2017

Evaluation of the Deadwood Bighorn Sheep Herd Translocation

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EVALUATION OF THE DEADWOOD BIGHORN SHEEP HERD TRANSLOCATION

BY

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A thesis submitted in partial fulfillment of the requirements for the

Master of Science

Major in Wildlife and Fisheries Sciences

South Dakota State University

2017

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This thesis is approved as a creditable and independent investigation by a candidate for the Master of Science in Wildlife and Fisheries Sciences degree and is acceptable for meeting the thesis requirements for this degree. Acceptance of this thesis does not imply that the conclusions reached by the candidate are necessarily the conclusions of the major department.

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ACKNOWLEDGEMENTS

I would like to thank my advisor, Dr. Jonathan Jenks, for allowing me to take on an important and exciting Masters project. Field work was often arduous and challenging, but you never seemed to doubt my ability while I was conducting my research in the Black Hills. I will always see you as an inspiration to my own career goals. As I've heard you say, you are not anyone's babysitter, and I appreciated the space I was given to grow and learn on my own. I would also like to thank my committee members, Dr. Chad Lehman and Dr. Teresa Frink. Dr. Lehman was instrumental in helping me to understand the vegetative techniques needed in the field. Dr. Frink, I can't thank you enough for the guidance and assistance you gave me as an advisor during my undergraduate years at Chadron State College, and the continued guidance you are always willing to give as I keep growing as a wildlife professional. I would not be where I am today without you.

To the ladies in the office, Kate Tvedt, Terri Symens, Diane Drake, and Dawn Van Ballegooyen, thank you so much for putting up with all my questions throughout the last two and a half years. I will always be grateful that you had the patience to deal with so many graduate students.

I would like to thank Federal Aid to Wildlife Restoration administered through South Dakota Department of Game, Fish and Parks (Study Number 7556) for financial support for this project. None of this would have been possible without the crew from South Dakota Department of Game, Fish and Parks. From our long trek to Alberta, to helping me dart sheep, you guys were always willing to help. John Kanta, thanks for putting so many hours in at the desk to make the translocation go smoothly. You always made yourself accessible and answered any and all questions I had. Trenton Haffley, thank you for all the bighorn knowledge you willingly passed on to me. Not to mention all the hiking, darting, and tracking you always made time to help with. Kris Cudmore, thank you for never being more than a phone call away and always willing to help. Jimmy Doyle, thank you for being so friendly and helping whenever a need arose. I'd also like to thank the seasonal workers who were willing to help in any way possible, whether it was darting bighorns or cleaning trailers with bleach.

To my grandmother, Phyllis, you always believed in me no matter what mistakes I made along the way. I hope that you are proud of me. I will miss you always. To my grandfather, Lee, thank you for instilling in me a great love for hunting and the outdoors. You are the reason I have a love for wildlife. To my father, Ron, you are what a man should be. You've taught be about hard work, taking care of a family, character, and how to be the best at everything I do. I will always strive to be just like you. To my mother, LuAnn, I might not be as smart as you think I am, but I'm thankful you have always made me believe that I can accomplish anything. It goes without saying, but I wouldn't be where I am without everything you've done along the way. To my sister, Kaycee, thank you for being so supportive through everything. You make me proud and I'm thankful to be able to watch you grow into an exceptional woman.

My wife, who I met the first day of my Masters education, has stuck by me and motivated me from the very beginning. Chelsea, thank you for your hard work as a technician. I know some days you really did not feel like having me order you around, and occasionally you even thought you were the boss. When I'm feeling like being lazy, you are always there to give me a little extra push to get things done. This has been the greatest time in my life, and it is because of you. From the many drives, back and forth to

Sioux Falls after class, to our marriage in Spearfish, every day has been a blessing. You deserve this degree just as much as I do.

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ABSTRACT

EVALUATION OF THE DEADWOOD BIGHORN SHEEP HERD TRANSLOCATION

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From 2015-2017, we evaluated a newly established bighorn sheep (*Ovis canadensis*) herd in the Deadwood Region of the Black Hills, South Dakota. Our objectives were to 1a) determine annual survival rates, 1b) determine cause-specific mortality, 1c) estimate population size, 2a) assess genetic diversity, 2b) assess disease prevalence, 3) evaluate movement patterns post-release, 4a) evaluate 3^{rd}-order habitat selection, and 4b) estimate herbaceous biomass at foraging sites post-release of translocated bighorn sheep. In February 2015, we captured and translocated 26 bighorn sheep from the Luscar Mine near Hinton, Alberta, Canada to the Deadwood Region of the Black Hills, South Dakota. Overall annual bighorn sheep survival rates were 64.4% (95% CI=0.48-0.77). Confirmed pneumonia accounted for 57.9% (n=11) of all cause-specific mortalities, while no predation was documented during the study. We estimated the population size at the end of the study period was 24 bighorn sheep (λ=0.92). Observed and expected heterozygosity were 0.71 (SE=0.06) and 0.64 (SE=0.05), respectively. The *Mycoplasma ovipneumoniae* pathogen found within the Deadwood bighorn sheep herd was of a strain type previously undocumented in the Black Hills. Dispersal among individual bighorn sheep occurred year 1, while establishment of home-ranges occurred year 2. We used 95% Brownian Bridge Movement Models for year 2, which resulted in a mean home-range size of 5.29 km^2. Forested habitat was actively avoided ($\hat{w}$=0.30), while barren

($\hat{w}$=16.93), shrubland ($\hat{w}$=1.28), and grassland ($\hat{w}$=1.65) habitats were selected. Foraging sites were typically located in areas with little overstory tree canopy cover (mean= 8.41%, SE=1.85), short distance to escape terrain (mean= 24.00 m, SE=3.21), and little woody debris (mean= 0.25 kg/ha, SE=0.07). Herbaceous biomass ranged from 302.07 kg/ha to 2,487.43 kg/ha. Our results indicate that the Deadwood Region of the Black Hills, South Dakota had sufficient forage and habitat capabilities to support a healthy population of bighorn sheep. Translocations to this region can be successful, however, pneumonia, caused by the *Mycoplasma ovipneumoniae* pathogen, was the greatest limiting factor to population growth within the Deadwood bighorn sheep herd.

