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Authors: Daily, Taylor S., Gonzalez, Carlos E., Harveson, Louis A., Conway, Warren C., and Hernandez, Froylan

Source: Western North American Naturalist, 82(1) : 94-106

Published By: Monte L. Bean Life Science Museum, Brigham Young University

URL: https://doi.org/10.3398/064.082.0109

Western North American Naturalist 82(1), © 2022, pp. 94–106

Comparing survival and cause-specific mortality of different translocation release methods for desert bighorn sheep

Taylor S. Daily[1], Carlos E. Gonzalez[1,*], Louis A. Harveson[1], Warren C. Conway[2], and Froylan Hernandez[3]

[1]*Borderlands Research Institute, Sul Ross State University, Alpine, TX 79832*
[2]*Department of Natural Resources Management, Texas Tech University, Lubbock, TX 79409*
[3]*Texas Parks and Wildlife Department, Alpine, TX 79830*

Abstract.—Historically, desert bighorn sheep (*Ovis canadensis mexicana*) were prevalent throughout the Trans-Pecos 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 the Texas Parks and Wildlife Department to increase population numbers of resident (i.e., animals that currently populate a region of interest) desert bighorn sheep at Black Gap Wildlife Management Area (BGWMA) through the use of translocations. Because there is a lack of knowledge on alternative release methods for large mammal translocations, our goals were to monitor cause-specific mortality and postrelease survival of desert bighorn sheep translocated during 2017. Survival estimates of desert bighorn sheep were compared amongst resident, hard-released, and soft-released individuals throughout the study. In winter 2017–2018, we radio-collared and released 30 resident (8 M, 22 F) and 70 within-state-translocated (36 M, 34 F) desert bighorn to BGWMA. Of the 70 translocated individuals, 28 (12 M, 16 F) were hard released (i.e., released immediately onto the landscape) and 42 (24 M, 18 F) were soft released (i.e., released into an enclosure before onto the landscape). Resident desert bighorn had the highest probability of survival over time ($\hat{S}$ = 0.83), followed by hard-released ($\hat{S}$ = 0.67) and then soft-released ($\hat{S}$ = 0.54) individuals. To date, 26 mortalities (13 M, 13 F) were recorded. Of those mortalities, 4 were residents (15%), 6 were hard released (23%), and 16 were soft released (62%). The soft release is thought to be a better strategy for translocating large mammals; however, in this study, it did not improve survival. Survival is potentially influenced by acclimation time and individual exit strategy from the soft-release pen, which should be managed for future restoration efforts. Incorporating a flushing-method exit strategy would aid in removing soft-released individuals from the high-fenced pen simultaneously and may increase survival estimates. This could potentially allow individuals to form larger groups when exiting the enclosure and entering the new habitat. The soft-release method is also more costly to implement, which could be challenging for wildlife managers.

Resumen.—Históricamente, el borrego cimarrón del desierto (*Ovis canadensis mexicana*) fue una especie prevalente en toda la región Trans-Pecos de Texas. Sin embargo, la población fue extirpada en la década de 1960 debido a la caza no regulada, la pérdida de hábitat, la depredación y la transmisión de enfermedades del ganado. El Departamento de Parques y Vida Silvestre de Texas ha llevado a cabo exitosamente el trabajo de restauración para aumentar el número de residentes (es decir, animales que actualmente habitan una región de interés) de borrego cimarrón del desierto en el Área de Manejo de Vida Silvestre de Black Gap (BGWMA, por sus siglas en inglés) mediante el uso de la translocación. Debido a la falta de conocimiento acerca de los métodos de liberación alternativos de translocación de grandes mamíferos, nuestro objetivo fue monitorear las causas específicas de mortalidad y supervivencia posterior a la liberación del borrego cimarrón del desierto, que fue translocado durante 2017. Se compararon las estimaciones de supervivencia entre individuos residentes, liberados de forma rápida y lenta a lo largo del estudio. Durante el invierno de 2017–2018, colocamos un radio-collar y liberamos a 30 residentes (8 machos, 22 hembras) y a 70 cimarrones del desierto translocados dentro del estado (36 machos, 34 hembras) a BGWMA. De los 70 borregos translocados, 28 (12 machos, 16 hembras) se liberaron rápidamente (es decir, los animales se liberaron inmediatamente al terreno) y 42 (24 machos, 18 hembras) se liberaron lentamente (es decir, se liberaron a un cerco antes que al terreno). El borrego cimarrón del desierto residente tuvo la mayor probabilidad de supervivencia a lo largo del tiempo ($\hat{S}$ = 0.83), seguida de aquellos que fueron liberados rápidamente ($\hat{S}$ = 0.67) y finalmente aquellos que fueron liberados lentamente ($\hat{S}$ = 0.54). Hasta la fecha, se registraron 26 muertes (13 machos, 13 hembras), de las cuales, cuatro eran residentes (15%), seis fueron liberados rápidamente (23%) y 16 fueron liberados lentamente (62%). Se cree que la liberación lenta es la mejor estrategia para trasladar a grandes mamíferos. Sin embargo, de acuerdo con este estudio, esto no mejoró la supervivencia. El resultado podría estar influenciado por el tiempo de aclimatación y la estrategia individual de salida del corral de liberación lenta, esto debe ser tratado en futuros esfuerzos de restauración. La incorporación de una estrategia de liberación como el método de flushing ayudaría a liberar simultáneamente a los individuos que salen lentamente del corral de cerca alta y podría

*Corresponding author: carlos.gonzales-gonzales@sulross.edu

aumentar la probabilidad de supervivencia. Lo anterior, potencialmente permite que los individuos formen grupos más grandes al salir del cerco y entrar al nuevo hábitat. El ejecutar el método de liberación lenta requiere de costos adicionales, lo que podría ser un desafío para los administradores de vida silvestre.

