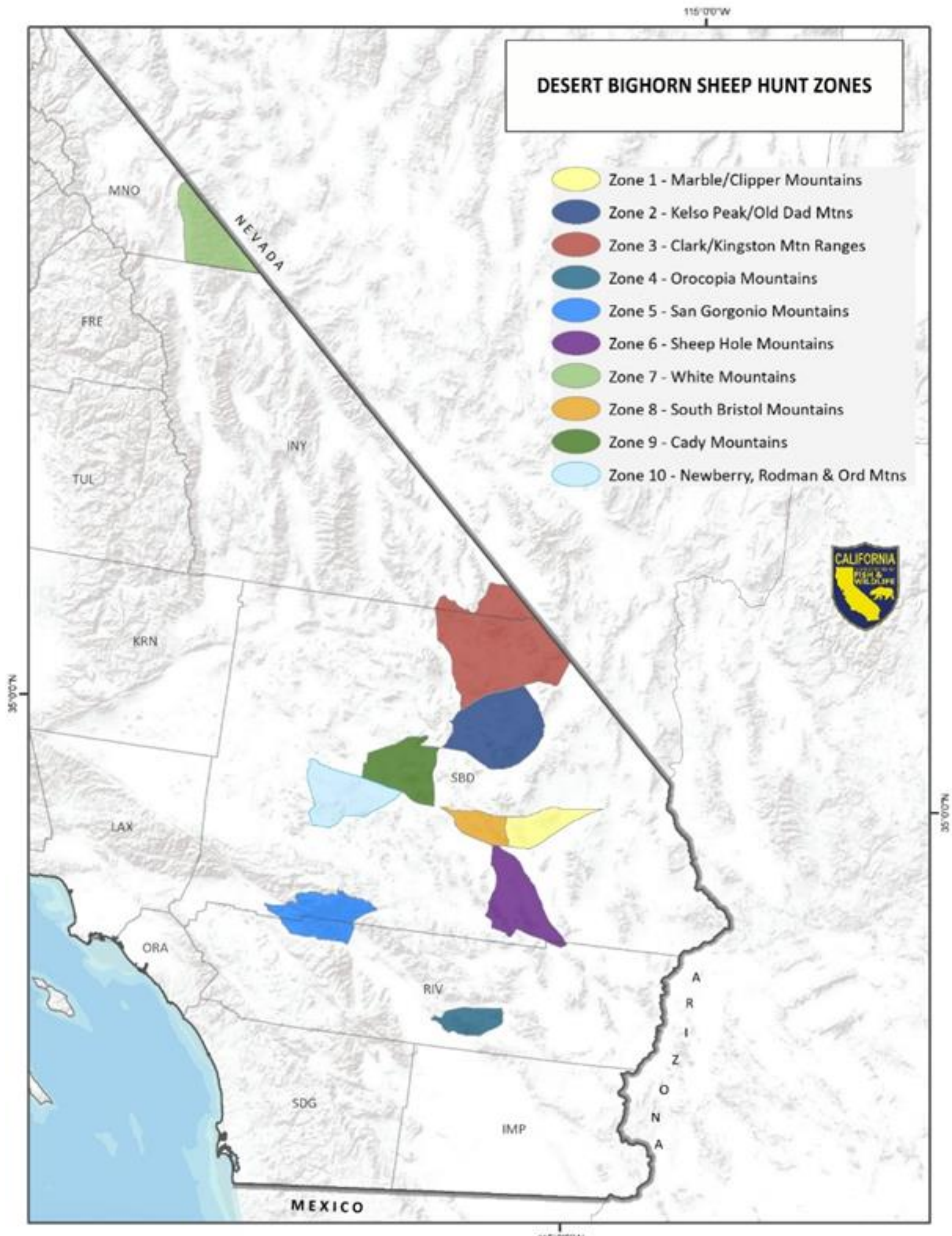

Figure 2. Desert bighorn sheep hunt zones in California as of 2019.

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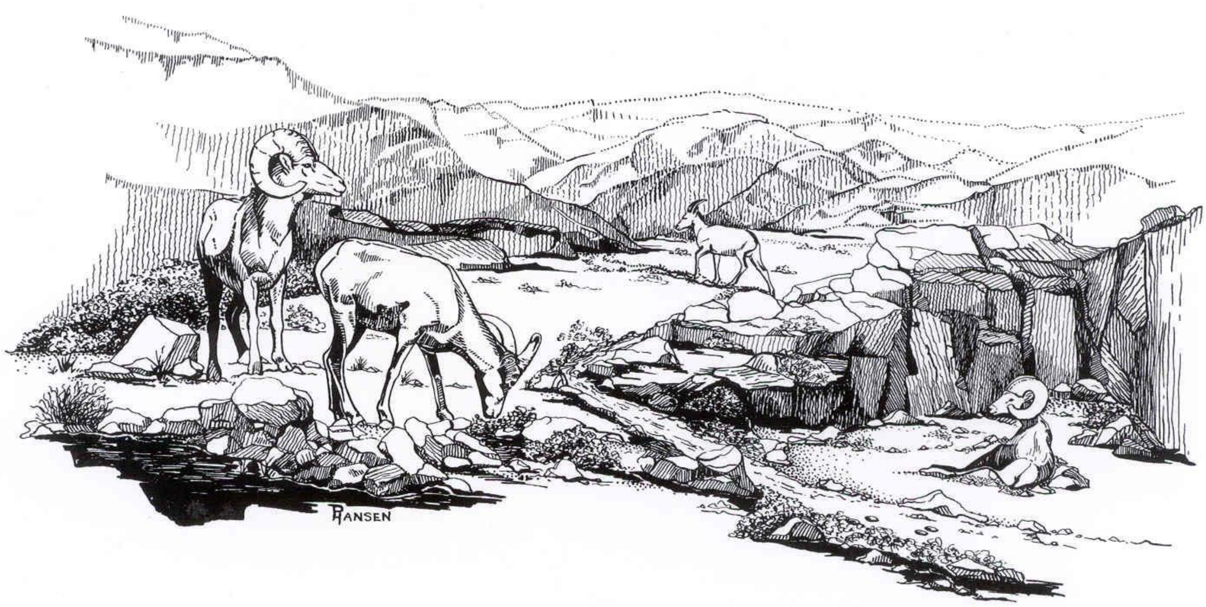

Appendix

Table 1. Extant and Extirpated populations of bighorn sheep in California as of 2019.

Metapopulation (Fragment)	Population	Population Status[1]	2019	Data Source /Year of Most Recent Data
Peninsular Ranges Recovery Regions	San Jacinto*	N	51–100	CDFW 2016[2,5,6]
	North Santa Rosa*	N	25–50	CDFW 2016[2,5,6]
	Central Santa Rosa*	N	101–150	CDFW 2016 [5,6]
	South Santa Rosa*	N	51–100	CDFW 2016[2,5,6]
	Coyote Canyon*	N	51–100	CDFW 2016[5,6]
	North San Ysidro*	N	51–100	CDFW 2016[5,6]
	South San Ysidro*	N	25–50	CDFW 2016[2,5,6]
	Vallecito*	N	151–200	CDFW 2016[2,5,6]
	Carrizo Canyon*	N	251–300	CDFW 2016[2,3,5,6]
Western Transverse Range	San Rafael Peak	R	25–50	CDFW 2002[5]
	Caliente Peak	E	0	No new data
San Gabriel	San Gabriel	N	401–450	CDFW 2011[2,5,7]
Sonoran	W. Chocolate (Gunnery)	N	51–100	CDFW 2009[5]
	E. Chocolate (Colorado R.)	N	51–100	CDFW 2004[5]
	Orocopia/Mecca Hills*	N	51–100	CDFW 2019[2,5]
	Chuckwalla	A	51–100	CDFW 2016[2,5]
	Cargo Muchacho	E	0	No new data
	Palo Verde	E	0	No new data
South Mojave	Newberry/Ord/Rodman*	N	301–400	CDFW 2019[2,5]
	Bullion	R	<25	DOD 2018[7,9]
	Sheep Hole	A	25–50	CDFW 2019[2,5,7,8]
	San Gorgonio*	N	51–100	CDFW 2019[2,5]
	N. San Bernardino (Cushenbury)	N	<25	CDFW 2019[6,7]
	Little San Bernardino	N	51–100	CDFW 2019[2,5]
	Queen	N	51–100	Longshore et al. (2009)
	Pinto	E	0	No new data
	Eagle*	N	51–100	C. Epps 2002–2003[8,9]
	Coxcomb	N	<25	C. Epps 2002–2003[8,9]
	Granite/Palen	N	<25	C. Epps 2002–2003[8,9]
	McCoy	T	0	No new data
	Little Maria	C	<25	Wehausen 2009[9]
	Big Maria	T	0	G. Mulcahy 2009[9]
	Riverside	T	0	G. Mulcahy 1995[9]
	Iron	C	<25	CDFW 2016[7]
	Turtle	N	51–100	C.Epps 2001–2003[8,9]
	Whipple	R	25–50	CDFW 1999[5]
	Old Woman*	N	25–50	CDFW 2016[2,7]
	Chemehuevi	N	25–50	C. Epps 2002–2003[8,9]

Table 1. Continued.

	Sacramento	E	0	C. Epps 2001–2003[8,9]
	Clipper*	N	151–200	CDFW 2019[2,5]
	South Bristol*	C	51–100	CDFW 2019[2,7]
	Marble*	N	151–200	CDFW 2019[7,8]
Central Mojave	Cady*	N	101–150	CDFW 2015[2,5]
	South Soda*	C	51–100	CDFW 2019[2,7]
	North Bristol*	R	51–100	CDFW 2017[5]
	Old Dad/ Kelso/Marl/Club*	N	51–100	CDFW 2018[2,5,7]
	Granite*	N	51–100	CDFW 2019[2,5]
	Providence	N	51–100	C. Epps 2001–2003[8,9]
	Wood/ Hackberry*	N	51–100	CDFW 2019[2,5]
	Castle/Hart/Piute*	N	101–150	CDFW 2019[2,5]
	Dead	N	<25	CDFW 2018[2,5]
North Mojave	Granite/Quail	E	0	No new data
	Owlshead	T	0	CDFW 2008[5]
	Eagle Crags	R	25–50	T. Campbell 2010
	Argus/Slate	R	51–100	R. Osgood 2003[9]
	Coso	C	<25	Epps et al. (2010)
	Black Mountains & Greenwater	N	25–50	CDFW & NPS 2018[5,9]
	South Panamint*	N	51–100	CDFW & NPS 2018[5,9]
	Tucki	N	25–50	No new data
	Panamint Butte/Hunter	N	51–100	No new data
	Funeral	N	51–100	CDFW & NPS 2018[5,9]
	Tin	N	51–100	J. Wehausen 2006[8]
	Grapevine	N	51–100	NPS 2017[7,9]
	Dry Mountain/Last Chance	N	51–100	CDFW 2017[7,9]
	Inyo	N	51–100	J. Wehausen 2003[8,9]2008[5]
	Deep Springs	C	<25	S. Hetzler 2000[9]
	North White*	N	301–400	CDFW 2019[2,7]
	South White*	R	25–50	CDFW 2019[7]
	Clark*	N	51–100	CDFW 2016[2,5]
	Kingston/Mesquite*	N	151–200	CDFW 2018[2,5]
	Nopah*	N	101–150	CDFW 2018[2,5]
	Resting Spring	N	<25	CDFW 2019[2,4,5]
	North Soda	T	0	G. Sudmeier 2010[9]
	Avawatz*	A	<25	CDFW 2018[2,5]
Sierra Nevada	Twin Lakes	E	0	SNBS Report 2017
	Green Creek	E	0	SNBS Report 2017
	Cathedral Range	R	<25	SNBS Report 2017[2,3,7]
	Mt. Warren	R	<25	SNBS Report 2017[2,7]
	Mt. Gibbs	R	25–50	SNBS Report 2017[2,7]
	Convict Creek/McGee Creek	C	<25	SNBS Report 2017[7]

Table 1. Continued.