CHAPTER 1: SURVIVAL, CAUSE-SPECIFIC MORTALITY, AND ESTIMATION OF POPULATION SIZE OF TRANSLOCATED BIGHORN SHEEP IN THE DEADWOOD REGION OF THE BLACK HILLS, SOUTH DAKOTA

ABSTRACT

Bighorn sheep (*Ovis canadensis*) historically inhabited the Black Hills region of South Dakota, but the species was extirpated from the area in the early 1900s. Several reintroductions have taken place in the central and southern regions of the Black Hills. We translocated 26 bighorn sheep from Alberta, Canada to the Deadwood Region of the Black Hills. Our objectives were to determine annual survival rates, determine cause-specific mortality, and to estimate population size of the Deadwood herd. Our overall annual survival rate was 64.4% (95% CI=0.48-0.77). Pneumonia accounted for the highest percentage of mortalities (57.9%), followed by natural causes (15.79%), vehicle collisions (10.53%), capture stress (5.26%), non-pneumonia related euthanization (5.26%), and unknown causes (5.26%). The growth rate for the entire study period showed a slight decline (λ=0.92), with 24 bighorn sheep remaining in the Deadwood herd. A pneumonia event late in the study caused a severe decline in population size.

INTRODUCTION

Prior to human colonization of North America, bighorn sheep (*Ovis canadensis*) were relatively abundant, numbering in the millions, and occupied habitats across the western United States, Canada, and Mexico (Buechner 1960). Bighorn sheep are an ecologically sensitive species, with many factors affecting their wilderness habitat (Buechner 1960, Zimmerman 2008). Human impacts in the form of uncontrolled harvest, introduced disease from domestic sheep (*Ovis aries*), introduced forage competition from domestic livestock, reduced and fragmented habitat, and loss of movement corridors led to major declines in bighorn sheep populations in the late 19th century through the mid-20th century (Buechner 1960, Douglas and Leslie 1999, Beecham et al. 2007). Since the mid-1900s, State and Federal wildlife management agencies have attempted hundreds of bighorn sheep reintroductions to the species' historic ranges with varying levels of success (Berger 1990, Singer et al. 2000, Hedrick 2014, Parr 2015).

In South Dakota, bighorn sheep historically inhabited the Black Hills region, but the species was extirpated from the area in the early 1900s (Seton 1929, Witte and Gallagher 2012, Zimmerman 2008, Parr 2015). South Dakota Department of Game, Fish and Parks (SDGFP) began reintroductions to the state in the 1960s, with successful restorations occurring in Badlands National Park and the central and southern regions of the Black Hills, including Custer State Park, Spring Creek, Rapid Creek, Sheridan Lake, and Elk Mountain areas (Zimmerman 2008, SDGFP 2013, Parr 2015). However, the Deadwood area of the northern Black Hills was vacant, but deemed potentially suitable for a reintroduction, based on habitat suitability models and a qualitative assessment of topography, forage, and water (SDGFP 2013). Despite a prerelease evaluation of the release site, no information was available regarding historical use of the area by bighorn sheep (SDGFP 2013).

Diseases and parasites can cause significant mortality to bighorn sheep. The pneumonia complex includes a number of causative diseases including lungworms (*Protostrongylus* spp.) and bacteria (*Mannheimia haemolytica*, *Bibersteinia trehalosi*, *Mycoplasma ovipneumoniae*; Besser et al. 2012) that become mortality agents affecting bighorn sheep when present in conjunction with other stressors (e.g., nutrition and climate) (Onderka and Wishart 1984, Forety 1990, Besser et al. 2012). Domestic sheep can expose bighorn sheep populations to these diseases if contact between the 2 species occurs (Besser et al. 2012). Plowright et al. (2013) documented that surviving ewes become immune to the effects of these pathogens, but that immunity is not transferred to lambs. Cassirer and Sinclair (2007) noted that pneumonia caused 43% of mortalities of adult bighorn sheep occupying Hells Canyon, Idaho, Oregon, and Washington. They designated pneumonia-caused mortality as the primary factor limiting population growth of bighorn sheep. In that study, mountain lion (*Puma concolor*) predation accounted for 27% of bighorn sheep mortalities, but was not associated with population decline. In contrast, McKinney et al. (2006) observed no significant diseases in bighorn sheep in the Mazatzal Mountains, Arizona. However, they hypothesized that mountain lion predation and nutritional condition influenced population status of bighorn sheep and suggested that short-term removal of mountain lions contributed to increased productivity and consequently, population growth. In the Black Hills, lamb survival of bighorn sheep occupying Spring Creek, Rapid Creek, and Hill City was 2% over a 3-year period (2010-2012) due to disease and predation (Smith et al. 2014). In contrast, Parr (2015) found that in the absence of disease, lamb survival in the Black Hills can reach as high as 44%.