Desert bighorn sheep (*Ovis canadensis mexicana*) once occurred throughout the Trans-Pecos region of Texas. They were believed to have been distributed throughout 16 mountain ranges with an estimated population of 1000–1500 individuals during the 1800s (Bailey 1905, Davis and Taylor 1939). However, by the 1930s, the population was estimated at approximately 300 individuals, and their distribution had diminished to only 4 mountain ranges (e.g., Baylor, Beach, and Carrizo Mountains, and Sierra Diablo; Davis and Taylor 1939). By the 1960s, it was believed that Texas desert bighorn sheep had been extirpated (Kilpatric 1990).

The extirpation of Texas desert bighorn sheep has been attributed to a combination of factors such as competition with domestic livestock, diseases, habitat fragmentation, predation, and overhunting (Davis and Taylor 1939, Buechner 1960). Desert bighorn sheep struggle when coexisting with or occurring near livestock (Jones 1980) because of direct competition for limited resources such as water and forage (Wilson et al. 1980). The presence of domestic sheep presents another challenge: diseases. Transmission of disease from domestic livestock has been a leading cause of decline for desert bighorn sheep and Rocky Mountain bighorn throughout North America (Sparker 1977, Jessup 1981, Onderka and Whisart 1984, Dassanayake et al. 2010, Bleich 2015). Fragmentation of habitat caused by the introduction of livestock fences has been suggested to be detrimental, as it restricts movements, exposes vulnerability, and limits resource access for desert bighorn sheep (Duncan 1960, Geist 1971).

The Texas Parks and Wildlife Department (TPWD) began the desert bighorn sheep restoration by relocating individuals from other states and Mexico (Geist 1971, Cook et al. 1990). These restoration efforts began at Black Gap Wildlife Management Area (BGWMA) in 1957 with the translocation of 16 desert bighorn sheep from Arizona (Kilpatric 1990). While translocations have been an essential tool for restoring large mammals to their native habitat (Krausman et al. 2001, Boyd 2018, Cain et al. 2018), they have the potential to fail due to capture myopathy, disease, postrelease predation, and dispersal (Rominger et al. 2004). The release of translocated animals may consist of a soft release or a hard release. Soft release is usually preferred because it is typically thought to aid in postrelease survival, although previous research does not always support that claim (Parker et al. 2012). It is documented that some species have increased postrelease survival due to a soft release, whereas others show no sign of increase but rather a decrease (Parker et al. 2012). Thompson et al. (2001) did not find a difference in survivorship between hard- and soft-released desert bighorn sheep. Despite the challenges, continuous efforts have been made to improve translocation success.

Fitting individuals with GPS collars is an effective method for monitoring survival and determining cause-specific mortality for desert bighorn sheep populations (Ruhl and Rominger 2015, Robinson et al. 2017, Cain et al. 2019), as well as other desert big game species such as pronghorn (*Antilocapra americana*) (Jacques et al. 2015, Larkins et al. 2018) and mule deer (*Odocoileus hemionus*) (Cain et al. 2018, Schuyler et al. 2018). Although past studies have evaluated desert bighorn sheep survival following translocation in Texas (Locke 2003, Janke 2015, Cross 2016), none have compared survival rates among resident, soft-released, and hard-released animals. In comparison, previous restoration efforts have utilized both release techniques for large mammals (Thompson et al. 2001, Parker et al. 2008, Martinez-Garcia 2009, Cain et al. 2018) but did not simultaneously collar residents to serve as a "control" to compare with translocated individuals.

The research objectives were to (1) compare survival of desert bighorn sheep following translocation among 3 treatments (resident, hard-released, and soft-released) and (2) compare cause-specific mortality of desert bighorn sheep among 3 treatments (resident, hard-released, and soft-released). The 3 treatments were set up to collect data in the same location on an equal temporal scale