	Wheeler Ridge	R	51–100	SNBS Report 2017[7]
	Coyote Ridge	E	0	SNBS Report 2017
	Taboose Creek	C	<25	SNBS Report 2017[2,3,4,7]
	Sawmill Canyon	N	51–100	SNBS Report 2017[7]
	Bubbs Creek	C	25–50	SNBS Report 2017
	Mt. Baxter	N	101–150	SNBS Report 2017[2,7]
	Mt. Williamson	N	25–50	SNBS Report 2017
	Mt. Langley	R	51–100	SNBS Report 2017[7]
	Olancha Peak	R	25–50	SNBS Report 2017[2,3,7]
	Big Arroyo	R	<25	SNBS Report 2017[2,3,7]
	Laurel Creek	R	<25	SNBS Report 2017[2,3,7]
Northeastern California	Truckee River	E	0	No new data
	Skedaddle/Smoke Cr.	E	0	No new data
	Warner	E	0	No new data
	Lava Beds/Mt. Dome	E	0	No new data
	Mt. Shasta	E	0	No new data
	Goosenest	E	0	No new data
	Bogus Mt.	E	0	No new data

[1] N = native; C = natural re-colonization (population may have been re-established by remnants of a previous population or re-colonized by nearby populations); A = augmented; R = reintroduced; E = extirpated; T = transient range, seasonal use
[2] Population status has been revised since 2011
[3] Population has been redefined since 2011
[4] Newly–discovered population
[5] Helicopter survey/capture
[6] Mark/resight population estimates
[7] Direct counts from ground and/or camera observations
[8] Partially based on genotypic capture-recapture estimates from non-invasive genetic data
[9] Field observations of animals or sign
***** *Mycoplasma ovipneumoniae* (*M. ovi*) has been detected in this population.

Status of Bighorn Sheep in Nevada, 2018 – 2019

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Desert Bighorn Council Transactions 55:85–90

HERD DISTRIBUTION AND POPULATIONS

Though there are approximately 75 desert bighorn herds currently in Nevada, some exist in the same game management unit with various levels of home range overlap and male foray interchange. For purposes of assessing population size frequency and variation, these herds involve 46 unique bighorn populations. Estimates for each herd are generated from deterministic spreadsheet models that reconstruct population dynamics based on known production/recruitment, known harvested male ages, and estimated adult survival. The median population size was 100-200 animals (n = 20 or 43% of all desert bighorn populations in Nevada; Fig. 1). The next highest category was > 300 (n = 11 or 24%). Of these populations, 6 are reintroduced and 5 are remnant. All but 1 of these populations are strongly supported by water developments added to existing limited natural water sources. Eight populations or 17% of total were < 100. The reintroduction of herds to historically occupied habitat involved construction of over 150 water developments and 137 translocation events involving 2,111 animals.

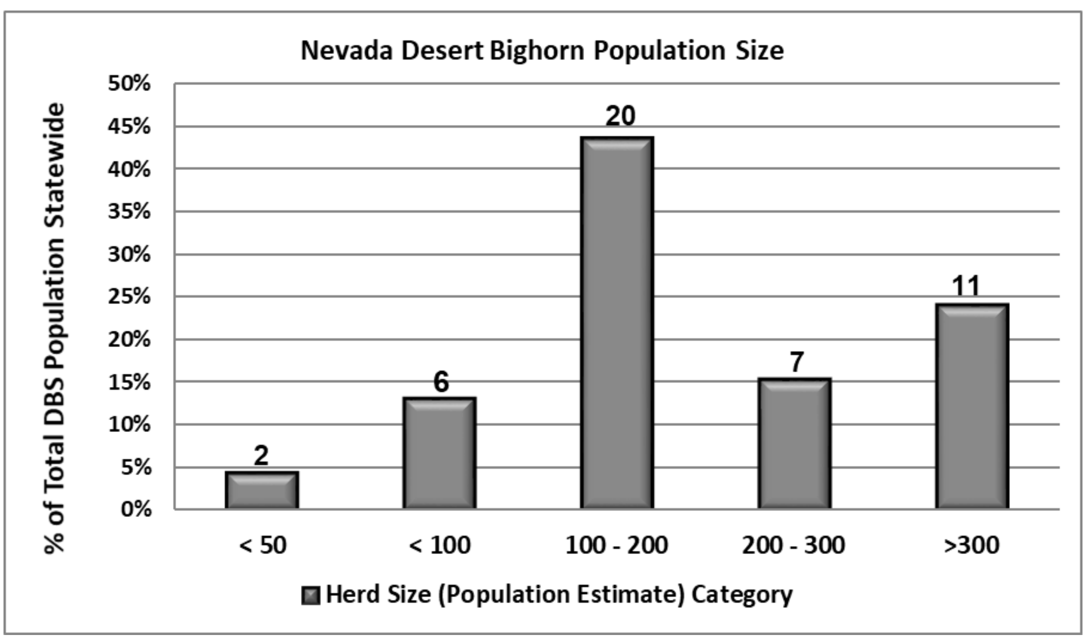

Figure 1. Frequency distribution of 2019 Desert Bighorn estimated populations in Nevada. The largest population is estimated at 750 and smallest is 20 (excluding lambs).

The statewide desert bighorn population estimate in 2019 was 10,300 (Fig. 2), compared to the lowest estimate of Nevada's bighorn population at 2,000 – 3,000 in 1960. It is estimated that state's bighorn population in 1860 exceeded 30,000 based on historical accounts, archeological, paleontological evidence, and areas with features of bighorn habitat features (Cox et. al. 2001). It was first acknowledged in the 2001 Nevada Bighorn Sheep Management Plan that the entire state of Nevada, the heart of the Great Basin, was a single but diverse metapopulation of desert bighorn sheep (Ramey 1993, Ramey 2000, Wehausen and Ramey 2000). The plan also recognized the decades of successful transplants of Rocky Mountain and California bighorn sheep and the need to continue to manage these herds in concert with expanding distribution of desert bighorn distribution (Fig. 3).

Abbreviated statewide helicopter surveys in August – October 2018 classified fewer than 4,000 bighorn (Fig. 4). The 23 lambs:100 ewes ratio was the lowest ever recorded in the history of Nevada helicopter surveys. Likely factors that contributed to this decline were extremely dry 2018 summer conditions in parts of the state, pneumonia-related lamb mortality in several large herds, and possible rising populations and increasing densities. The sex ratio of 50 males:100 females was the lowest recorded since 1990. The causes of this decline are unclear.

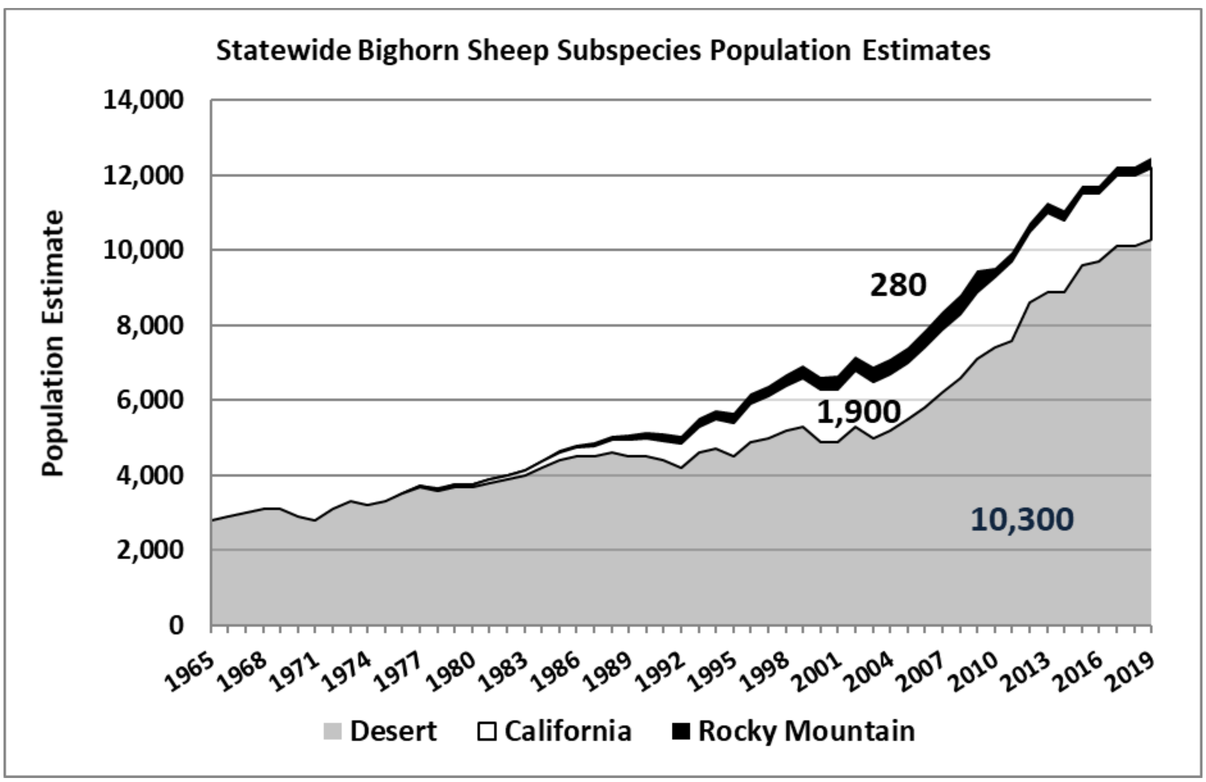

Figure 2. Nevada bighorn sheep population estimates by subspecies, 1965 – 2019

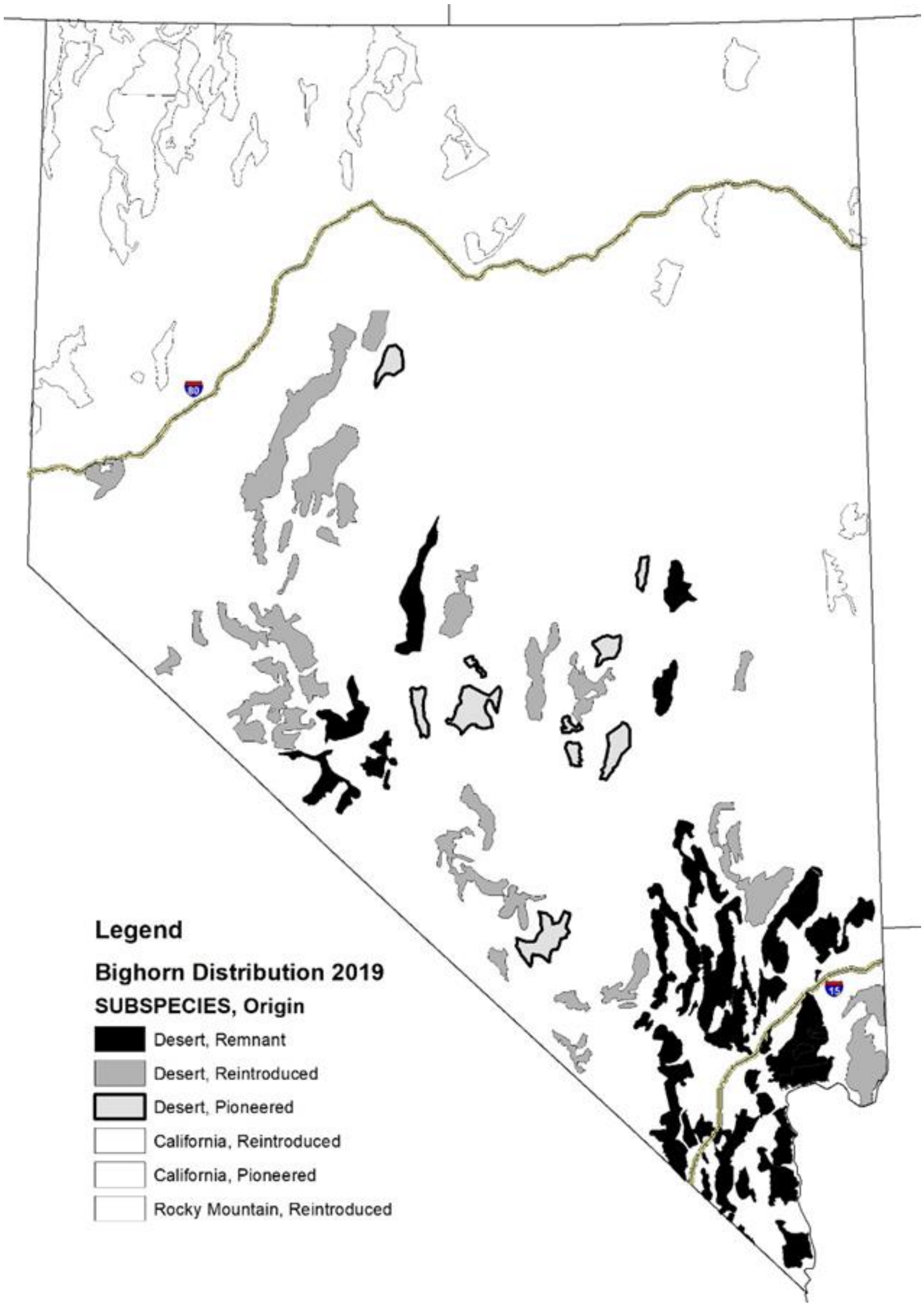

Figure 3. Occupied bighorn sheep habitat in Nevada by subspecies and origin (remnant, reintroduced, or pioneered), 2019.