It has been suggested that mountain lions pose a significant threat to bighorn sheep populations due to ease of capture of this prey species (Festa-Bianchet et al. 2006, Rominger et al. 2004). Predation by mountain lions was the primary proximate cause of mortality (75% of mortalities) on bighorn sheep in one population in Arizona (Rominger et al. 2004). Moreover, Kamler et al. (2002) documented that mountain lions caused 66% of mortality on a translocated bighorn sheep population in Arizona. In California, mountain lions were responsible for 69% of bighorn sheep mortalities (Hayes and Rubin 2000). In contrast, others have suggested that mountain lions can cause limited mortality to bighorn sheep and other large mammal populations (Rominger et al. 2004, Cougar

Management Guidelines Working Group 2005). In the Black Hills, lamb production and survival are generally correlated with summer climatic conditions and populations of bighorn sheep can experience disease-mediated lamb mortality as well as mortality due to mountain lions during this season (Smith et al. 2014). However, other predators such as coyotes (*Canis latrans*; Dekker 2009) and bobcats *(Lynx rufus*; Parr et al. 2014), have been associated with bighorn sheep mortality.

To expand bighorn sheep restoration in the Black Hills, we translocated 26 bighorn sheep from the Luscar Mine near Hinton, Alberta, Canada to the Deadwood region of the northern Black Hills. In an effort to evaluate a critical large mammal translocation, our objectives were to: determine annual survival rates of bighorn sheep, determine cause-specific mortality of bighorn sheep, and to estimate population size of the Deadwood herd.

STUDY AREA

Bighorn sheep were initially captured in Alberta, Canada and translocated to our study area, the Deadwood region, located in the northern Black Hills in western South Dakota, USA (44°20'56.55''N, -103°42'28.64''W) (Fig. 1). This area encompasses approximately 8,177 ha of public (5,203 ha) and private (2,974 ha) land and is located immediately adjacent to the Deadwood, Lead, and Central City communities in Lawrence County, South Dakota (SDGFP 2013). Elevations range from 1,073 to 2,209 m above mean sea level. The Deadwood region of the Black Hills occurs within the central core of the Blacks Hills, which is typified by canyons, mountain peaks, and broad valleys (Hoffman and Alexander 1987). Soils of the region include limestones, dolomites, and sandstones of Paleozoic origin (Hoffman and Alexander 1987). This region of the Black

Hills receives more precipitation in the form of snow (156 cm) and is cooler (-5 C) than more southern areas within the Black Hills (Hoffman and Alexander 1987, NOAA 2017).

Ponderosa pine (*Pinus ponderosa*) is the dominant overstory tree species of the region; it occurs in monotypic stands and is intermixed with small stands of quaking aspen (*Populus tremuloides*) and paper birch (*Betula papyrifera*) (Mcintosh 1949, Orr 1959, Thilenius 1972, Richardson and Petersen 1974, Hoffman and Alexander 1987). Common plant species include Kentucky bluegrass (*Poa pratensis*), timothy (*Phleum pretense*), smooth brome (*Bromus inermis*), sedges (*Carex* spp.), western wheatgrass (*Pascopyrum smithii*), prairie dropseed (*Sporobolus heterolepis*), fleabane (*Erigeron* spp.) and yarrow (*Achillea* spp.) (Uresk et al. 2009). Additional ungulate species occupying the study area included mule deer (*Odocoileus hemionus*), white-tailed deer (*O. virginianus*), and elk (*Cervus elaphus*). Potential species known to predate on bighorn sheep occurring in the study area include mountain lions (*Puma concolor*; Smith et al. 2014, Wilckens et al. 2016), coyotes (*Canis latrans*), bobcats (*Lynx rufus*; Parr et al. 2014), bald eagles (*Haliaeetus leucocephalus*), and golden eagles (*Aquila chrysaetos*).

METHODS

Translocation and Data Collection

In February 2015, we (i.e., SDGFP and SDSU personnel) traveled to Hinton, Alberta, Canada to capture and transport bighorn sheep to South Dakota. Two sites within the Luscar Mine were baited with alfalfa (*Medicago sativa*) hay for one week prior to our capture date. On 10 February 2015, modified 18 m x 18 m electromagnetic drop-nets were constructed over bait sites, and the following morning nets were used to capture bighorn sheep (Jedrzejewski and Kamler 2004). Adult male bighorn sheep were aged based on horn annuli (Geist 1966) and adult females were aged via tooth eruption and wear (Hemming 1969, Krausman and Bowyer 2003). Twenty-one adult females and 1 adult male bighorn sheep were fitted with store-on-board global positioning system (GPS; Model 2110D; 154-155 MHz) radio collars (Advanced Telemetry Systems, Isanti, MN, USA). Two adult female bighorn sheep were fitted with very high frequency (VHF; Model 2520B; 154-155 MHz) radio collars (Advanced Telemetry Systems, Isanti, MN, USA). One female bighorn lamb and 1 male bighorn lamb were fitted with very high frequency (VHF; Model M4200M; 154-155 MHz) expandable break-away radio collars (Advanced Telemetry Systems, Isanti, MN, USA).

Ear tags were attached to each individual bighorn sheep for future identification in the field. We collected blood samples and swabbed nasal and pharyngeal passages for disease testing; swab and blood samples were sent to Washington Animal Disease Diagnostic Laboratory (WADDL) to test for the presence of *Mycoplasma ovipneumoniae* (*M. ovi*) and pathogens related to pneumonia; blood samples were sent to The Holmes Research Centre University of Idaho for selenium analysis; collected serum used to test for *Brucela ovis*, *B. abortus*, *B. suis*, PI-3, bovine viral diarrhea virus, and *Bacillus thuringiensis* was sent to USDA APHIS National Veterinary Services Laboratories; blood for DNA extraction and analysis was sent to the University of Alberta. In addition, we administered a pneumonia vaccine (IM and intranasally) to all bighorn sheep individuals. All capture and handling methods were approved by the South Dakota State University Institutional Animal Care and Use Committee (Approval No. 14-096A).