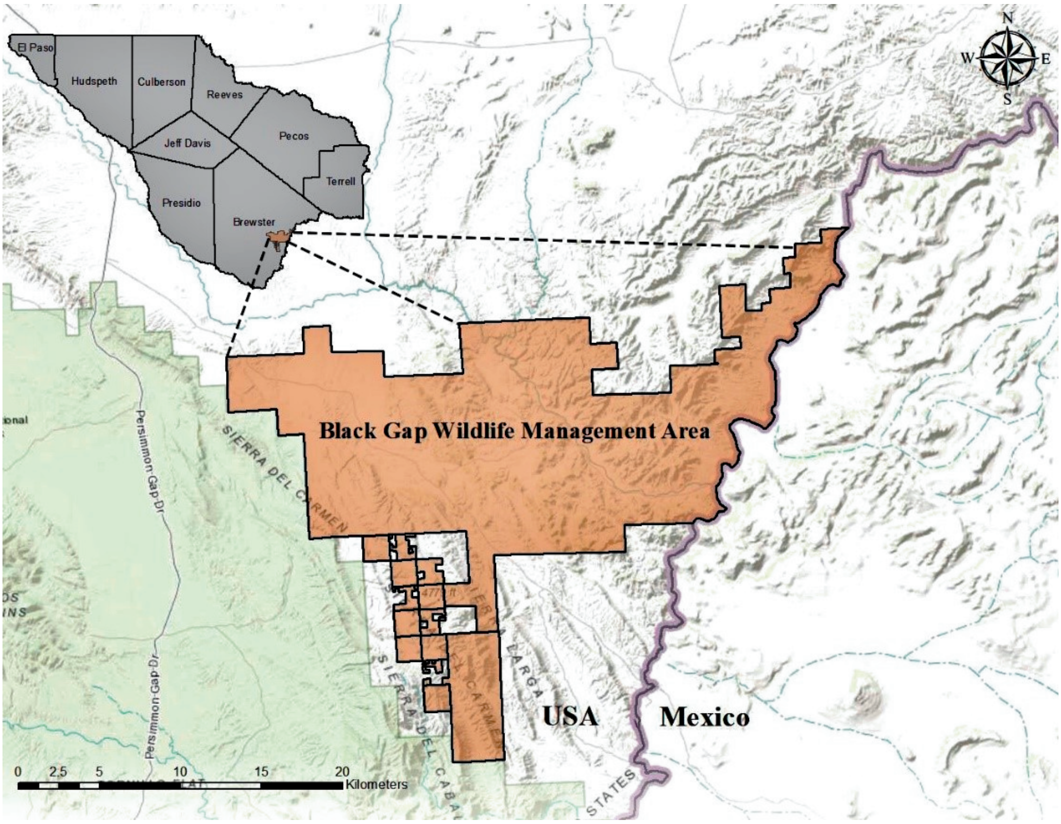

Fig. 1. Location of Black Gap Wildlife Management Area in Brewster County, Texas, USA.

throughout the duration of the study. We hypothesized that there would be no differences in survival between sheep released by either method and resident desert bighorn sheep.

METHODS

Study Site

The BGMWA was the primary study site for this research. The BGWMA is located in the Chihuahuan Desert and the Trans-Pecos ecological region of Texas. It is 93 km south of Marathon, Texas, in southern Brewster County, and covers approximately 41,734 ha (TPWD 1996, Pittman 1999) (Fig. 1). The Rio Grande borders BGWMA for 40 km to the east, with Big Bend National Park bordering it to the west. Elevations range from 518 m to 1450 m (TPWD 1996). The National Oceanic and Atmospheric Administration database for the Persimmon Gap, Texas, weather station (located approximately 29 km west of BGWMA) reports an average annual temperature of 19.8 °C and an average annual precipitation of 28.93 cm (NOAA 2018). Vegetation is diverse but is defined by Tamsitt (1954) and Rogers (1964) as having 8 main types: (1) persimmon (*Diospyros texana*) and walnut (*Juglans* spp.), (2) whitethorn (*Acacia* spp.) and creosotebush (*Larrea tridentata*), (3) rocky canyon cliff, (4) mesquite (*Prosopis* spp.) and whitethorn (*Vachellia constricta*), (5) sotol (*Dasylirion leiophyllum*) and lechuguilla (*Agave lechuguilla*), (6) riparian, (7) grama (*Bouteloua* spp.) and prickly pear (*Opuntia* spp.), and (8) yucca (*Yucca* spp.) and oak (*Quercus* spp.). Three different soil types occur, which include limestone, alluvial deposits, and basalt (Brownlee 1981, Cooke 1988). In 1948, BGWMA was purchased by the Texas Game and Oyster Commission (now TPWD) and originally covered 11,402 ha. Since that time, BGWMA has expanded and is currently the largest wildlife management area in Texas.

Capture

A total of 37 resident desert bighorn sheep (12 M, 25 F) were captured at BGWMA from 25 to 26 October 2017, using the helicopter net-gun method (Krausman et al. 1985). Each desert bighorn sheep was hobbled, blindfolded, and moved via helicopter to a processing site. Morphological data were collected, and disease sampling was performed. Other data and samples collected included sex, age, body condition (amount of body fat present on lumbar vertebrae), fecal and hair samples, blood, nasal and tonsil swabs, ram class, a skin biopsy, and pregnancy and/or lactation of females. Age was determined from horn growth rings and tooth wear and replacement techniques (Geist 1966, Hansen and Deming 1980). Desert bighorn sheep temperatures were monitored, and veterinary personnel tended to any apparent injuries. If an individual's body temperature reached 40 °C, it was sprayed with water inside the forelegs, rear flanks, and hind legs to help stabilize body temperature and prevent overheating. If the temperature continued to increase, the lead veterinarian administered a dose of the anti-inflammatory drug Banamine (flunixin meglumine, Merck Animal Health Corporation, Madison, New Jersey, USA), all processing ceased, and the animal was released. Following the completion of data collection, desert bighorn sheep were released on-site back into the habitat.

Desert bighorn sheep intended for translocation were captured on Elephant Mountain Wildlife Management Area, Texas, on 10–11 December 2017, using the same helicopter net-gun method and processing as was used for the BGWMA resident desert bighorn sheep. Once captured, desert bighorn sheep were hobbled, blindfolded, and transported aerially to a designated processing site. After processing, individuals were separated and placed in modified livestock trailers with hay and reduced lighting to ensure minimal stress. A total of 82 desert bighorn sheep (37 M, 45 F) were captured. At the end of each capture day, desert bighorn sheep were transported, via the modified livestock trailers, to a predetermined release site at BGWMA. As for desert bighorn sheep selected for the soft-release method, we used an acclimation period of 3 weeks. The 3-week time frame for the acclimation period was selected based on recommendations and protocol from TPWD. At that time, gates to the enclosure were opened, and alfalfa was placed near the exits to encourage desert bighorn sheep dispersal out of the soft-release enclosure and onto the landscape. The soft-release enclosure, located in the south-central region of BGWMA, was a 2.5-m-tall fence surrounding 210 ha. Individuals selected for hard release were released at campsite 24, located approximately 6.5 km east of the soft-release enclosure (Fig. 2).

Collars

One hundred desert bighorn sheep (44 M, 56 F) were randomly selected and fitted with Lotek Lifetrack Iridium-420 collars (Newmarket, Ontario, Canada). Thirty individuals (8 M, 22 F) were residents, 28 (12 M, 16 F) were hard released, and 42 (24 M, 18 F) were soft released. Collars were programmed to continuously record a fixed location every 5 h and transmit all location data to a satellite web page. The very high frequency (VHF) beacon was scheduled to transmit from 06:00 to 18:00, and a mortality mode (80 beeps/min [bpm] instead of 40 bpm) would trigger if collars were inactive for a period ≥8 h. Each collar possessed a drop-off mechanism, which was scheduled to detach 2 years from collar activation.