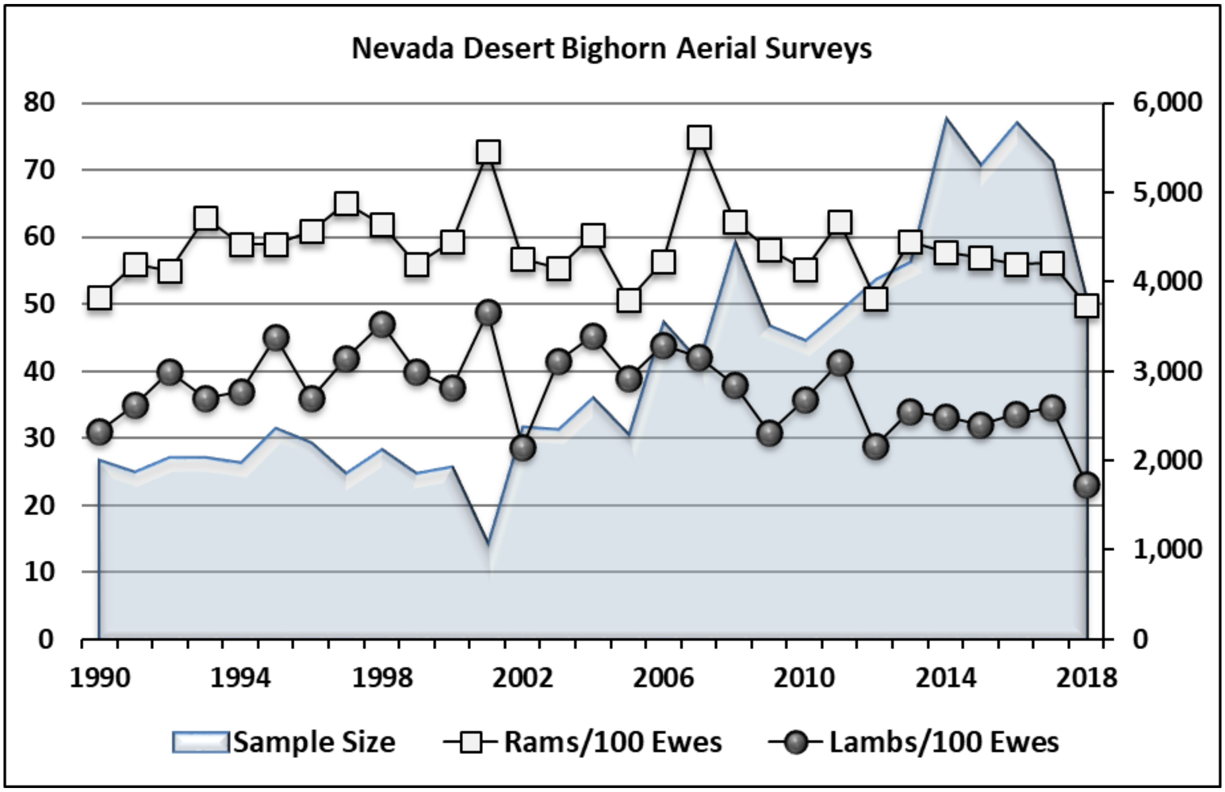

Figure 4. Desert bighorn helicopter survey results, 1990-2018.

HARVEST

A total of 312 desert bighorn tags were available to residents and nonresidents (90:10 split) through a restricted tag draw process. A total of 9,196 residents and 10,063 nonresidents applied for 282 and 30 tags, respectively. An additional 2 auction tags and 3 special raffle/draw tags were also issued in 2018. Statewide hunter success was 90%, comparable to the average hunter success over the last decade of 89%. Since the first year of the any male regulation in 1996, the average age of harvested males has been 6.3 years. The 2018 average male age was 6.4. From 2010 to 2016 there were 1 or more males harvested that exceeded 180 B & C score. No harvested males in 2017 and 2018 exceeded 180 B & C score. The highest number of 170+ B & C males in a single season occurred in 2017 at 21 males with 17 males of this score in 2018, and the average number since 2010 of 16.

Nevada's annual desert bighorn male harvest totals since the first legal hunting season in 1952 to the present is a classic exponential growth curve all the while maintaining strong age structure in the harvest and quality hunting experiences (Fig. 5). The fruits of the past bighorn restoration labors continue to result in an increase of male tags available from reintroduced herds. In 2018, 54% of the statewide desert bighorn male tags were from reintroduced and pioneering herds compared to remnant herds. This percent has slowly been increasing over the last decade.

Figure 6 illustrates the strong trend that male tag increases were supported by ample availability of mature males and the resulting harvest of mature males. Though the decline in average male harvest age in 2018 may reflect either a lack of male lamb recruitment 6-8 years ago, a slight overharvest over the last 4 years, or reduced hunter effort or selection for older age males.

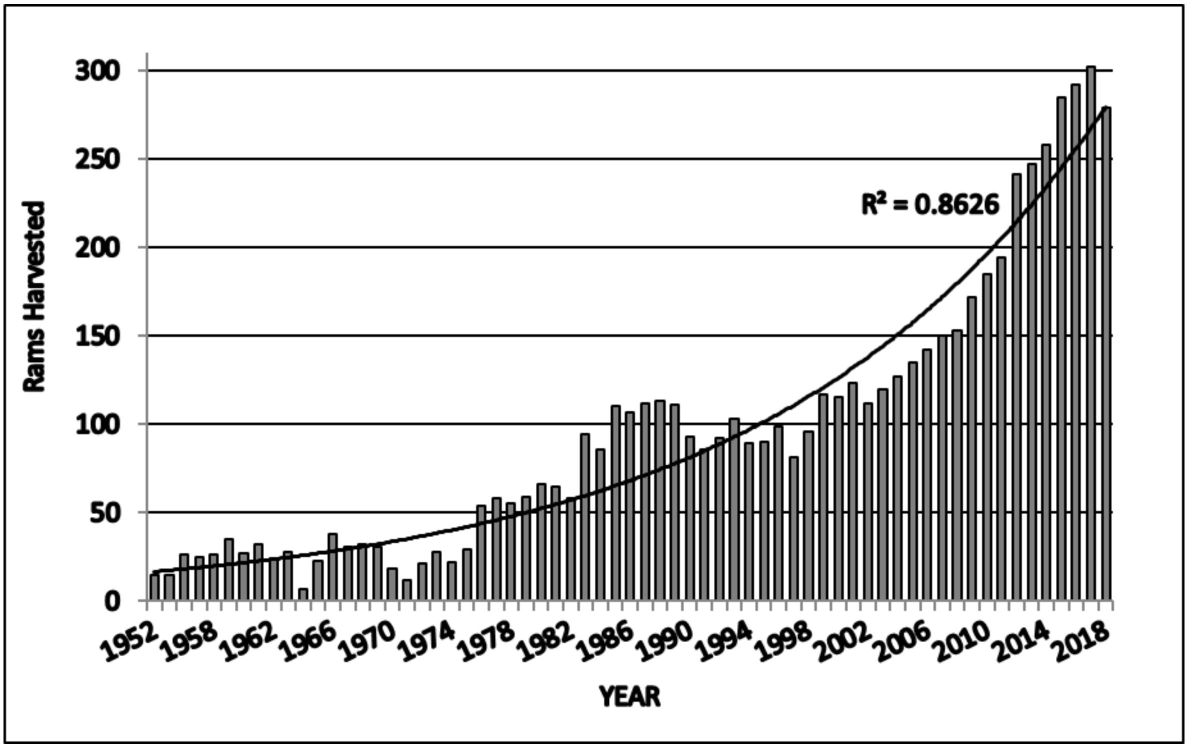

Figure 5. Desert bighorn male harvest from the first legal hunting season in 1952 through 2018 in Nevada. The annual male harvest is a strong fit to exponential growth.

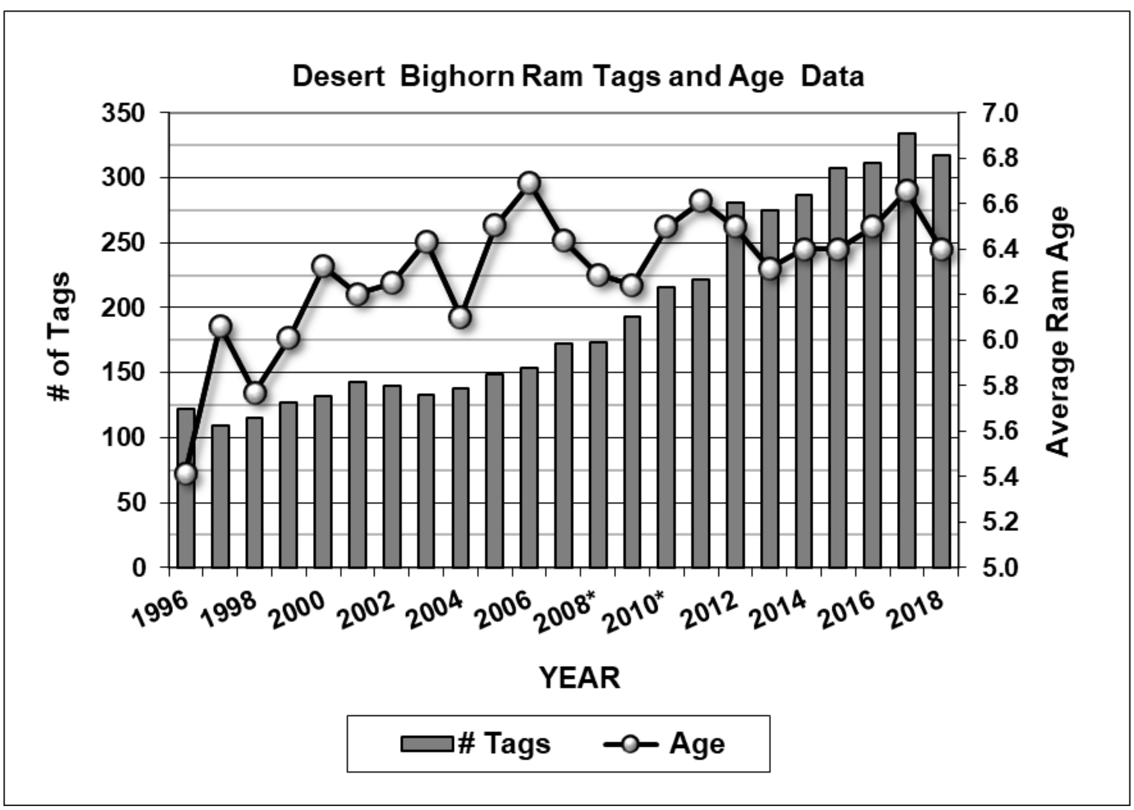

Figure 6. Trend of total desert bighorn male tags and average age of male harvest, 1996 – 2018.

FUTURE MANAGEMENT CONSIDERATIONS

Polymicrobial upper respiratory disease events and die-offs continue to impact Nevada desert bighorn herds. With the broad and connected distribution of bighorn populations, the ability to isolate or stop pathogen transmission among bighorn herds is simply not feasible. NDOW has nearly completed a statewide pathogen surveillance of all bighorn herds in 2018; this program began in 2011. Only a handful of desert bighorn herds have not had the pathogen of concern, *Mycoplasma ovipneumoniae* detected. Varied demographic responses have been documented including 1 to 5 years of compromised lamb recruitment and minimal to 25% adult mortality in a single year from pneumonia. NDOW is collaborating with Dr. Kezia Manlove and her 2 graduate students at Utah State University to compile and assess relationships and patterns from all the past data collected on pathogen profiles, *M. ovi* strain types, herd responses, habitat productivity, various covariates, and possible predictor variables to hopefully elucidate why certain herds respond differently to pathogen exposure. It is also the vision that once Dr. Manlove has developed a database structure/schema and appropriate analytical tools, to collaborate regionally with all other southwestern states and agencies (state and federal) to evaluate desert bighorn disease ecology with insight to future herd management.

NDOW will continue to seek herd management opportunities involving both translocating bighorn sheep (intra- and inter-state) and conducting female hunts to manage herds in relation to limiting habitat components such as summer water availability. Since the inception of ewe hunts in 2014 through 2018, NDOW has issued 656 ewe tags to both residents and nonresidents with total harvest of 440 animals.