Translocated bighorn sheep were released approximately 3.5 km southwest of Deadwood, South Dakota on private land. All radio-collared bighorn sheep were located a minimum of 5 times per week post-release between February-August 2015 and May-July 2016, and a minimum of 3-4 times per week September 2015-April 2016 and August-December 2016 using a hand-held directional antenna and portable receiver (model RA-23K, Telonics, Inc., Mesa, AZ, USA). Mortality events were generally located within 12 hours of receiving mortality signals from collars; in the event bighorn carcasses were decayed or scavenged beyond recognition, samples were not collected and individuals were listed as "unknown" mortality events. Upon finding bighorn sheep mortalities, we documented observations at the site and carcasses were transported to the SDGFP laboratory in Rapid City, South Dakota where necropsy and cause of death were determined. The respiratory tract, including the lungs and trachea, were sent to the Washington Animal Disease Diagnostic Lab (WADDL) in Pullman, Washington where comprehensive testing for pneumonia strains was conducted. Predation events were documented by species of predator.

Data Analysis

We estimated survival using the Kaplan-Meier method (Pollock et al. 1989, DePerno et al. 2000, Brinkman et al. 2004, Swanson et al. 2008, Smith et al. 2014, Smith et al. 2015) with known-fate models in Program Mark (Klaver et al. 2008, Smith et al. 2014, Smith et al. 2015). Collared bighorn sheep encounter histories were converted to monthly encounter histories (n=12) (White and Burnham 1999). No individual bighorn sheep were censored within the model, as each translocated individual was identified as living or dead visually or via telemetry during each encounter interval. GPS collars fitted on live bighorn sheep released automatically after ~700 days and were recovered in the field, while GPS collars fitted on bighorn sheep mortalities were recovered at mortality sites; satellite location and time data were offloaded from GPS collars. Mortalities were assigned to the monthly encounter interval based on GPS data or date of mortality signal. We developed 9 *a priori* models to investigate effects on bighorn survival (Table 1). Our variables included 2 temporal seasonal models (winter season [Oct-Jan] versus remainder of year [Feb-Oct] and lambing season [May-June] versus remainder of the year), age of individuals at capture (adult versus subadult), year 1 (Feb 2015-Jan 2016) versus year 2 (Feb 2016-Jan 2017), regions (northern versus southern), sex of individual, winter season-year ([Oct-Jan] and year), and month; these variables were then compared to a constant survival model.

Population size of the Deadwood bighorn sheep herd was estimated weekly via telemetry and visual identification. In lambing months (May-June), bighorn sheep were located daily and a spotting scope was utilized to observe neonate lambs from a distance >300 meters. We classified a ewe as having a lamb if it was observed nursing or alone with a lamb, and assumed lambs had died if they were no longer observed with the ewe (Cassier and Sinclair 2010). Lamb population numbers were recorded and they were monitored alongside collared adults throughout the study period. Growth rates of the population were calculated using geometric growth rate (λ) and instantaneous growth rate (r) models; $\lambda = N_{t+1}/N_t$ and r=ln(λ).

RESULTS

In February 2015, we captured and radio-collared 26 bighorn sheep near Hinton, Alberta, Canada and translocated them to the Deadwood region of the Black Hills, South

Dakota, USA. Among the 26 individuals, there were 23 adult female ewes (>1.5 years), 1 adult male ram (>1.5 years), 1 subadult female (<1.5 years), and 1 subadult male (<1.5 years). On 12 February 2015, the 26 bighorn sheep were released onto private property 3.5 km southeast of Deadwood, South Dakota.

Of the original 26 translocated bighorn sheep, we documented a total of 19 mortality events February 2015-January 2017 (Table 1). Three mortalities that resulted from a fall from a cliff (adult female ewe), a drowning (adult female ewe), and a broken neck (adult female ewe) were categorized as natural causes and accounted for 15.79% of translocated bighorn sheep mortalities. Two adult female ewe mortalities resulted from collisions with vehicles (10.53%); one on Interstate 90 and one on a county road. A single adult female ewe died within the first 3 weeks post-release due to stress caused by capture and translocation (5.26%). We euthanized 4 total translocated bighorn sheep (21.05%); one adult male ram was euthanized after moving to an area near domestic sheep 17 km north of the study area, near St. Onge, South Dakota (pneumonia was not confirmed post-euthanization by WADDL) and 3 adult female ewes were euthanized based on symptoms analogous with pneumonia (pneumonia was confirmed post-euthanization by WADDL). Confirmed pneumonia accounted for the highest percentage (42.11%) of mortalities of translocated bighorn sheep (*n*=8). If total confirmed pneumonia related mortalities are combined (*n*=11), 57.9% of all mortalities were a direct result of the disease. Necropsies at SDGFP laboratory showed that mortalities that were pneumonia related had varying stages of fused lung tissue and infection. One adult female ewe's cause of death could not be determined due to scavenging of the carcass.

We considered {$S_{oct\text{-}jan,year}$} as the top model, of 9 total models evaluated, for estimating annual translocated bighorn sheep survival in the Deadwood region of South Dakota (w_i=0.96). The remaining 8 models were ≥2 ΔAIC_c units from the top model, and the weight of evidence supporting the top model was 23.6 times greater than all other models combined (Table 2). The top model, {$S_{oct\text{-}jan,year}$}, continued to exhibit the lowest $QAIC_c$ even after $\hat{c}$ was artificially inflated to moderate ($\hat{c}$=2.0, $QAIC_c$ wt=0.71) and extreme dispersion ($\hat{c}$=3.0, $QAIC_c$ wt=0.47). Monthly survival for October-January, Year 1 (Feb 2015-Jan 2016) was 91.5% (95% CI = 0.85-0.95), and for all other months it was 99% (95% CI = 0.97-1). The overall annual translocated bighorn sheep survival rate was 64.4% (95% CI = 0.48-0.77).