Monitoring

From December 2017 to December 2019, GPS collars were monitored from the satellite web page weekly, and ground telemetry was performed with a VHF receiver (Model R-4000, ATS, Isanti, MN) and antenna (Yagi 3-element, folding directional antenna). For ground telemetry, data collected included date, observer, alive or mortality signal, general location, direction, and signal strength. If collars malfunctioned and failed to update GPS fixes, they were considered high priority during ground telemetry efforts to determine whether the collar was in alive or mortality mode. If battery life began to diminish, the collars switched into recovery mode. Once recovery collars were heard, they were tracked and located via VHF telemetry and remotely triggered to drop off with a Lotek radio-release transmitter (Lotek, Newmarket,

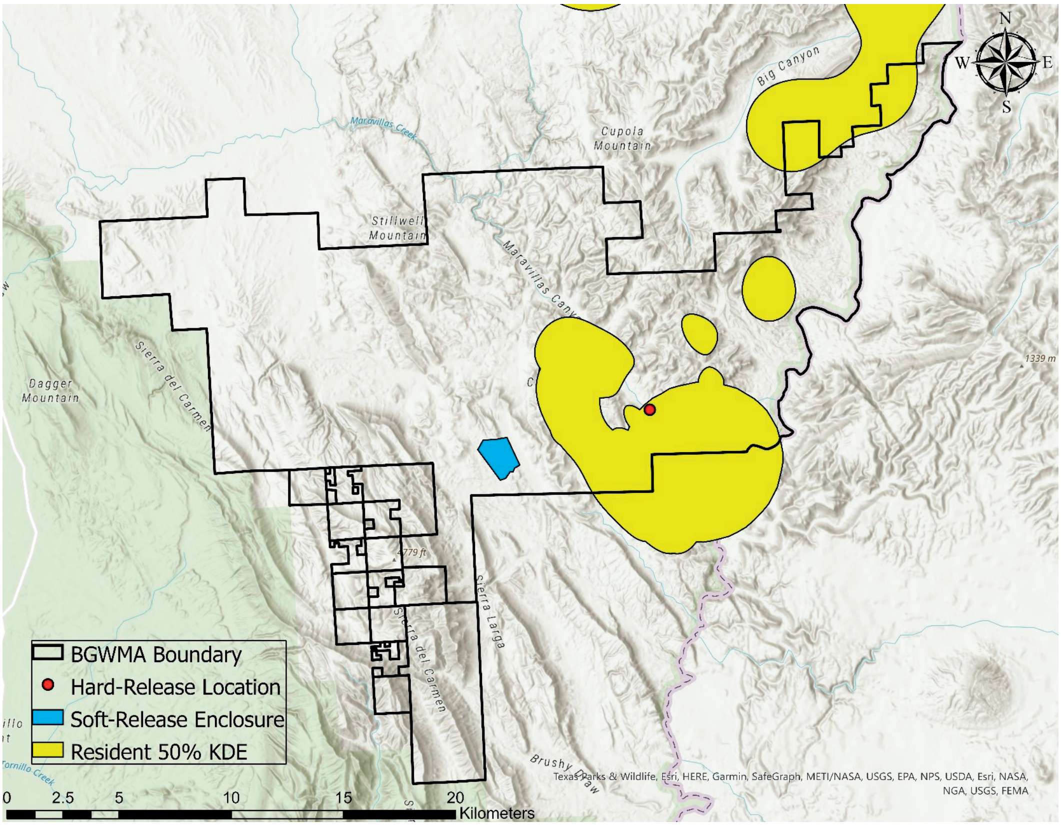

Fig. 2. Locations for hard- and soft-release sites, and the resident 50% kernel density estimate (KDE) for desert bighorn sheep at Black Gap Wildlife Management Area (BGWMA), Texas, USA.

Ontario, Canada; https://lotek.com). All mortalities were investigated immediately following notification (e.g., email and text message) of a GPS collar switching to mortality mode. Notifications were sent as soon as the collar could connect to the Lotek web service (M. Crawford, Lotek, personal communication).

Mortality Site Investigation

Average response time (i.e., amount of time between estimated desert bighorn sheep mortality and discovery of the carcass) was 72 h (3 days) for all mortalities investigated (n = 26), with the lowest response time of 23 h and the greatest of 369 h (~15 days). Investigations were conducted if a mortality signal was discovered during ground telemetry. Aerial telemetry was also conducted opportunistically when flights were conducted. Once the desert bighorn sheep was found, a mortality investigation and necropsy were completed to determine the cause of mortality. Data consisted of general site description, carcass description (e.g., broken/chewed bones, body condition, hoof and horn condition, and presence of canine marks), signs of struggle, cache and/or drag trail presence, and predator feces presence (Janke 2015). Due to the complexity of determining the cause of mortality, it is possible to incorrectly misclassify mountain lion predation (Logan and Sweanor 2001). To alleviate and reduce possible misclassifications, strong indicators of mountain lion predation consisted of mountain lion feces and/or tracks, partial or complete cache site, drag trail, unconsumed rumen evisceration, and canine marks located on the bottom of the mandible or top of the rostrum (Rominger et al. 2004). If the carcass was intact with salvageable organs, samples of the heart, kidney, lung, liver, and spleen were collected and submitted to the Texas A&M Veterinary Medical Diagnostic Laboratory (TVDML in College Station, Texas, USA) for

Table 1. Akaike's information criterion with small sample size correction (AICc) model evaluation results for desert bighorn sheep survival across sex, treatment, season, year, and time following translocation of the animals to Black Gap Wildlife Management Area, Texas, USA, December 2017–2019.