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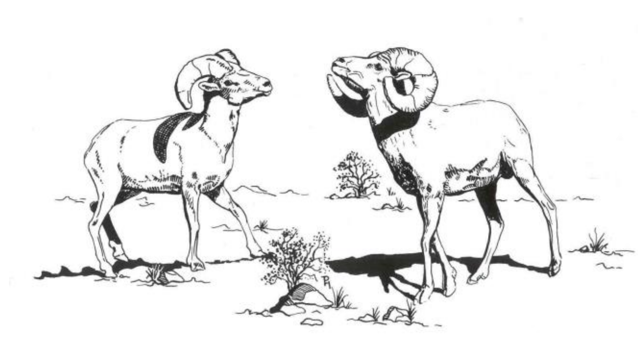

Status of Desert Bighorn Sheep in New Mexico, 2017 – 2018

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Desert Bighorn Council Transaction 55:91–94

SYNOPSIS

The total number of desert bighorn sheep continues to increase in New Mexico (Fig. 1). Populations in the Peloncillos, Ladrones, and Hatchet mountains received augmentations in this timeframe. This brought population estimates for all current herds above 100 sheep. Additionally, the Department released 34 desert bighorn into the vacant historical habitat in the western Sacramento Mountains. This was the first new population started via translocation since 1995. *Mycoplasma ovipneumoniae* (*M. ovi*) was detected for the first time in the Fra Cristobal population. This recent detection of *M. ovi* coincided with observations of respiratory disease symptoms in Fra Cristobal bighorn and its presence is expected to impact future restoration by transforming the geographic outlook for translocations.

POPULATION STATUS

Bootheel Metapopulation

The Peloncillo Mountains (165-180) population received an augmentation of 33 desert bighorn from the Red Rock Captive Facility in October 2018. Sheep were released at Granite Peak, to bolster this subpopulation. Since the release, three radio-collared animals died; two due to lion predation and one to unknown causes. The Peloncillo population ranges from the mountainous canyons near Rodeo, New Mexico northward to the Arizona border. Interstate 10 bisects the northernmost portion of the Peloncillo Mountains in New Mexico and bighorn are consistently observed immediately north of I-10. Sheep captured and fitted with GPS collars by Arizona Game and Fish Department (AZGFD) have been found to use this portion in New Mexico. No movements across Interstate 10 (I-10) have been documented from GPS collars deployed on sheep by New Mexico Department of Game and Fish (NMDGF) and AZGFD. However, several years ago, a male fitted with a VHF collar did cross I-10 from the south side and returned. A bighorn sheep was reported killed on I-10 in 2018. The most recent survey resulted in 105 sheep observed and a spring lamb:ewe (L:E) ratio of 38:100.

The Hatchet Mountains (180-230) were surveyed twice in this timeframe. NMDGF typically attempts to fly the Little Hatchets and Big Hatchets consecutively, but the most recent surveys are from separate seasons. The 2017 fall L:E ratio in the Little Hatchets was 27:100 and the 2018 spring L:E in the Big Hatchets was 50:100. Two males were released from Red Rock into the Little Hatchets in October 2018. Radiocollared mortalities include 5 bighorn, three were lion predation, one suspected wounding loss, and one due to unknown causes.

Fra Cristobal & Caballo Metapopulation

The overall trend for this metapopulation is stable compared to the prior 2-year period. The Caballo Mountains (200-230) population estimate increased, however, and the Fra

Cristobal estimate (225-275) decreased. The Caballo survey produced a minimum count of 199 sheep and a L:E of 49:100. Five radiocollars were deployed in this herd in October 2018, and one was recovered after going in mortality mode, but no carcass was found. The estimated decrease in population in the Fra Cristobal, followed a translocation removal and an apparent disease outbreak. There was a 15% loss of radio-collared animals during the suspected respiratory event. Pneumonia could not be confirmed upon field necropsy but the event coincided with the detection of *M. ovi* and observation of symptoms including coughing and lethargy. Surveys conducted in the fall months following the spring disease event resulted in L:E ratios of 21:100 (September ground survey, n = 78) and 32:100 (October helicopter survey, n = 179).

Ladron Mountains

The population in the Ladron Mountains (125-150) received an augmentation of 22 sheep in December 2017 from the Fra Cristobal herd. It was discovered post-release that one translocated female tested PCR positive for *M. ovi*, providing the first indication of *M. ovi* presence in the Fra Cristobal Mountains. There has been no evidence of disease occurrence in the Ladron population since the release. A record 121 sheep were observed on the 2-day helicopter survey in May 2018. Additionally, a record number of females was observed for this mountain range (n = 58). The L:E ratio was 46:100. This herd is wide-ranging, with the northernmost and southernmost groups separated by approximately 70 miles. Five radio-collared sheep died in this timeframe (3 lion, 1 road kill, and 1 unknown).

San Andres Mountains

The most recent survey of the San Andres Mountains (200-240) occurred in November 2017 and yielded a minimum count of 190 sheep. GPS collars were deployed on this herd in December 2017 (n = 16). Two sheep died within days of the capture and since the 2017 collaring one more radio collared female died due to unknown causes. In October 2018, 34 bighorn were translocated from the San Andres to the Sacramento Mountains.

Sacramento Mountains

The Sacramento Mountain (30) restoration in October 2018 ended nearly a century of bighorn absence from this historically occupied habitat. Two radiocollared sheep died within a couple months of the release, including one female that traveled a straight-line distance of 35 miles from the release site. One uncollared female was shot accidentally by a barbary sheep hunter. Six mountain lions were removed from bighorn sheep habitat within the first two months post –release. An augmentation within 2 – 3 years will occur if surplus sheep are available in a desirable source population.

MOUNTAIN LION CONTROL

In 2017 and 2018, 33 lions were removed from desert bighorn habitat. Control efforts occurred across 6 occupied desert bighorn ranges including the newly established Sacramento Mountains. NMDGF's removals result in an average of 2.75 lions removed per range per year. This is consistent with previous reporting periods. During this timeframe private landowners could trap or snare lions on their private deeded acreage using sport harvest tags. Related lion removals, therefore, include 5 lions taken on a private property in the Ladron bighorn range during this 2-year period.

DISEASE

M. ovi has emerged as a significant pathogen of concern for bighorn sheep. Recent research supports prioritizing the monitoring

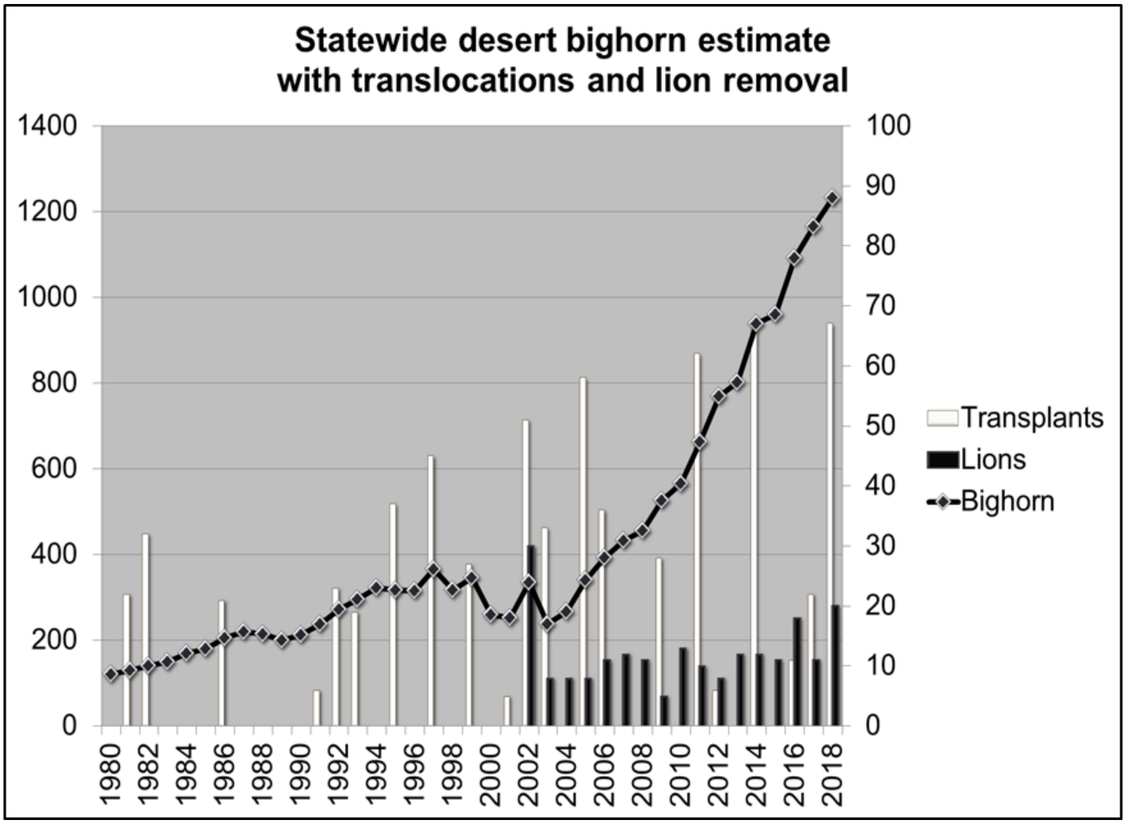


Figure 1. New Mexico statewide desert bighorn population trend from 1980-2018. Transplanted desert bighorn sheep and mountain lion removals are also shown.

of this bacteria whenever possible as the consequences of spillover can lead to pneumonia events that include morbidity, mortality (sometimes across all age classes), and chronically low lamb recruitment. Though other pathogens contribute to pneumonia, *M. ovi* is considered the primary pathogen found during respiratory disease events in bighorn populations. NMDGF plans to expand monitoring of baseline *M. ovi* status of herds and continue monitoring for potential disease events using radio-collared animals and annual surveys.

Bighorn captured in the Peloncillos and Ladron mountains, and the Red Rock captive facility have not tested positive for *M. ovi*. Testing of bighorn in the Hatchet and Caballo mountains has not yet been completed. *M. ovi* was recently discovered in the Fra Cristobal Mountains. The *M. ovi* strain detected in the Fra Cristobal matches that found in the San Andres, and Kofa, AZ. *M. ovi* was unknowingly introduced to San Andres when bighorn were translocated from the Kofa in the early 2000s. Aside from some initial pneumonia mortality at that time, no significant die-off events have been documented in the San Andres Mountains. This subsequent spillover to bighorn in the Fra Cristobal Mountains suggests some inter-mountain movement between the San Andres and Fra Cristobal mountains. Such movement has otherwise never been documented, despite the cumulative monitoring of more than 300 collars between both herds.

RED ROCK CAPTIVE FACILITY

This facility is censused annually via a 2-day ground survey. In May 2017, the census resulted in 81 (34 females, 22 lambs, 25 males) bighorn observed and in May 2018, 104 (48 females, 26 lambs, and 30 males) were documented. Thirty-six sheep were removed using helicopter net-gun capture methods in October 2018 for an augmentation of the Peloncillo and Hatchet herds. Lions can breach the fenced facility so there are removal efforts when tracks are found in or adjacent to the pens. Three lions were taken in 2017 and 2018, two shortly after being captured on a trail camera inside the enclosure.

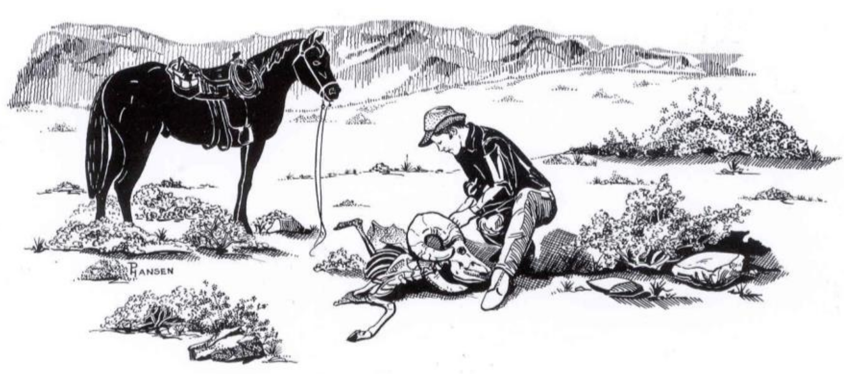
HUNTING

Desert bighorn male licenses in New Mexico continue to be "once-in-a-lifetime" unless they are acquired through the annual auction or raffle. Each year, there were 29 desert bighorn male licenses. Trophy opportunity is premier, with 28 % and 58 % of harvested males measuring above Boone and Crockett minimum record book standards in 2017 and 2018, respectively. The desert auction tags raised $373,500 for New Mexico bighorn during this timeframe, and raffle proceeds contributed an estimated $156,576 in funding (Table 1). These totals exclude monies retained by the organizations for processing.