We began the study with a known number of 26 individual translocated bighorn sheep in a closed population post-release. Each of the individuals was identifiable by a radio collar and unique ear tag numbers. Adult (>1.5 years) population, subadult (<1.5 years) population, recruitment, deaths, total population, and growth rates were recorded based on weekly telemetry and visual monitoring (Table 3). During May-June 2015 there were 15 lambs recruited into the population (11 females, 4 males; 65:100 lamb to ewe ratio; 100% lamb survival), while there were only 5 lambs recruited into the population during the May-June 2016 lambing season (3 females, 2 males; 25:100 lamb to ewe ratio; 60% lamb survival). The year 1 (Feb 2015-Jan 2016) growth rate (λ= 1.38, r= 0.322) was positive, while the year 2 (Feb 2016-Jan 2017) growth rate (λ= 0.667, r= -0.405) and rate for the entire study period (Feb 2015-Jan 2017) (λ= 0.92, r= -0.08) was negative.

DISCUSSION

Annual bighorn sheep survival and population estimates documented in year 1 (Feb 2015-Jan 2016) indicated that the translocated Deadwood bighorn sheep herd was increasing in size; there were no disease or predation related mortalities documented during year 1, which was contrary to previous studies. Kamler et al. (2002) found that 66% of mortalities were caused by mountain lion predation and 13% of mortalities were caused by disease and Rominger et al. (2004) found that 75% of mortalities in a subpopulation were caused by mountain lion predation. Cassirer and Sinclair (2007) found that 43% of adult mortalities and 86% of lamb mortalities were due to pneumonia and 27% of adult mortalities were caused by mountain lion predation. In the Black Hills, Smith et al. (2014) found that 19% of adult ewe mortalities were caused by predation and 19% of adult ewe mortalities were caused by pneumonia in a Black Hills bighorn sheep population whereas Parr (2015) found that 33% of adult and 35% of lamb bighorn mortalities were caused by predation in the southern Black Hills.

Annual bighorn sheep survival and population estimates documented in year 2 (Feb 2016-Jan 2016) reversed drastically from year 1, as we observed a sharp decline in the Deadwood herd size. This was due to multiple factors, with a pneumonia event, which began 29 October 2016, being the most severe. This type of quick and severe die-off due to pneumonia has been documented in recent years (Cassirer and Sinclair 2010, Besser et al. 2012, Smith et al. 2014). Telemetry, visual monitoring, and GPS locations showed no indication of collared translocated bighorn sheep coming into contact with domestic sheep in the area, although there were domestic sheep and goat (*Capra hircus*) locations in the vicinity (within 5 km) of the Deadwood bighorn sheep home range. The pneumonia strain attributed to the Deadwood bighorn sheep herd die-off, is one that had not been previously discovered in other Black Hill's bighorn sheep herds (SDGFP 2013, Smith et al. 2014, Parr 2015). One hypothesis that could explain this pneumonia epizootic is that a livestock trailer hauling domestic sheep came in close proximity to bighorn sheep foraging in ditches along a main road, and thus, transmitted the disease without direct contact. Other factors that may have contributed to the translocated Deadwood bighorn sheep herd decline include the loss of the single breeding age ram, a distinct separation in ranges between 2 subherds, and acclimation to their new habitat (i.e., cliff composition, water sources).

The overall Deadwood bighorn sheep survival rate of 64.4% was lower than that found by Parr (2014) who studied bighorn sheep in the southern Black Hills; she documented an annual ewe survival rate of 88.1% and ram survival rate of 85.1%. Comparatively, our survival rate also was much lower than that of healthy bighorn sheep populations (Jorgenson et al. 1997 [95%], Singer et al. 2000b [89%], Cassirer and Sinclair 2010 [91%]). Population estimates documented throughout the study period (Feb 2015-Jan 2017) showed declines in herd size due to mortalities suffered during the last 4 months of the study. Parr (2014) found that a bighorn sheep population in the southern Black Hills was slightly increasing (λ=1.197) during her study. An interesting finding was that there were no predation events during the entire study. Mountain lions were hypothesized to be the greatest predation threat to the translocated Deadwood bighorn sheep herd, based on harvest and population data from SDGFP (2014). Mountain lion caches were found in the immediate area of the Deadwood bighorn sheep herd, but as the contents of the caches indicated, mountain lions may have been actively selecting for mule deer, which occupy the same habitat (SDGFP 2013). We now hypothesize that mule deer populations are at an adequate level to sustain mountain lion populations, but if mule deer populations decline or if mountain lions obtain skills for preying upon bighorn sheep (Jenks 2018), predation may begin to occur on resident bighorn sheep. Previous studies in the Black Hills have found that predation often occurs on lambs and adults, even if the mortality was compensatory (Smith et al. 2014, Parr 2015).

Visual observations of lambs with radio-collared ewes may lead to an over-estimation of true survival or recruitment rates (Smith et al. 2014). However, during the first year of our study, intensive visual monitoring (5-7 times per week during the lambing period of May-June) of a closed population with all individuals known, led us to observe lamb survival at an unprecedented level of 100%, while previous studies of pneumonia-free Black Hills' bighorn sheep populations have shown lamb survival only as high as 44.7% (Parr 2015). In the Hells Canyon region of Idaho, Oregon, and Washington, pneumonia free populations had lamb survival as high as 76% (Cassirer and Sinclair 2010). Similar to that documented by Parr (2015), bighorn sheep in the Deadwood region of the Black Hills tended to form groups based on lamb survival; ewes that were without lambs (possibly due to undocumented lamb mortality) made larger and more erratic movements, while ewes with lambs formed nursery groups near their respective lambing sites.