Model[a]	No. of parameters	AICc	ΔAICc[b]	AICc weight
Season	4	209.74	0	0.48
Treatment + Sex + Season	7	210.64	0.90	0.30
Treatment	3	213.30	3.56	0.08
Null	1	213.82	4.08	0.06
Treatment + Sex + Time	11	214.93	5.19	0.04
Year	2	215.83	6.09	0.02
Sex * Year	4	216.79	7.05	0.01
Treatment * Year	6	218.42	8.68	0.01
Treatment * Sex	6	303.64	93.90	0
Treatment * Sex * Season	24	436.19	226.45	0
Treatment * Sex * Year	12	471.70	261.96	0
Treatment * Sex * Time	48	563.76	354.02	0
Treatment * Time	24	2037.57	1827.83	0

[a]Season = seasons combined for year 1 and 2 postrelease (i.e., gestating, lambing, lactating, and breeding in general).
[b]ΔAICc refers to the difference in AICc between the most supported model and the given model.

further analyses. Additionally, pictures of the mortality site and carcass were collected and shared with professionals to determine the cause of mortality. Cause of mortality was recorded in Microsoft Excel and sorted by the collar, cause-specific mortality, and treatment (resident, hard-released, and soft-released). The frequency was then graphed cumulatively by cause of mortality among treatment.

Data Analysis

Collar data were acquired following a mortality, following a scheduled collar drop after 2 years of activation, or online from the Lotek web service web page. Data were downloaded and saved as a text file, converted to a comma-separated value file, and imported into Microsoft Excel. All GPS points before release and after mortality or collar drop were deleted.

Program MARK® 9.0 (Program MARK, Department of Fish, Wildlife, and Conservation Biology, Colorado State University, Fort Collins, Colorado, USA) was used to create models of known parameters affecting survival. The parameters included sex, biological season, and treatment (resident, hard-released, and soft-released). Seasons were defined as gestating (15 November–14 February), lambing (15 February–14 May), lactating (15 May–14 August), and breeding (15 August–14 November; Janke 2015). A known-fate analysis was used to determine which known parameters were influencing desert bighorn sheep survival. A total of 16 models were delineated based on the aforementioned parameters. Models were evaluated based on Akaike's information criterion (AIC). The corrected value, AICc, converges with AIC as n increases and is generally recommended regardless of sample size (Zar 2009). All models that had a ΔAICc ≤ 2 were considered appropriate for evaluation. Collars that malfunctioned and were not retrieved had to be censored from the date of lost communication onward but included data up until the date of lost communication (n = 30; Kaplan and Meier 1958).

Naïve survival estimates were produced in Microsoft Excel and were analyzed among treatment, sex, biological season, and year (i.e., year 1 after release and year 2 after release). All naïve survival estimates were calculated as

$$(1 - \text{number dead})/(\text{number at risk}).$$

A Kaplan–Meier survival curve was produced in Microsoft Excel. Each treatment was analyzed on a weekly basis from 31 December 2017 to 29 December 2019 (104 weeks). Survival over time was calculated as

$$\text{previous week's survival} \times \text{naïve survival estimate}$$

(Kaplan and Meier 1958).

Results

Models

The top model for survival (Season) had an AICc weight of 0.48. The following model (Treatment + Sex + Season) had a ΔAICc < 2 and was also considered appropriate for

TABLE 2. Annual survival estimates (with standard errors) for resident, hard-released, and soft-released desert bighorn sheep at Black Gap Wildlife Management Area, Texas, USA, December 2017–2019.

	Resident			Hard-released			Soft-released		
	n[a]	$\hat{S}$	SE	n	$\hat{S}$	SE	n	$\hat{S}$	SE
Males									
Year 1[b]	8	1.00	0.00	11	0.91	0.02	24	0.75	0.02
Year 2[c]	5	0.60	0.08	6	1.00	0.00	15	0.73	0.03
Overall	8	0.75	0.05	11	0.91	0.02	24	0.58	0.02
Females									
Year 1	22	0.91	0.01	16	0.75	0.02	18	0.83	0.02
Year 2	17	1.00	0.00	7	0.86	0.05	15	0.80	0.02
Overall	22	0.91	0.01	16	0.69	0.02	18	0.67	0.02
Combined[d]									
Year 1	30	0.93	0.01	27	0.81	0.01	42	0.79	0.01
Year 2	22	0.91	0.01	13	0.92	0.02	30	0.77	0.01
Overall	30	0.87	0.01	27	0.78	0.01	42	0.62	0.01

[a]Number of desert bighorn sheep radio-collared during the time period.
[b]First-year postrelease translocation.
[c]Second-year postrelease translocation.
[d]Both male and female desert bighorn sheep combined.

TABLE 3. Seasonal survival estimates (with standard errors) for resident, hard-released, and soft-released desert bighorn sheep at Black Gap Wildlife Management Area, Texas, USA, December 2017–2019.

	Resident			Hard-released			Soft-released		
Season[a]	n[b]	$\hat{S}$	SE	n	$\hat{S}$	SE	n	$\hat{S}$	SE
Year 1									
Gestating	30	1.00	0.00	27	0.93	0.01	42	0.98	0.00
Lambing	30	1.00	0.00	25	0.96	0.01	41	0.95	0.01
Lactating	30	0.97	0.01	24	1.00	0.00	38	0.92	0.01
Breeding	27	0.96	0.01	21	0.90	0.01	34	0.91	0.01
Year 2									
Gestating	22	1.00	0.00	13	1.00	0.00	30	0.97	0.01
Lambing	21	1.00	0.00	13	1.00	0.00	28	1.00	0.00
Lactating	21	0.90	0.01	11	1.00	0.00	28	0.93	0.01
Breeding	16	1.00	0.00	9	0.89	0.03	24	0.83	0.01

[a]Biological seasons were delineated as gestating (15 Nov–14 Feb), lambing (15 Feb–14 May), lactating (15 May–14 Aug), and breeding (15 Aug–14 Nov).
[b]Number of desert bighorn sheep radio-collared during the time period.

evaluation. It produced an AICc weight of 0.30 (Table 1).