Table 1. Total funds generated from enhancement authorizations and scores from males hunted on auction, raffle, and public (top score only) licenses in New Mexico, 2015 – 2018.

	2015	**2016**	**2017**	**2018**
Auction	$200,000	$177,500	$145,000	$270,000
Raffle	$143,560	$126,200	$73,000	$122,720
Auction Score	DNH	170 5/8	188 0/8*	175 0/8
Raffle Score	182 2/8	186 6/8*	163 0/8	177 0/8
Public Score	176 0/8*	182 0/8	181 2/8	185 0/8

*indicates official B&C scores.
DNH indicates "Did Not Harvest"



Status of Desert Bighorn Sheep in Texas, 2017 – 2019

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Desert Bighorn Council Transactions 55:95–98

POPULATIONS

Prior to 2008, desert bighorn populations in Texas were rising. Since, the Texas population has seemingly leveled off (Fig. 1). Annual aerial surveys were conducted in August 2017 and 2018. During the 2017 survey, 1,143 bighorns observed with a lamb ratio (lambs per 100 females) of 47:100. In 2018, 1,020 bighorns were observed with a 38:100 lamb ratio. There are an estimated 1,500 desert bighorn sheep statewide.

HARVEST

There were 38 permits issued for the reporting period (2017-2019). In the 2017-18 hunting season, 13 permits were issued, which included 2 public and 11 private landowner permits. The 2017-18 hunt season resulted in a 100% success rate. For the 2018-19 season, 25 permits were issued, 22 were issued to private landowners and 3 were public permits. The 2018-19 hunt season resulted in a 96% success rate (one of the permits was not hunted).

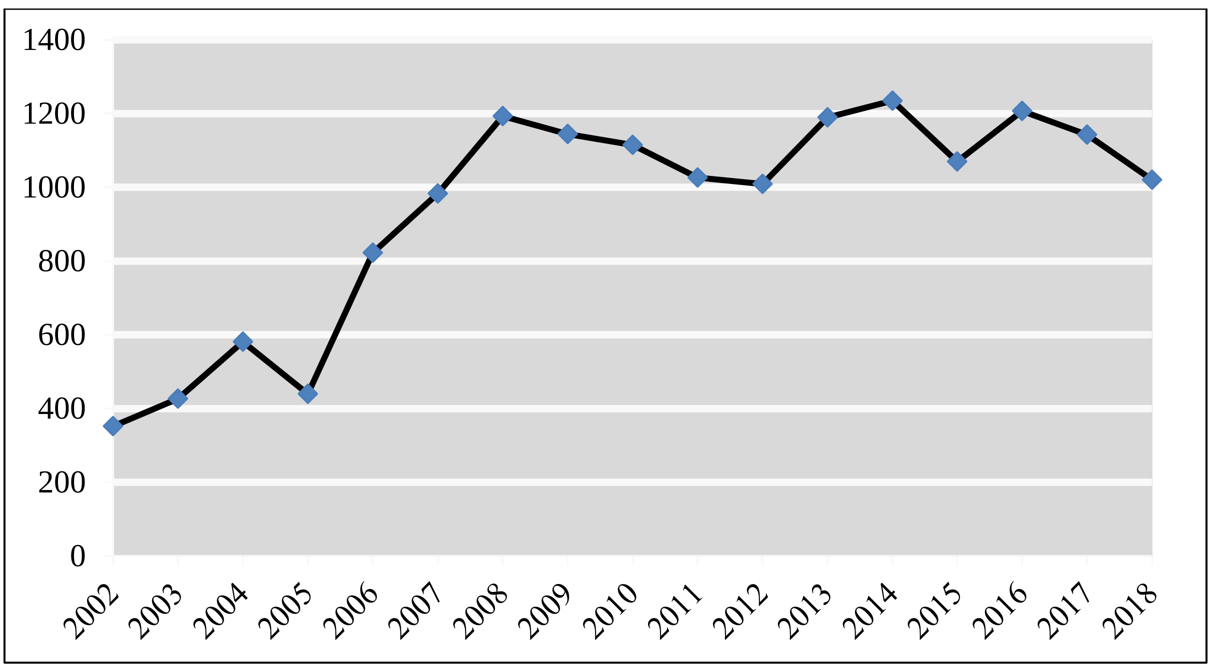


Figure 1. Statewide desert bighorn survey results for Texas. 2002 – 2018.

The increase in number permits during 2018-19 from the 2017-18 season does not reflect an increase in population. Rather, it was change in permit issuance system which allowed more flexibility, as well as an increase in number of permits issued.

The average age and score for males harvested through hunts hosted and guided by TPWD were 10 yrs old and 171 inches, respectively.

WATER DEVELOPMENT

Six new water guzzlers were constructed in strategic locations which will benefit bighorns as well as other wildlife. These water guzzlers were constructed on public land, and on mountain ranges located private property. This added a potential 30,000 total gallons of water for those 6 guzzlers across the landscape. In addition to the new guzzlers, and in collaboration with the Mule Deer Foundation, 4 new guzzlers were constructed on the fringes of bighorn habitat. Additionally, repairs were performed on 15 existing guzzlers, which are within bighorn ranges.

RESTORATION

In October 2017, 37 bighorns were captured on Black Gap Wildlife Management Area (BGWMA) to collect tissue samples as part of the enhanced Disease Surveillance and Monitoring Program, as well as to contribute towards WAWFA-Wild Sheep Working Group Disease Management Venture Program (DMV). Thirty (30) out of the 37 bighorns were fitted with radio telemetry collars to facilitate monitoring and to conduct BGWMA population investigations. All bighorns were released on site.

In December 2017, 82 bighorns were captured on Elephant Mountain WMA and translocated to BGWMA to augment that population. Seventy (70) out of the 82 bighorns were radio-collared to facilitate post-release monitoring and increase sample size for the BGWMA population investigation. Out of the 82 translocated bighorns, 35 were hard-released at a strategic location which was selected based on location data form radio-collared resident bighorns. The first translocated hard-released bighorns had integrated with resident bighorns within 24 hours of being released. The remaining 47 bighorns were placed in a soft-release pen (524 ac enclosure). After a 17-day acclimation period, the gates were opened and bighorns “trickled” out on their own.

Elephant Mountain WMA has played a vital role in bighorn restoration. Since aggressive restoration efforts were initiated in December 2010, Elephant Mountain has served as the stock source for 4 translocations. These translocations have helped restore populations in 3 mountain ranges where bighorn were extirpated nearly 60 years prior, and to augment existing populations (Table 1).

There is yet another capture on Elephant Mountain scheduled for December 2019. The target quantity for the 2019 capture is 80+ animals.

Table 1. Captures and translocations from Elephant Mountain WMA since 2010.

Year	Release Site	Males	Females	Total
2010	Big Bend Ranch State Park (Bofecillos Mountains)	12	34	46
2012	9 Point Mesa Mountain	22	22	44
2014	Capote Peak (Sierra Vieja Mountains)	21	40	61
2017	Black Gap WMA*	37	45	82
			TOTAL	233

*Augementaion

RESEARCH

The radio-collaring of bighorns during captures/translocations have provided study animals for research for 2 M.S. projects and 1 Ph.D. project. One of the M.S. projects included investigating the movements and survival of translocated bighorns from two distinct herds and comparing survival between 2 release methods (hard- vs. soft-release). The second M.S. project is investigating bighorn-aoudad interactions. The Ph.D. project is investigating the spatial, temporal, and demographic characteristics of desert bighorn sheep in Texas.

Though the first M.S. project is nearing its term, it is still ongoing. Some of the results to date are showing highest overall annual survival for resident bighorns in comparison to translocated animals, which was expected given their familiarity with the landscape. In comparing hard- vs soft-released bighorns, hard-released individuals showed higher overall annual survival rates.

The students involved in the second M.S and the Ph.D. projects are still performing data analysis.

A tri-species study was initiated in January 2019 in the Van Horn Mountains of Texas. This study, which to our knowledge is the first of its kind, will be investigating the interactions between desert bighorn, aoudad and desert mule deer. These investigations will include habitat use, overlap and partitioning, disease transmission potential, and movements, among other things. We are optimistic that the Van Horn Mountains tri-species project investigations will shed light into some potential negative impacts and interactions.

DISEASE MONITORING

Even though Texas does not appear to have the disease problems seen in the western states due to domestic sheep/goat interactions and contact, disease monitoring and surveillance continues to be an important aspect of desert bighorn restoration. As such, biological tissues are collected from all bighorns captured and tested for various pathogens, including *Mycoplasma ovipneumoniae*. In addition to sampling bighorns, aoudad are now also being tested. The tissue samples, which have routinely been collected from bighorns including blood, hair, fecal, and ear/nasal/tonsil swabs are now also being collected from aoudad.

To help with this effort, tissue samples were collected from 47 aoudad which were dispatched on the Sierra Vieja and Chinati mountains during October–November 2018. Results are not yet available.

EMERGING THREATS

Barbary sheep, more commonly known as aoudad are emerging as challenging management issue in Texas. The aoudad is an exotic species from the arid mountains of northern Africa. They were introduced into Texas in the late 1950s, mainly in the Palo Duro Canyon area. However, they have since been either introduced to other parts of Texas or expanded naturally onto other areas. Aoudad are currently found in high-fenced game operations and in free-ranging populations primarily throughout the Hill Country, Panhandle and West Texas. Though aoudad populations are struggling in their native ranges in northern Africa, aoudad have done well in Texas. It is not uncommon to encounter herds of >50 animals, and many groups with >100 in the herd.

To get a better sense for aoudad densities, surveys conducted in late October 2018 on 2 mountain ranges resulted in observing nearly 4,000 animals. Total survey area encompassed approximately 38,000 ha. During 27.15 hours of flight time, an average of 134.4 aoudad per hour were observed. However, due to logistical challenges, one of the mountain ranges was not completely surveyed. Had that mountain range been completely surveyed the count would have likely been closer to 5,000.

Some groups during the October 2018 aoudad survey were in excess of 200 animals. These heavy concentrations or high densities can certainly impact native ungulate species, including desert bighorn and mule deer, as well as negatively affect the habitat.

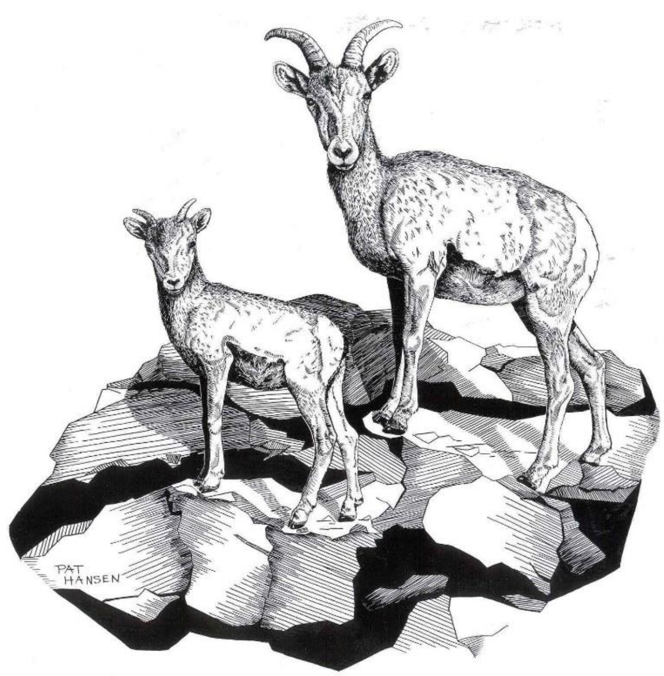
Aoudad populations need to be drastically reduced to lessen impacts to habitat and native wildlife populations. TPWD is conducting its own Aerial Gunning Training Program. This program focuses on helicopter safety, weapon safety and handling, target acquisition, marksmanship and in-flight communication. All personnel performing aerial gunning operations are required to participate in the training.

But recognizing the growing popularity of aoudad hunting, a high level of reduction will be challenging to achieve. Aoudad hunting continues to be a supplemental source of income for some landowners, which adds to the difficulty. Until the detrimental impacts of high aoudad densities are better understood through research findings and presented to the public, it will be problematic to make progress.