In July 2015, the lone translocated breeding age ram (>1.5 years) was euthanized after moving to an area near domestic sheep 17 km North of the study area and leaving only a subadult yearling ram with the adult bighorn ewes. However, bighorn sheep, regardless of sex, have been known to breed at 18 months of age, so our expectation was that the subadult ram would become reproductively active before the November-December breeding season (Geist 1971). Another obstacle to breeding in the 2015 season was the separation of adult bighorn ewes into 2 distinct ranges within the region; six ewes were within the Gilt Edge Mine, approximately 6 km southeast of the larger subherd in the Deadwood region, with little or no contact for much of the year. Without the use of vaginal implant transmitters (VITs), lambing rates for November-December 2015 could not be determined until parturition in May-June 2016. Intensive visual monitoring during the 2016 lambing period (5-7 times per week during May-June) led us to observe a lambing rate of 25:100 lamb to ewe ratio (5 lambs of 20 adult ewes). This was a significant decrease in lamb to ewe ratio from 2015 (65:100), most likely due to the presence a single young ram within the Deadwood bighorn herd. Lamb survival during the summer and fall remained at 100%, but after our first adult pneumonia event in October 2016, lamb survival declined to 40% (2 lamb mortalities). Carcasses of lambs were not found, but Smith et al. (2014) estimated a low lamb survival rate of 2% in the eastern Black Hills due to predation and disease. This leads us to hypothesize that pneumonia was the most likely cause of lamb mortality in 2016.

MANAGEMENT IMPLICATIONS

Domestic sheep and their ability to transmit pneumonia disease agents to bighorn sheep was the biggest threat to the survival of bighorn sheep in the Deadwood region. As the Deadwood bighorn sheep herd is a relatively closed population within the Black Hills, it is important to keep them restricted to that area, and continue to closely monitor for disease and mortality. Mountain lion predation was not a factor in survival of bighorn sheep in the Deadwood region; however, that could change in the future. We also recommend that a more thorough investigation of the area for domestic sheep and goats be completed. We recommend that testing of domestic sheep and goats be conducted in this area to attempt to find the source of the disease, and development of additional vaccines for domestic sheep, domestic goats, and bighorn sheep in the area.

ACKNOWLEDGEMENTS

Financial support for this project was provided by Federal Aid to Wildlife Restoration administered through South Dakota Department of Game, Fish and Parks (Study Number 7556). We thank South Dakota Department of Game, Fish and Parks, Civil Air Patrol, Deadwood Police Department, Lawrence County Sheriff's Office, and private property owners in the Deadwood area for their assistance and property access. We thank J. Smith and B. Simpson for their assistance with data analyses. We thank T. Haffley, K. Cudmore, J. Doyle, J. Clark, and C. Werdel for their assistance with monitoring, capturing, and euthanizing bighorn sheep during the study period.

LITERATURE CITED

Beecham, J. J., C. P. Collins, and T. D. Reynolds. 2007. Rocky Mountain bighorn sheep (*Ovis canadensis*): A Technical Conservation Assessment. http://www.fs.fed.us/r2/projects/scp/assessments/rockymountainbighornsheep.pdf (accessed 2/27/2017).

Berger, J. 1990. Persistence of different-sized populations: an empirical assessment of rapid extinctions in bighorn sheep. Conservation Biology 4:91-98.

Besser, T. E., M. Highland, K. Baker, E. F. Cassirer, N. J. Anderson, J. M. Ramsey, K. Mansfield, D. L. Bruning, P. Wolff, J.B. Smith, and J. A. Jenks. 2012. A comparative study of the etiology of eight epizootics of bronchopneumonia affecting free-ranging bighorn sheep. Emerging Infectious Diseases 18:406-414.

Buechner, H. K. 1960. The bighorn sheep in the United States, its past, present, and future. Wildlife Monographs 4:3-174.

Cassirer, E. F., and A. R. E. Sinclair. 2007. Dynamics of pneumonia in a bighorn sheep metapopulation. Journal of Wildlife Management 71: 1080-1088.

Cassirer, E. F., and A. R. E. Sinclair. 2010. Dynamics of pneumonia in a bighorn sheep metapopulation. Journal of Wildlife Management 71:1080-1088.

Cougar Management Guidelines Working Group. 2005. Cougar Management Guidelines 1st Edition. Wild Futures, Bainbridge Island, Washington, USA.

Dekker, D. 2009. Declines of bighorn sheep, *Ovis canadensis*, on deteriorating winter range in Jasper national park, Alberta, 1981-2010. Canadian Field-Naturalist 123:157-164.

Douglas, C. L., and D. M. Leslie, Jr. 1999. Management of bighorn sheep. Pages 238-262 in R. Valdez and P. R. Krausman, editors. Mountain sheep of North America. The University of Arizona Press, Tucson, Arizona, USA.

Festa-Bianchet, M. 1988. Seasonal range selection in bighorn sheep: conflicts between forage quality, forage quantity, and predator avoidance. Oecologia 75:580-586.

Forety, W. J. 1990. Pneumonia in bighorn sheep: effects of *Pasteurella haemolytica* from domestic sheep: effects on survival and long-term reproduction. Biennial Symposium of the North American Wild Sheep and Goat Council 7:92-101.

Geist V. 1966. Validity of horn segment counts in aging bighorn sheep. Journal of Wildlife Management 30:634-635.

Hedrick, P. W. 2014. Conservation genetics and the persistence and translocation of small populations: bighorn sheep populations as examples. Animal Conservation 17:106-114.

Hoffman, G. R., and R. R. Alexander. 1987. Forest vegetation of the Black Hills National Forest of South Dakota and Wyoming: a habitat type classification. USDA Research Paper RM-276. Rocky Mountain Forest and Range Experiment Station, Fort Collins, Colorado. 48pp.