Survival

Annual naïve survival rate for resident desert bighorn sheep was 0.93 (SE = 0.01) for the first year and 0.91 (SE = 0.01) for the second year. Annual naïve survival rate for hard-released desert bighorn sheep was 0.81 (SE = 0.01) in year 1 and 0.92 (SE = 0.02) in year 2. For soft-released desert bighorn sheep, first-year annual naïve survival rate was 0.79 (SE = 0.01) and second year was 0.77 (SE = 0.01). Overall annual naïve survival for resident males was 0.75 (SE = 0.05) for the 2-year study duration. Overall annual naïve survival for hard-released males was 0.91 (SE = 0.02). Overall annual naïve survival rate for soft-released males was the lowest among the treatments at 0.58 (SE = 0.02). Resident female overall annual naïve survival was 0.91 (SE = 0.01). Overall annual naïve survival for hard-released females ($\hat{S}$ = 0.69, SE = 0.02) was similar to the overall annual naïve survival for soft-released females ($\hat{S}$ = 0.67, SE = 0.02) (Table 2).

Naïve survival rates for resident desert bighorn sheep were identical for the first 2 seasons (gestating and lambing) ($\hat{S}$ = 1.00, SE = 0.00) and similar for the following 2 seasons (lactating and breeding) ($\hat{S}$ = 0.97, SE = 0.01; $\hat{S}$ = 0.96, SE = 0.01) for the first year. For the second year, there was a constant naïve survival rate of 1.00 (SE = 0.00) for gestating, lambing, and breeding, but a lower estimate during the lactating season ($\hat{S}$ = 0.90, SE =

TABLE 4. Seasonal survival estimates (with standard errors) for resident, hard-released, and soft-released male desert bighorn sheep at Black Gap Wildlife Management Area, Texas, USA, December 2017–2019.

	Resident			Hard-released			Soft-released		
Season[a]	*n*[b]	$\hat{S}$	SE	*n*	$\hat{S}$	SE	*n*	$\hat{S}$	SE
Year 1									
Gestating	8	1.00	0.00	11	0.91	0.02	24	1.00	0.00
Lambing	8	1.00	0.00	10	1.00	0.00	24	0.96	0.01
Lactating	8	1.00	0.00	10	1.00	0.00	22	0.86	0.01
Breeding	8	1.00	0.00	8	1.00	0.00	18	0.89	0.02
Year 2									
Gestating	5	1.00	0.00	6	1.00	0.00	15	0.93	0.02
Lambing	4	1.00	0.00	6	1.00	0.00	13	1.00	0.00
Lactating	4	0.50	0.09	4	1.00	0.00	13	0.92	0.02
Breeding	1	1.00	0.00	3	1.00	0.00	10	0.80	0.04

[a]Biological seasons were delineated as gestating (15 Nov–14 Feb), lambing (15 Feb–14 May), lactating (15 May–14 Aug), and breeding (15 Aug–14 Nov).
[b]Number of desert bighorn sheep radio-collared during the time period.

TABLE 5. Seasonal survival estimates (with standard errors) for resident, hard-released, and soft-released female desert bighorn sheep at Black Gap Wildlife Management Area, Texas, USA, December 2017–2019.

	Resident			Hard-released			Soft-released		
Season[a]	*n*[b]	$\hat{S}$	SE	*n*	$\hat{S}$	SE	*n*	$\hat{S}$	SE
Year 1									
Gestating	22	1.00	0.00	16	0.94	0.01	18	0.94	0.01
Lambing	22	1.00	0.00	15	0.93	0.02	17	0.94	0.01
Lactating	22	0.95	0.01	14	1.00	0.00	16	1.00	0.00
Breeding	19	0.95	0.01	13	0.85	0.03	16	0.94	0.01
Year 2									
Gestating	17	1.00	0.00	7	1.00	0.00	15	1.00	0.00
Lambing	17	1.00	0.00	7	1.00	0.00	15	1.00	0.00
Lactating	17	1.00	0.00	7	1.00	0.00	15	0.93	0.02
Breeding	15	1.00	0.00	6	0.83	0.06	14	0.86	0.02

[a]Biological seasons were delineated as gestating (15 Nov–14 Feb), lambing (15 Feb–14 May), lactating (15 May–14 Aug), and breeding (15 Aug–14 Nov).
[b]Number of desert bighorn sheep radio-collared during the time period.

0.01). Naïve survival rates for hard-released desert bighorn sheep varied throughout the seasons of year 1 but were consistent throughout the gestating, lambing, and lactating seasons of the second year ($\hat{S}$ =1.00, SE = 0.00). Naïve survival rates for soft-released desert bighorn sheep varied from 0.83 (SE = 0.01) to 1.00 (SE = 0.00) seasonally for both the first and second year (Table 3).

Seasonal naïve survival for resident males was constant at 1.00 (SE = 0.00) for both the first and second year, except for the lactating season of 2019 ($\hat{S}$ = 0.50, SE = 0.09). Seasonal naïve survival for hard-released males was 1.00 (SE = 0.00) for every season of year 1 and 2, except for the gestating season during the first year ($\hat{S}$ = 0.91, SE = 0.02). Soft-released males' seasonal naïve survival varied from 1.00 (SE = 0.00) to 0.80 (SE = 0.04), with the lowest naïve survival rate occurring during the breeding season of 2019 (Table 4). Resident females had seasonal naïve survival rates that ranged from 1.00 (SE = 0.00) to 0.95 (SE = 0.01), with the lactating and breeding season of the first year having the lowest rates. Hard-released female seasonal naïve survival rates varied the first year, with their lowest survival occurring during the breeding season of year 2 ($\hat{S}$ = 0.83, SE = 0.06). Soft-released females' seasonal naïve survival varied, ranging from 0.86 (SE = 0.02) during the breeding season of the second year to 1.00 (SE = 0.00) (Table 5).