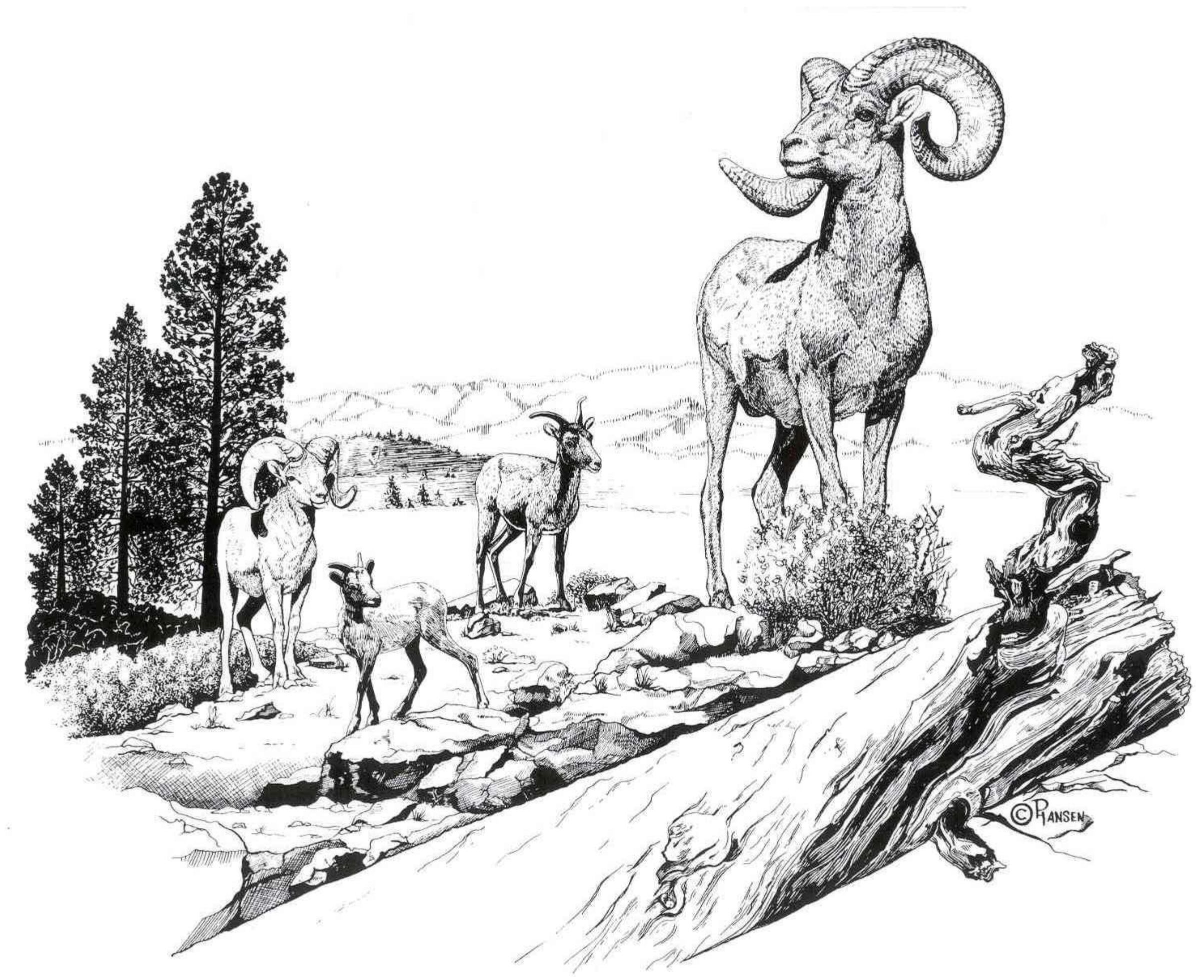
CLOSING

Overall the desert bighorn populations in Texas are holding steady. TPWD plans to continue efforts to restore desert bighorns to historically occupied mountain ranges which are currently uninhabited, or augment populations when deemed appropriate.

Luckily, since the early stages of desert bighorn restoration efforts in Texas, the Texas Parks and Wildlife Department has had the good fortunate of great relations with hunters and outdoor enthusiasts, dedicated landowners, committed individuals, loyal volunteers and great conservation organizations, who share the passion for wildlife. Without their support, bighorn restoration would have been nearly impossible. TPWD will continue to work collaboratively with all interested parties to ensure that the restoration, management, research and hunting of desert bighorn sheep in Texas keeps moving forward.



Abstracts of Presented Papers



THE BIGHORN HABITAT ASSESSMENT TOOL: A CONCEPTUAL FRAMEWORK FOR QUANTIFYING THE VALUE OF MITIGATION LANDS FOR BIGHORN SHEEP IN A WORKING INDUSTRIAL LANDSCAPE.

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A conceptual methodology was developed to assess the suitability of mitigation lands as bighorn sheep habitat within landscapes affected by historical and ongoing mining activity. The Bighorn Habitat Assessment Tool (BHAT) is proposed to aid the development of an adaptive management plan for the Cushenbury population of bighorn sheep (*Ovis canadensis*) on the north slope of the San Bernardino Mountains in Southern California. A formulation of conservation value is presented using results of resource selection function analysis and mitigation credits reflecting the degree to which degraded habitat is enhanced to benefit wild sheep. The BHAT seeks to a) establish a habitat reserve providing maximum benefit to the unique requirements of bighorn sheep, b) incentivize voluntary actions by industry to ensure mining activities are compatible with bighorn sheep conservation, and c) allow for the objective evaluation of multiple mine planning and resource management alternatives. The proposed framework would be transferrable to other mountain sheep populations occupying mine-influenced landscapes for which sufficient data are available to complete resource selection analysis.

ESTIMATING DETECTION PROBABILITY THROUGH MARK-RESIGHT IN A CENTRAL NEVADA BIGHORN SHEEP POPULATION.

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Aerial surveys for desert bighorn sheep (*Ovis canadensis nelson*) are biased by imperfect detection, partially because of variable habitat types, precipitous terrain, and the inability to cover entire survey areas. This bias in count data can lead to imperfect population estimates. To quantify factors that influence bias and variation in aerial surveys and produce a defensible population estimate with confidence intervals, we conducted a mark–resight aerial survey on Lone Mountain, NV during September 2018. This was accomplished by using 24 existing GPS satellite radiocollars that were previously deployed in the study area. Radiocollars were programmed to collect locations every 15 minutes to increase our ability to synchronize identified groups and marked individuals. Previous data collected from these GPS radiocollars allowed us to determine that the area was a closed population and that individual distribution was limited to Lone Mountain and the Weepah Hills during the survey period, thus limiting assumptions made during population modeling. Helicopter surveys were conducted via a directed search design, where observers flew within drainages throughout the mountain range and altered course when individuals were observed to identify and enumerate individuals and identify group composition, age structure, and radiocollar presence. Survey efforts accounted for 9 of 24 collared individuals, yet this does not account for individual availability along flight paths. We also assessed behavior during survey to determine if a "trapper" effect existing among individuals that were captured up to 3 years in a row, and we detected no significant influence on individual behavior.

RESOURCE SELECTION IN FEMALE DESERT BIGHORN SHEEP: TRADEOFFS ASSOCIATED WITH REPRODUCTION.

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Different time periods of reproduction, provisioning, and recruitment of young will cause females to vary in how they select habitats. Females may select areas with higher nutritional value to support gestation and lactation or they may tradeoff nutritional resources for safety of dependent young. Understanding how desert bighorn sheep (*Ovis canadensis nelsoni*) select resources to aid in safety of young and nutrition for the mother while provisioning young

is largely unknown. To increase understanding of how females select resources to increase survival of young during gestation and following parturition, we captured and radiocollared 30 adult, female sheep on Lone Mountain in Western Nevada. We also captured neonatal young and determined location of birth sites as well as information on survival. We monitored parturition events, adult resource selection, and neonate survival. We used a machine learning algorithm, random forest, to identify habitat selection during late gestation, following parturition, and in the event of mortality of young. Our results indicated that adults shifted resource selection from areas with higher nutritional availability to more precipitous terrain immediately following parturition events, when neonates were most vulnerable to predators. In addition, our results indicated that females shifted resource selection to areas with higher quality vegetation and reduced terrain ruggedness following the mortality of a neonate and as neonate age progressed. Following the death of a neonate, females immediately shifted selection of resources to increase their nutrient intake.

COMBINING MARK-RESIGHT WITH ADDITIONAL METHODS TO IMPROVE ESTIMATES OF ABUNDANCE FOR MONITORING SMALL POPULATIONS.

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Monitoring studies often use marked animals to estimate population abundance at small spatial scales. Wildlife conservationists and managers may need accurate estimates of population abundance to determine if a population has fallen below a threshold. However, marking animals is invasive, costly, and may be dangerous for the animals, which is of particular concern for monitoring endangered populations. In addition, when populations are small, minimum counts and abundance estimate from mark-resight may be similar, and mark-resight methods are often more time consuming and arduous to conduct appropriately. However, minimum counts normally underestimate population abundance and often show high variation from count to count and year to year, making them a poor method for detecting declines or determining when a population has truly fallen below a management threshold. Thus, there is a trade off in the expense, time, and danger for higher precision mark-resight estimates versus more the typically biased and more stochastic minimum counts with their higher risk of missing precipitous declines. Including groups found using VHF or GPS radiomarked animals, which we refer to as telemetry assisted, may improve precision of abundance estimators and be less biased than minimum counts. Here, we conducted simulations, based on field data collected on 4 small populations of Sierra Nevada bighorn sheep (SNBS, *Ovis canadensis sierrae*) 2006–2017, to determine how the inclusion of marks found via telemetry affects the bias and precision of mark-resight abundance estimates, and compare the different methods to minimum count. We found that using the telemetry assisted mark-resight reduced variance of abundance estimates. For a sampling intensity typical of SNBS surveys, (3 surveys, 30% of the animals marked, and a population size of 100), the CV was reduced by about 50% for telemetry assisted mark-resight. These reductions mean that ≥25% declines can be detected in approximately 4 years when using telemetry-assisted mark-resight, compared to 15 years with regular mark-resight. Although telemetry assisted mark-resight has the largest variance reduction, it comes with some negative bias; 4% in this case. However, it still has potential to be useful because the bias is constant across population sizes for a given proportion marked. This bias constancy over population size changes means telemetry assisted mark-resight can provide a good estimate trends in population abundance and rate of population change (λ). Over the longer 10–15-year window, small populations can have undetected declines that increase their risk of extirpation due to a combination of environmental conditions, predation events and demographic stochasticity. We recommend using telemetry to assist with mark-resight surveys for small populations with the caveat that if the proportion of marked animals in the population changes, there needs to be an adjustment for the change in bias.

WILD SHEEP RAM HUNTING PERMIT PROCESS FOR WESTERN STATES AND PROVINCES.

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A questionnaire was completed in early 2018 by 19 of the 20 wild sheep (*Ovis* spp.) program managers in the western US and Canada on their ram hunting permit or tag setting process, demographic survey efforts, season structure, and limited hunt results. A similar review of west-wide ram harvest strategies was conducted 10 years ago. The goal of the questionnaire was to: review the demographic information collected and guidelines and criteria used in setting

ram hunting permit or tag numbers; compare season structure and harvest metrics; and challenge jurisdictions to use the best available science and consider more ram hunting opportunities without sacrificing ram horn quality. To determine ram hunting permit numbers, most agencies use a guideline of 1) percent of the current estimated population size, 2) total rams, 3) mature rams in population or survey, or 4) previous year's ram harvest metric. Two agencies have no standard guideline. The ranges of long-term mean ram harvest age by jurisdiction and species or subspecies were: 7.8–9.3 for Dall or Stone sheep (*O. dalli*); 6.5–7.0 for California bighorn sheep (*O. canadensis*); 6.4–10 for Rocky Mountain bighorn sheep (*O. canadensis*); and 6.4–9.0 for desert bighorn sheep (*O. c. nelson* or *mexicana*). Most jurisdictions have a similar hierarchical decision and approval ram permit process of: field-regional review of wild sheep biological data and information and recommendations; program lead and Bureau-Division heads provide oversight and support; wide array of stakeholder involvement; and final Board or Commission review and approval. Many agencies follow guidance provided by their wild sheep management plan. One state has a single committee that sets permit numbers with no public process. One jurisdiction is moving to a formal "Structured Decision Making" process to better engage stakeholders, provide transparency, account for uncertainty and values and opinions, while incorporating science and following management objectives. Finally, I apply each of the jurisdiction's ram permit guideline to Nevada's desert bighorn sheep herds to compare the resulting ram permit numbers compared to Nevada's 2017 approved desert bighorn sheep ram permit numbers.