Jedrzejewski, W., and J. F. Kamler. 2004. Modified drop-net for capturing ungulates. Wildlife Society Bulletin 32:1305-1308.

Jenks, J. A. 2018. Mountain lions of the Black Hills; history and ecology. Johns Hopkins University Press, Baltimore.

Jorgenson, J. T., M. Festa-Bianchet, J. M. Gaillard, and W. D. Wishart. 1997. Effects of age, sex, disease, and density on survival of bighorn sheep. Ecology 78:1019-1032.

Kamler J. F., R. M. Lee, J. C. Devos, W. B. Ballard, and H. A. Whitlaw. 2002. Survival and cougar predation of translocated bighorn sheep in Arizona. Journal of Wildlife Management 66: 1267-1272.

Krausman P. R. and R. T. Bowyer. 2003. Mountain sheep (*Ovis canadensis* and *O. dalli*). In:Feldhamer GA, Thompson BC, Chapman JA, editors. Wild mammals of North America: biology, management, and conservation. 2nd Ed. Johns Hopkins University press, Baltimore, Maryland, pp. 1095-1115.

Mcintosh, A. C. 1949. A botanical survey of the Black Hills of South Dakota. Black Hills Engineer 28:1-74.

McKinney, T., T. W. Smith, and J. C. deVos, Jr. 2006. Evaluation of factors potentially influencing a desert bighorn sheep population. Wildlife Monographs 164:1-36.

National Oceanic and Atmospheric Administration. 2017. Data Tools: 2010 Normals. <www.ncdc.noaa.gov>. Accessed 10 January 2017.

Onderka, D. K., and W. D. Wishart. 1984. A major bighorn sheep dieoff from pneumonia in southern Alberta. Biennial Symposium of the North American Wild Sheep and Goat Council 4:356-363.

Orr, H. K. 1959. Precipitation and streamflow in the Black Hills. USDA Station Paper 44. Rocky Mountain Forest and Range Experiment Station, Fort Collins, Colorado. 25pp.

Parr, B. L., J. Kanta, J. Sandrini, D. J. Thompson, and J. A. Jenks. 2014. Bobcat predation on bighorn lamb in the western Black Hills of South Dakota. The Prairie Naturalist 46:41-43.

Parr, B. L. 2015. Population parameters of a bighorn sheep herd inhabiting the Elk Mountain region of South Dakota and Wyoming. M.S. Thesis, South Dakota State University, Brookings. 148pp.

Plowright, R. K., K. Manlove, E. F. Cassirer, P. C. Cross, T. E. Besser, and P. J. Hudson. 2013. Use of exposure history to identify patterns of immunity to pneumonia in bighorn sheep (*Ovis canadensis*). Plos ONE 8: e61919.

Richardson, A.H., and L. E. Peterson. 1974. History and management of South Dakota deer. South Dakota Department of Game, Fish and Parks Public Bulletin No. 5. Pierre, South Dakota. 113pp.

Rominger, E. M., H. A. Whitlaw, D. L. Weybright, W. C. Dunn, and W. Ballard. 2004. The influence of mountain lion predation on bighorn sheep translocations. Journal of Wildlife Management 68:993-999.

Seton, E. T. 1929. Lives of game animals. Doubleday, Doran and Co., Inc., New York Volume 4:441-501.

Singer, F. J., C. M. Papouchis, and K. K. Symonds. 2000a. Translocations as a tool for restoring populations of bighorn sheep. Restoration Ecology 8:6-13.

Singer, F. J., E. Williams, M. W. Miller, L. C. Zeigenfuss. 2000b. Population growth, fecundity, and survivorship in recovering populations of bighorn sheep. Restoration Ecology 8:75-84.

Smith, J. B., J. A. Jenks, T. W. Grovenburg, and R. W. Klaver. 2014. Disease and predation: sorting out causes of a bighorn sheep (*Ovis canadensis*) decline. Plos ONE 9: e88271.

Smith, J. B., T. W. Grovenburg, K. L. Monteith, and J. A. Jenks. 2015. Survival of female bighorn sheep (*Ovis canadensis*) in the Black Hills, South Dakota. The American Midland Naturalist 174:290-301.

South Dakota Department of Game, Fish and Parks. 2013. Action Plan for Management of bighorn sheep in South Dakota. Available: http://gfp.sd.gov/wildlife/management/plans. Accessed 27 February 2017.

Thilenius, J. F. 1972. Classification of deer habitat in the ponderosa pine forest of the Black Hills, South Dakota. USDA Forest Service Research Paper RM-91. Fort Collins, Colorado. 28pp.

Uresk, D. W., D. E. Mergen, and T. A. Benzon. 2009. Monitoring meadows with a modified Robel pole in the northern Black Hills, South Dakota. The Prairie Naturalist 41:121-125.

Wilckens, D. T., J. B. Smith, S. A. Tucker, D. J Thompson, and J. A. Jenks. 2016. Mountain lion (*Puma concolor*) feeding behavior in the recently recolonized Little Missouri Badlands, North Dakota. Journal of Mammalogy 97:373-385.

Witte, S. S., and M. V. Gallagher. 2012. The North American Journals of Prince Maximilian of Wied. University of Oklahoma Press, Norman, Oklahoma, USA. Volume 3, September 1833-August 1834.

Zimmerman, T. J. 2008. Evaluation of an augmentation of Rocky Mountain bighorn sheep at Badlands National Park, South Dakota. Ph.D. Dissertation, South Dakota State University, Brookings. 139pp.

Figure 1. The translocated Deadwood bighorn sheep study area, located in the northern Black Hills of South Dakota, USA.