The Kaplan–Meier survival estimator showed that resident desert bighorn sheep had the highest probability of survival over time at 0.83. The next highest probability of survival over time was for hard-released desert bighorn sheep, with an estimate of 0.67. Soft-released desert bighorn sheep had the lowest probability of survival over time (0.54), according to the Kaplan–Meier survival estimator (Fig. 3).

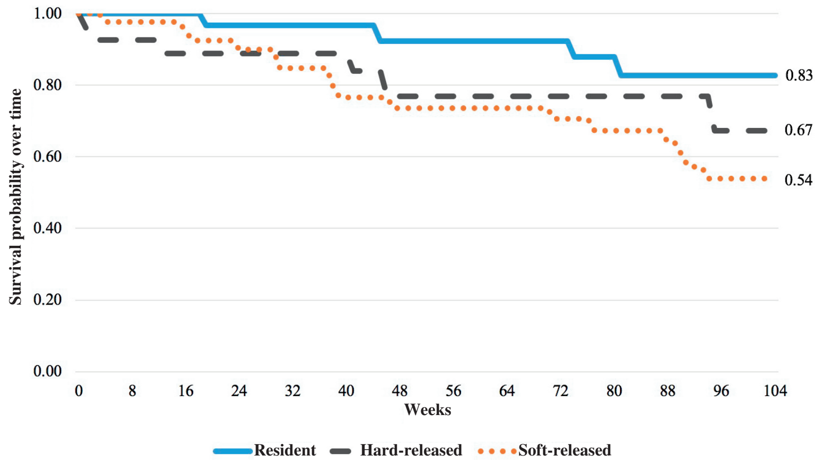

Fig. 3. Kaplan–Meier survival estimator curve based on weekly intervals for desert bighorn sheep at Black Gap Wildlife Management Area, Texas, USA, December 2017–December 2019.

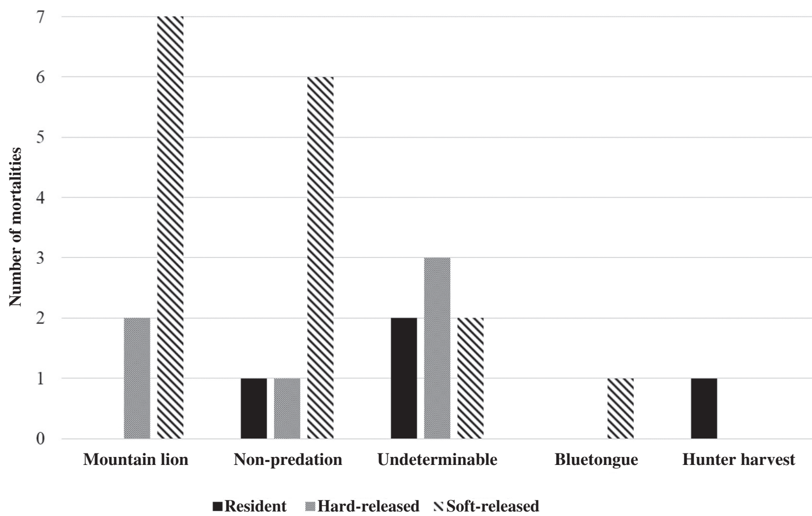

Fig. 4. Causes of mortality among different release methods of radio-collared, translocated desert bighorn sheep at Black Gap Wildlife Management Area, Texas, USA, December 2017–2019.

Cause-specific Mortality

A total of 26 mortalities (13 M, 13 F) were recorded throughout the duration of the study. Of those mortalities, 4 were resident (15%), 6 were hard released (23%), and 16 were soft released (62%). Nine mortalities of desert bighorn sheep were attributed to mountain lions (*Puma concolor*) (34%), 8 were non-predation (i.e., carcass was found intact with no signs of predation) (31%), 7 were undeterminable (i.e., carcass was too heavily scavenged or in too poor of condition to determine the cause of mortality) (27%), 1 was presumedly caused by blue tongue (4%), and 1 was a hunter harvest (4%). Of the 9 mountain lion kills (5 M, 4 F), 7 were soft released (78%) and 2 were hard released (22%) (Fig. 4). No mountain lion kills occurred within the soft-release enclosure. The investigation criteria for mortality sites possessed aspects commonly associated with mountain lion kills (e.g., cache, drag trails, presence of canine marks), which have been outlined in multiple studies (Rominger et al. 2004, Janke 2015, Cross 2016). Of the 9 kills, 7 (78%) were cached or had a cache pile present, 6 (67%) had distinct drag trails, and 6 (67%) had canine marks suggestive of mountain lions.

DISCUSSION

The top 2 models suggest that season (i.e., gestating, lambing, lactating, and breeding) and treatment (i.e., resident, hard-released, or soft-released) are influential variables for translocated desert bighorn sheep survival. A similar study by Gonzalez-Gonzalez (2018) also had "season" as a top variable for translocated desert bighorn sheep survival models.