BALANCING CONNECTIVITY, GENETIC DIVERSITY, AND DISEASE: A FRAMEWORK TO STUDY THE INHERENT TRADEOFFS IN METAPOPULATION MANAGEMENT.

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Management of desert bighorn sheep (*Ovis canadensis nelsoni*) exemplifies the "double-edged sword" of connectivity. Desert bighorn sheep often exist in metapopulations subject to local extinction but linked by movement allowing demographic rescue or recolonization. If isolated, local populations are subject to very rapid genetic drift and loss of genetic diversity. Connectivity among populations thus appears to be a primary means for maintaining genetic diversity and metapopulation resilience. Yet, with such connectivity comes the threat of rapid spread of respiratory pathogens such as *Mycoplasma ovipneumoniae*. Theoretical and empirical evidence indicate that loss of genetic diversity and inbreeding will eventually compromise fitness, but the thresholds at which such consequences appear are obscure. Moreover, extinction and colonization dynamics in metapopulations play out over long time scales. Thus, managers are faced with a severe dichotomy. Should they work to bolster or reestablish populations and maintain or improve connectivity, or create "firewalls" by allowing fragmentation, isolation, and empty habitat so that epizootics do not move rapidly through the system? Here, I review recent evidence for positive and negative consequences of metapopulation connectivity in the Mojave Desert of California in the face of recent disease outbreaks, describe changes in connectivity observed in recent decades through genetic studies, and discuss gaps in our understanding of those consequences. I present a framework of hypotheses about the history and trajectory of respiratory disease in this system given the history of population occupancy and connectivity and propose research to address those hypotheses and inform future management.

NEXT GENERATION MEASURES OF TOPOGRAPHIC RUGGEDNESS IMPROVE HABITAT MODELING FOR BIGHORN SHEEP.

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Topographic ruggedness is an important habitat element for a variety of taxa and has proved an important predictor variable in countless GIS-based habitat modeling studies. At broad spatial scales topographic ruggedness has been shown to be a very important component of desert bighorn sheep (*Ovis canadensis*) escape terrain providing cover from predators during the lambing season. One of the most widely used measures of ruggedness, the vector ruggedness measure (VRM) of Sappington et al. (2007) was developed to address the problem that earlier measures were correlated with slope, making it impossible to disentangle the ecological effects of slope and ruggedness on habitat selection. Despite these advantages, VRM itself is strongly correlated with curvature, the second derivative of elevation, which quantifies a gradient of terrain surface morphometry from extreme convexity to extreme concavity. This is problematic along ridgelines and drainages that exhibit high values of both convexity and concavity over relevant scales. We have developed a new version of the vector ruggedness measure (VRML) that is independent of both slope and curvature, thus making it suitable for dissected landscapes with abundant ridgelines and drainages. Our multi-step study 1) involves the creation of artificial landscapes to test the relationship between slope, curvature,

and various ruggedness metrics, 2) assesses different ruggedness metrics in multidimensional space, and 3) applies both the old and new ruggedness measures to modeling habitat selection by bighorn sheep in the Lone Mountain and Garfield Hills study areas.

EXTREME DROUGHT AND ADAPTIVE HABITAT SELECTION BY DESERT BIGHORN SHEEP.

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Studies of wildlife-habitat relationships that focus on the influence of resources but ignore constraints on resource use frequently fail to identify underlying mechanisms. We investigated habitat selection in desert bighorn sheep (*Ovis canadensis mexicana*) across periods of highly variable climatic conditions and at multiple spatial and temporal scales. Sheep altered use of escape terrain in response to drought, decreasing their use of ridgelines, using areas with lower ruggedness and slope, and increasing use of valleys. In many seasons and diel periods, forage biomass and quality (as proxied by NDVI) were not associated with habitat selection, which could be related to the notion that water and nitrogen content of forage is more nutritionally limiting for desert ungulates than digestible energy. At the population scale, sheep exhibited very strong selection for areas near perennial water, and their proximity to water decreased with declining precipitation. However at the home range scale, sheep used areas further from water in autumn and winter, and distance to water was generally uninformative in summer models. Sheep typically selected more northerly aspects and locations with lower solar radiation during summer days. In early summer, sheep use of cooler locations coincided with periods when forage covariates and several topographic features were less important for habitat selection. Previous studies of habitat selection in desert bighorn sheep have primarily focused on components of the landscape and vegetation associations; however, abiotic factors in a desert climate likely exert a significant influence on selection of these features and should also be considered.

ARIZONA AND NEVADA COLLABORATING TO MAINTAIN DESERT BIGHORN SHEEP HABITAT CONNECTIVITY AND PREVENT SHEEP-VEHICLE COLLISIONS: INTERSTATE-11'S BOULDER CITY BYPASS.

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A newly constructed section of Interstate-11 located south of Boulder City, Nevada near Hoover Dam and passing through desert bighorn sheep habitat (*Ovis canadensis*) opened 9 August 2018. More than 4 years prior, the Arizona Game and Fish Department (AGFD) worked collaboratively with the Nevada Department of Transportation, Regional Transportation Commission of Southern Nevada, National Park Service, Nevada Department of Wildlife, roadway design engineers, Las Vegas Paving, and others to provide project planning and construction design advice to mitigate roadway permeability effects on desert bighorn sheep. Through this collaboration, the project team was able to implement several "lessons learned" from Arizona's bighorn sheep roadway mitigation efforts on US 93 south of Hoover Dam. AGFD, in consultation with the project team, was able to make numerous suggestions regarding fence placement, escape ramp location, wildlife overpass and underpass contour grading, and other wildlife-oriented modifications that were incorporated into the final plans and finished project. A few notable examples involved wildlife overpass and underpass modifications, the rethinking and redesigning of the I-11, US 93, and State Route

172 interchange, and proactively reducing future maintenance costs by redesigning escape mechanisms. While the multiple agencies and organizations involved in this process had various obligations to their respective stakeholders, all, without exception, worked to mitigate the roadways effects on desert bighorn sheep. The presentation will include examples of modifications based on adaptive management opportunities and preliminary results of desert bighorn sheep using the wildlife crossings.

HOW DESERT BIGHORN SHEEP ARE REPATRIATING THE NEVADA NATIONAL SECURITY SITE.

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Ecological studies have been conducted on the Nevada National Security Site (NNSS) since the 1960s. Desert bighorn sheep (*Ovis canadensis nelsoni*) were considered rare visitors on the NNSS with only 8 recorded observations between 1963 and 2009, most of which were rams. Ewes and lambs were not documented definitively until winter 2011 when several were killed by a radiocollared female mountain lion (*Puma concolor*). This led to a collaborative study involving US Geological Survey, Nevada Department of Wildlife, and National Security Technologies to capture and radiocollar bighorn sheep on the NNSS to better understand their movements and interactions with other populations, radionuclide burdens, potential dose to humans via hunting, prevalence of disease, and origin. Six (2 ewes, 4 rams) were marked and radiocollared in November 2015, and 15 (7 ewes, 8 rams) were marked and radiocollared in November 2016. Blood samples were taken for genetic and disease testing and nasal swabs were taken for disease testing. Sheep from the NNSS spent most of their time around Shoshone Mountain, Fortymile Canyon, and Yucca Mountain but also moved to Bare Mountain and Thirsty Canyon-Black Mountain area. Radionuclide burden was minimal with no significant difference from bighorn sheep captured on the Nevada Test and Training Range and northern Nevada. One marked adult ram was legally harvested off the NNSS north of Bare Mountain. Of 18 bighorn sheep sampled for disease on the NNSS during 2015 and 2016, nearly 70% showed an immune response to *Mycoplasma ovipneumoniae*. Several had the bacteria present. Genetic testing revealed the ancestry of NNSS sheep is from the Bare Mountain, Specter Range, and Stonewall Mountain reintroduced populations.

A LACK OF GENETIC HOMOGENIZATION IN DESERT BIGHORN SHEEP POPULATIONS FOUNDED BY MIXING TWO GENETICALLY DIFFERENTIATED SOURCES.

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Every year, hundreds of translocations are used to manage wildlife populations worldwide, either by restoring populations in previously occupied habitat or by augmenting currently existing populations. One principle consideration for founding new populations via translocation is the resulting genetic diversity, as higher diversity is thought to be positively associated with long-term persistence and health. As such, managers often use individuals from more than one genetically differentiated source population to maximize genetic diversity, but it is typically unknown whether individuals from multiple sources successfully hybridize in future generations. We evaluated patterns of genetic homogenization in Nevadan bighorn sheep (*Ovis canadensis*) populations founded by individuals from 2 genetically distinct source populations (Muddy and River Mountains, NV) over the past 50 years using a

genotyping-by-sequencing dataset. The genetic identities of individuals from mixed populations were classified using a hierarchical Bayesian model based on more than 17,000 loci sequenced across the genome. We failed to discover any advanced stage hybrid individuals (i.e., F2s or F3s) in any of the populations founded by individuals from both the Muddy and River Mountains. Instead, most individuals were classified as backcrosses, suggesting that mixed source translocations have not maximized levels of genetic diversity in these populations. Additional future work is needed to better understand how management decisions contribute to the resulting genetic identities of bighorn sheep populations founded from multiple translocation sources.

KOFA BIGHORN SHEEP AND MOUNTAIN LION APPLIED RESEARCH UPDATE.

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The Kofa bighorn sheep (*Ovis canadensis mexicana*) population was a robust and important population that supported numerous transplants throughout the range of southern desert bighorn sheep from Texas to Arizona. The population remained high until a precipitous decline from 2000 to 2006, when the population declined from around 800 to 400. Beginning in 2007, annual surveys of bighorn sheep, GPS radiocollaring, and disease sampling of bighorn sheep began, as well as the capture and radiocollaring of mountain lions (*Puma concolor*). The bighorn sheep population remained stable between 2006 and 2012, after which the population has steadily increased. Between 2007 and 2011, few mountain lions were captured. Yet beginning in 2011, there was a marked increase in the number of mountain lions captured annually. The Kofa bighorn sheep population has increased coincident to the reduction of mountain lions dwelling within the range. Although the population has not reached the management objective of 800, estimates are approaching that number and the project continues. Lessons from our experience are that predation control can result in population level changes for bighorn sheep, if the agency can apply the necessary intensity to alter the population of predators. The frequency of predator captures must be greater than the immigration and birth rate and the duration of the project must be long enough to maintain sufficient time for the ungulate population to reproduce and grow. Successful capture programs are related to personnel and agency dedication and persistence over the long-term.

A REGIONAL COMPARISON OF HABITAT USE VERSUS AVAILABILITY: WHAT IS FUNDAMENTAL ABOUT DESERT BIGHORN SHEEP HABITAT?

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Mountain ranges occupied by desert bighorn sheep (*Ovis canadensis*) in southern Nevada and California vary widely in environmental conditions and topographic characteristics known to influence resource use by bighorn sheep. From a regional perspective, it is not known if resource selection function-based habitat selection and home range characteristics are: (1) consistent across mountain ranges, indicative of shared behavioral responses to the same values of environmental variables or (2) differ among mountain ranges because bighorn sheep responses to given environmental variables are altered by the local range of available environmental conditions or influenced by mountain-range specific characteristics in a non-additive manner (statistical interaction). We explore which environmental factors related to habitat selection are most variable among mountain ranges and are consistent with bighorn sheep having a relative preference, contingent upon locally available sites within a mountain range. Using location data from 113 GPS-radiocollared rams and ewes in 7 populations, we employ MANOVA to quantify variation in biotic and abiotic environmental variables within and among mountain ranges for used and available locations for 3 seasons across multiple year data sets. We also assess how presence and absence of cougars (*Puma concolor*) and anthropogenic disturbance affects variation in use among populations relative to environmental factors (e.g., slope, ruggedness, planiform curvature, viewshed, vegetation class, and distance to water). Distance to water and spatial distribution of water varied widely across mountain ranges. Average slope of bighorn sheep locations was particularly variable between ranges and interacted strongly with other factors including ruggedness and viewshed. Planiform curvature at bighorn sheep locations was much less variable but was not associated with strong selection.

HAVE WE MISINTERPRETED THE HISTORICAL REALIZED ECOLOGICAL NICHE OF MOUNTAIN LIONS?

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Mountain lions (*Puma concolor*) are the primary apex predator of desert bighorn sheep (*Ovis canadensis*) under current ecological and sociological conditions. High levels of predation have vexed wildlife managers for more than 4 decades. Factors associated with this high predation include: 1) increased presence of mountain lions in habitats where they were historically absent or rare because of the expansion of mule deer (*Odocoileus hemionus*) following the extensive conversion of native-American fire-maintained grasslands to shrublands in the late-1800s, 2) the extirpation of the 2 often sympatric and dominant apex carnivores, wolves (*Canis lupus*) and grizzly bears (*Ursus arctos*), during this same time period and a hypothesized numerical response of mountain lions to those extirpations, and, 3) the end of more than 70 years of intensive predator control that coincides with mathematically unsustainable mountain lion:desert bighorn sheep ratios. Additionally, the effect of mountain lion predation is exacerbated by 1) declines in bighorn sheep that are not associated with declines in mountain lions because of the ability to prey-switch to more numerous alternative prey including domestic cattle, 2) kleptoparasitism of mountain lion kills by Ursids and Canids, resulting in higher kill-rates for mountain lions, and 3) a possible evolutionary trap where adaptations derived over evolutionary time are no longer adaptive because of human-induced changes in the sympatric apex predator guild. The assumption that mountain lions were the primary apex predator of bighorn sheep prior to the 1970s may be a misinterpretation of the realized ecological niche of this predator.

EPIDEMIOLOGY OF *MYCOPLASMA OVIPNEUMONIAE* AND POTENTIAL IMPACTS TO POPULATION HEALTH OF ENDANGERED PENINSULAR BIGHORN SHEEP.

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Polymicrobial, epizootic pneumonia is a source of mortality and decreased lamb recruitment in Peninsular bighorn sheep (*Ovis canadensis nelsoni)* throughout their range. Epizootic pneumonia originally entered the Peninsular bighorn sheep population through contact with domestic sheep (*Ovis aries*) but can be maintained by carrier bighorn sheep (BHS) for years, causing intermittent epizootics. BHS pneumonia is a complicated disease process, involving co-infection with several infectious pathogens, environmental and immune factors, and host behavior. Recent research on BHS populations across the western USA suggests that *Mycoplasma ovipneumoniae* is a primary pathogen associated with many pneumonia outbreaks and may exacerbate the effects of other pathogens by decreasing immune function. This study is the first to investigate associations between *Mycoplasma ovipneumoniae* exposure and shedding and the population health of BHS in the Peninsular Ranges. Samples were collected from Peninsular BHS from 1999–2017 and tested for *Mycoplasma ovipneumoniae* by PCR (n = 194) and/or ELISA (n = 485). Estimates of population size, annual survival, and lamb:ewe ratios were also made over the same time period. Spatial and temporal clusters that had higher or lower than expected pathogen prevalence were identified across the study area. Using multiple regression models, we identified significant relationships between *Mycoplasma ovipneumoniae* and the population performance of BHS across the region. These results will be used to inform BHS management and conservation, as BHS habitat range continues to overlap with areas of use by humans and domestic livestock, increasing the risk of pathogen transmission and complicating the control of this devastating disease.

HUMAN-INDUCED MIGRATION AND HOMING BEHAVIOR OF A DESERT BIGHORN RAM IN THE WHIPPLE MOUNTAINS, CALIFORNIA: 20 YEAR RETROSPECTIVE *or* **"HERMAN THE TRAILER PARK RAM."**

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On 12 July 1999, a mature desert bighorn ram (≥9 years-old) was reported causing a disturbance at a resort property on the Colorado River about 2 km south of Parker Dam, San Bernardino County, California. Subsequent monitoring confirmed this animal to be a repeat offender, and the decision was made to capture, radiocollar, and move the animal about 16 km to the northwest, where he was released in the Whipple Mountains. The animal returned to the original capture site within 4 days. It was recaptured on 20 August 1999, and then transported via helicopter about180 km (airline) northwest to Old Dad Peak, where he again was released; he was last recorded at Old Dad Peak on 27 September 1999. On 4 November 1999, the animal was confirmed to have returned to the original capture area along the Colorado River. We describe the potential movement path of this animal and discuss the ramifications of these movements in the context of current knowledge, and the implications of homing behavior for management and conservation.

MAKING RELIABLE INFERENCES FROM RELIABLE SCIENCE – IN MY OPINION.

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Wildlife research generally employs carefully selected field methods, analytical techniques, and scrutiny of results when drawing conclusions subject to appropriate peer review. At times, we collectively draw inappropriate inferences or make inappropriate references despite our efforts at sound science due to unfamiliarity or overreaching in our basic assumptions. I use 4 published papers to illustrate my concerns where bighorn sheep (*Ovis candensis*) populations are substantially and inaccurately referenced (Kamler et al. 2002), the effects of hunting season structure on mountain lion (*Puma concolor*) is probably mischaracterized (O'Malley et al. 2018), the premise for conducting bighorn sheep surveys is misstated (Conroy et al. 2018), or the effect of a source of mortality on mountain lion populations may be perceived to be misleading (Andreasen et al. 2018). I offer caution about mischaracterizing or sensationalizing our research findings to appeal to a broader audience when collateral harm that may occur to the wildlife management profession.

CAMERA-BASED MARK-RESIGHT ESTIMATES OF DESERT BIGHORN POPULATIONS USING NATURALLY MARKED EWES; THE REST OF THE STORY.

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At the last DBC meeting, I presented information that demonstrated the huge potential for using automated cameras at water to produce high resolution mark-resight estimates of population sizes of desert bighorn sheep (*Ovis canadensis*) ewes, using natural variation in horn patterns to identify individual ewes. While I identified a number of issues involved in this estimation, and discussed how I resolved them, at the end I questioned whether the logit normal estimator in program MARK was the right estimator to use because of its apparent lack of ability to adequately deal with high heterogeneity in the data (variation among ewes in water visitation frequency). Since then I have explored this and other issues considerably more, including comparison of 3 available estimators: Bowden, logit normal, and poisson log normal. The Bowden estimator emerged as clearly the best. Under ideal hot conditions, precise estimates required remarkably few days of data because data heterogeneity was minimal. Spatial data heterogeneity due to different visitation rates at different water sources was another issue. I have also developed a different approach to dealing with this issue that provides more flexibility and precision for this estimation procedure. I will present these findings with a focus on issues.

UPDATING WILD SHEEP CAPTURE AND TRANSLOCATION GUIDELINES.

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Capture and translocation are key components of wild sheep (*Ovis canadensis*) restoration efforts. In 2005, the development of *Wild Sheep Capture Guidelines* was sponsored by both the Northern Wild Sheep and Goat and Desert Bighorn Councils and compiled by Craig Foster of Oregon Department of Fish and Wildlife. In 2019, with support from the Wild Sheep Foundation and the Western Association of Fish and Wildlife Agencies (WAFWA), Wild Sheep Working Group (WSWG) these capture guidelines are being reviewed and refined by wild sheep managers and wildlife veterinarians. Specifically, much of the information concerning importation of wild sheep from Canada was condensed and disease sampling guidelines were removed as they are already referenced in the WAFWA, Wild Health Committee *Bighorn Sheep Herd Health Monitoring Recommendations* (2014). Additions include photographs of equipment, an update on sedatives, tranquilizers and immobilization agents used in wild sheep handling and transport. Guidelines for diagnosis and treatment of hyperthermia and other complications and an expanded formulary for dugs commonly administered during capture operations are included. When completed, the revised *Guidelines* will be available through the WAFWA, WSWG website so that they are accessible by all jurisdictions.

Abstracts of Presented Posters

COMPARISON OF DESERT BIGHORN SHEEP HOME RANGES AMONG DIFFERENT RELEASE METHODS.

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Historically, desert bighorn sheep (*Ovis canadensis*) were a prevalent species throughout the Trans-Pecos ecological region of Texas. However, they were extirpated by the 1960s due to unregulated hunting, habitat loss, predation, and disease transmission from livestock. Restoration efforts have been successfully conducted by Texas Parks and Wildlife Department to increase population numbers of resident desert bighorn sheep (i.e., animals that currently populate a region of interest) at Black Gap Wildlife Management Area (BGWMA) through the use of translocations. In winter 2017–2018, we radiomarked and released 30 resident (8 M, 22 F) and 70 translocated desert bighorn sheep (36 M, 45 F). Of the 70 translocated animals, 28 (12 M, 16 F) were hard released (i.e., translocated animals immediately released onto landscape) and 42 (24 M, 18 F) soft released (i.e., released into an enclosure before the entire landscape). Preliminary home range size estimates were delineated, for each individual desert bighorn sheep using kernel density estimates and were compared among the resident, hard-released, and soft-released bighorn sheep. I hypothesized that home range size will be different for translocated and resident desert bighorn sheep at 1-year post release. An analysis of variance detected hard-released desert bighorn sheep differed in home range size when compared to both resident and soft-released bighorn sheep ($P < 0.01$). These preliminary results will provide wildlife biologists with knowledge pertaining to first-year movements of translocated and resident desert bighorn sheep at BGWMA, as well as provide insight into approaches for future translocation efforts.

DEVELOPMENT OF THE BIGHORN SHEEP WITH CROSS-BORDER HOME RANGE BETWEEN BAJA CALIFORNIA AND CALIFORNIA.

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The management and conservation of bighorn sheep (*Ovis canadensis)* has suffered a series of problems in Baja California, including loss of natural habitat, introduction of cattle species in their home ranges, and illegal hunting. The conservation and management of species like the bighorn sheep allows its use as a resource, either extractive or non-extractive. However, limited knowledge and interruption of the research in the state of Baja California, Mexico, have not allowed conservation programs to have the ideal results for the care of bighorn sheep populations. This is opposed to the conservation and management programs that can be found in states such as Sonora, and in countries such as Canada and the United States. Thanks to the last project carried out by the UABC and the Government of the State of Baja California, Maldonado (2016) determined that there are individuals of bighorn sheep that use a cross-border home range, covering habitat between Baja California, Mexico, and California, United States. Although management practices have been different in these countries, the employment of a Transboundary Conservation Area program can be an important factor for the conservation of wild populations in the border zones, preventing their extirpation, allowing the use of the species as a resource, and improving relations between the involved governments and institutions.

BIGHORN SHEEP DISTRIBUTION AND LAMBING HABITAT IN THE PINTWATER RANGE OF THE NEVADA TEST AND TRAINING RANGE.

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In November 2016 the Nellis Natural Resources Program, together with the Nevada Department of Wildlife, US Fish and Wildlife Service, and US Geological Survey conducted desert bighorn sheep (*Ovis canadensis*) radiocollaring efforts in the Pintwater Mountains located on the central portion of the South Range of the Nevada Test and Training Range. GPS-satellite radiocollars were affixed to 9 female and 10 male adults for about 19 months. This data was collected in support of the Legislative Environmental Impact Statement that was submitted in October 2018. Using these location data, we determined habitat use, lambing areas, and home and core range sizes for desert bighorn sheep for different seasons throughout the study period. Additionally, wildlife camera photos and location data for ewes were isolated from December through March to create a predictive lambing area model within the Pintwater Range. The information contained here may facilitate future land use decisions by resource land managers.

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 the same calendar 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) 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 copies.

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. If submitting hard copies, lightly write the senior author's name, figure number, and "Top" on the back of each illustration.

Submission and Proof: All papers will be reviewed for acceptability by the Editor 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.

DESERT BIGHORN COUNCIL MEETINGS 1957–2019

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

DESERT BIGHORN COUNCIL MEETINGS 1957–2019

Year	Location	Chairperson	Secretary	Treasurer	Transactions Editor
1996	Holtville, CA	Andy Pauli	Charles Douglas	Charles Douglas	Ray Boyd
1997	Grand Junction, CO	Dale Reed & Van Graham	Steve Torres	Charles Douglas	Raymond Lee
1998	Las Cruces, NM	Eric Rominger & Dave Holdermann	Darren Divine	Charles Douglas	Raymond Lee
1999	Reno, NV	Rick Brigham & Kevin Hurley	Darren Divine	Charles Douglas	Allan Thomas & Harriet Thomas
2000	Bullhead City, AZ	Ray Lee & Jim deVos	Darren Divine	Charles Douglas	Jon Hanna
2001	Hermosillo, Sonora, Mexico	Carlos Castillo & Jim deVos	Darren Divine	Charles Douglas	Jon Hanna
2002	Palm Springs, CA	Mark Jorgenson	Darren Divine	Charles Douglas	Jon Hanna
2003	St. George, UT	Jim Karpowitz	Darren Divine	Darren Divine	Brian Wakeling
2005	Alpine, TX	Clay Brewer	Esther Rubin	Stacey Ostermann	Brian Wakeling
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
2017	St. George, UT	Rusty Robinson & Justin Shannon	Amber Munig	Kathleen Longshore	James W. Cain
2019	Mesquite, NV	Steven Kimble & Mike Cox	Erin Butler	Kathleen Longshore	James W. Cain