During this study, the resident desert bighorn sheep had the greatest overall 2-year naïve survival estimate ($\hat{S}$ = 0.87), which was expected given their familiarity with the landscape. The hard-release method had a higher overall 2-year naïve survival estimate ($\hat{S}$ = 0.78) than that of the soft-release method ($\hat{S}$ = 0.62). Survival rates differed among release methods and between sexes and years. The soft-released males also showed a lower 2-year naïve survival rate ($\hat{S}$ = 0.58) than the resident ($\hat{S}$ = 0.75) and hard-released males ($\hat{S}$ = 0.91). The soft-released females had a lower 2-year naïve survival estimate ($\hat{S}$ = 0.67) than the residents ($\hat{S}$ = 0.91) but were similar to hard-released females ($\hat{S}$ = 0.69).

This research was unique due to the presence of collared resident individuals, which allowed us to compare the survival of translocated desert bighorn sheep to individuals already present on the landscape. The resident desert bighorn sheep had greater survival than both hard- and soft-released individuals, possibly due to their familiarity with the landscape. For translocated individuals, integration with resident individuals may play a role in survival. However, other research has found social integration to be low and infrequent between resident and translocated individuals (Roy and Irby 1994, Poirier and Festa-Bianchet 2018, Robinson et al. 2019).

Previous research on translocation release methods had different results when comparing hard and soft releases. For example, Cain et al. (2018) found that soft release did not enhance survival for translocated mule deer, whereas Martinez-Garcia (2009) found an increase in soft-released mule deer survival compared to hard-released. Thompson et al. (2001) also did not find a difference in survival between hard- and soft-released bighorn sheep. Our study corroborates previously mentioned findings, in that a soft release did not improve or enhance survival.

A combination of the acclimation time before desert bighorn sheep left the high-fence pen and whether or not they left individually or in small herds could have made the animals more vulnerable, influencing their survival. Following the 3-week acclimation period, soft-released desert bighorn sheep exited the high-fence pen in a "trickle out" effect (i.e., in small groups and individually over 2 months). Exposure windows and vulnerability could have been influenced by this exit strategy exhibited by individuals in the soft-release treatment.

Enclosure size and holding time could also be a factor contributing to the success of soft-releases (Cain et al. 2018). At 210 ha, our enclosure was larger than those in similar studies: 7 m^2 in Thompson et al. (2001), 8–11 ha in Parker et al. (2008), 16 ha in Martinez-Garcia (2009), and 0.81 ha in Cain et al. (2018). And our acclimation period (3 weeks) was shorter than that reported in most of these studies (12–24 weeks). It is likely that a combination of the enclosure size and acclimation period have an effect on the survival of the soft-released individuals.

In this study, desert bighorn sheep at BGWMA (resident, hard-released, and soft-released) had lower mortality rates from mountain lion predation, 34%, than reported in several other studies: 55% in Janke (2015), 64% in McKinney et al. (2006), 75% in Rominger et al. (2004), 66% in Kamler et al. (2002), and 69% in Hayes et al. (2000). However, Cross (2016) reported lower mountain lion predation rates of 9% but attributed the low percentage to active mountain lion trapping. Mountain lion trapping was also conducted before and during this research by TPWD at BGWMA. Furthermore, mountain lion predation estimates could be biased due to mortality site assessment. Clear sign of a mountain lion kill (e.g., cached carcass, presence of drag trail, stomach evisceration with rumen not consumed, scat, canine marks on jaw or snout) can be identified. However, evidence for all other potential causes of mortality was not always clear.

Bluetongue is a viral disease found in wild and domestic ruminants, predominantly those of the genus *Ovis*. It is noncontagious, spread by midges (*Culicoides* sp.), and can overwinter in mild temperate zones. Robinson et al. (1967) reported a single young male desert bighorn sheep at BGWMA that had contracted bluetongue and died shortly after discovery. Desert bighorn sheep that reside in low-elevation areas with a high density of human-made water sources are more susceptible to bluetongue transmission due to the presence of midges (Jessup 1985). Bluetongue can be a harmful virus that can cause significant die-offs (Blaisdell 1975). The case of bluetongue discovered by TVDML in this study does not necessarily mean the individual died from the disease. It is possible that the desert bighorn sheep had bluetongue but died from other unknown causes. However, no other indicators of cause of mortality for this individual were present, so the presumed cause of mortality was classified as bluetongue.

Soft release is thought to be a better strategy for translocating large mammals. However, in this study, it did not improve survival. Hard-released desert bighorn sheep had greater survival than soft-released desert bighorn sheep. The soft-released individuals made up 62% of the total mortalities in this study, whereas the hard-released individuals made up only 23%. A combination of the acclimation time before desert bighorn sheep left the high-fence pen and their previously mentioned exit strategy could have made them more vulnerable, which in turn could have influenced the survival of soft-released desert bighorn sheep. The soft-release method also requires extra costs (e.g., building cost, maintenance, personnel, food, water, predator removal in and around the enclosure) to conduct, which could be challenging for wildlife managers. Since individuals from this study exhibited a “trickle out” exit strategy, future research should assess whether enouraging all individuals to leave simultaneously in a “flushing out” exit strategy could increase survival by allowing animals to form larger groups when exiting the enclosure and entering the new habitat.

Mountain lion control is a controversial topic and may be recommended at the initial stages of translocation. Knowledge of mountain lion ecology is limited in Texas, and scientists do not currently know the severity of their threat to the long-term sustainability of desert bighorn sheep populations in Texas. A predator management program specifically for mountain lions should be considered on a site-specific basis. Future research should investigate mountain lion–desert bighorn sheep interactions using satellite collars to evaluate their predator and prey dynamics. Implementing a focused and effective predator management research project would benefit desert bighorn sheep restoration in Texas.

ACKNOWLEDGMENTS

Financial support was provided by the Texas Parks and Wildlife Department, the Borderlands Research Institute, and the San Antonio Livestock Exposition. We would like to thank all private landowners who supported this research and provided access to their property.

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Received 22 February 2021
Revised 3 August 2021
Accepted 3 September 2021
Published online 31 March 2022