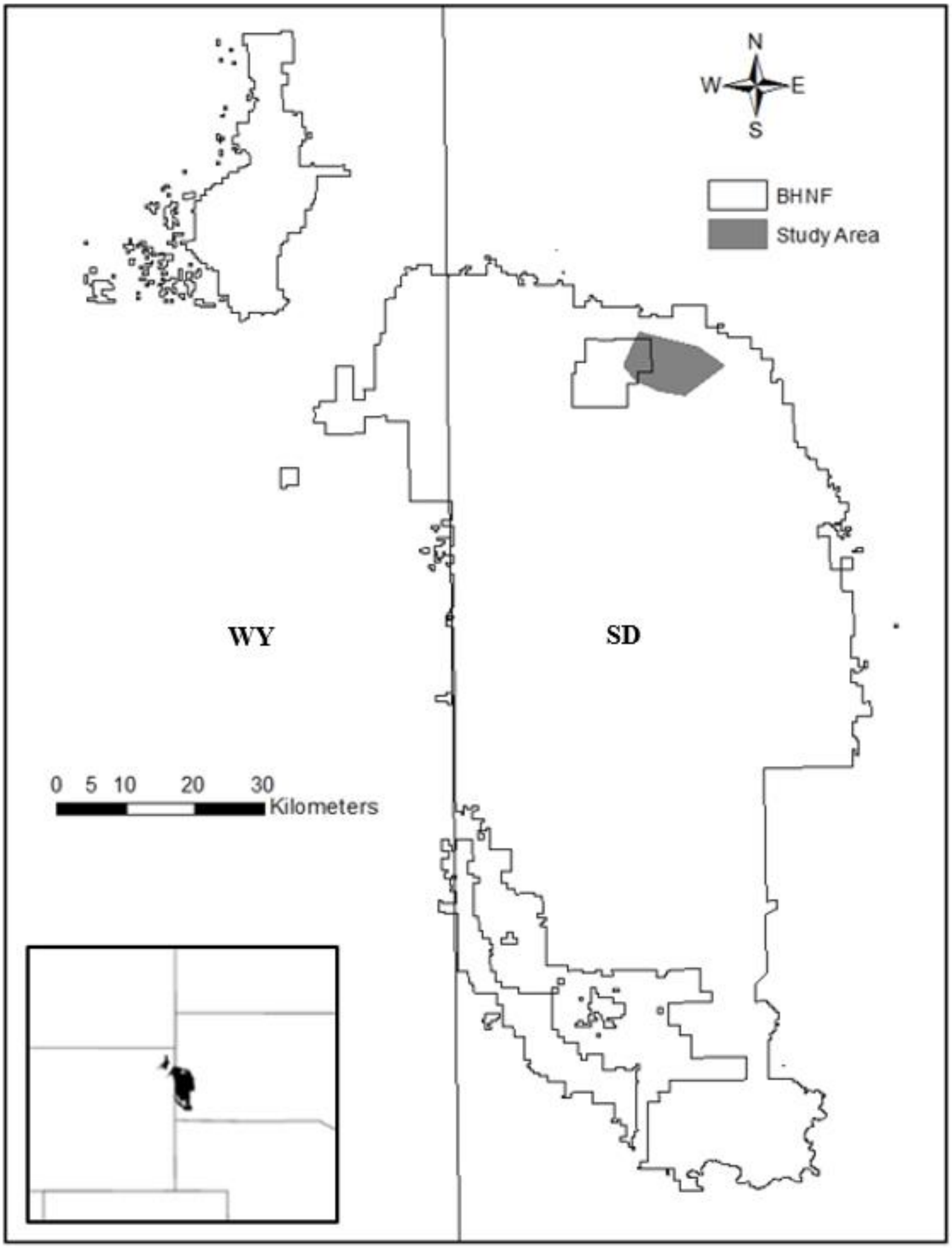


Table 1. Cause-specific mortality of translocated bighorn sheep residing in the Deadwood region of South Dakota, USA, 2015-2017.

Cause-Specific Mortality	*n*	%
Natural Causes	**3**	**15.79**
Falls from cliffs	1	5.26
Drowning	1	5.26
Broken neck	1	5.26
Capture stress	**1**	**5.26**
Vehicle Collision	**2**	**10.53**
Euthanization	**4**	**21.05**
Contact with domestic sheep	1	5.26
Pneumonia symptoms	3	15.79
Pneumonia	**8**	**42.11**
Unknown	**1**	**5.26**
Total	19	100

Table 2. Models constructed *a priori* to evaluate influences on annual translocated bighorn sheep survival in the Deadwood region of South Dakota, USA, 2015-2017.

Model	K[a]	Description
$\{S_{oct\text{-}jan}\}$	3	Survival varied between winter (Oct-Jan) and rest of year (Feb-Sept), and between year 1 (Feb 2015-Jan 2016) and year 2 (Feb 2016-Jan 2017)
$\{S_{oct\text{-}jan}\}$	2	Survival varied between winter (Oct-Jan) and rest of year (Feb-Sept)
$\{S_t\}$	12	Survival varied by month
$\{S_{year}\}$	2	Survival varied by year
$\{S_{may\text{-}june}\}$	2	Survival varied between lambing season and non-lambing season
$\{S_{constant}\}$	1	Survival was constant
$\{S_{region}\}$	2	Survival varied by region (Norther and Southern)
$\{S_{sex}\}$	2	Survival varied by sex
$\{S_{pneumonia}\}$	2	Survival varied by pneumonia positive and pneumonia negative
$\{S_{agecapture}\}$	2	Survival varied by age at capture [Adult (>1.5 years) and Subadult (<1.5 years)]

Table 3. Population estimates of translocated bighorn sheep in the Deadwood region of South Dakota, USA, 2015-2017.

	Adult Ewes	Adult Rams	Subadult Ewes	Subadult Rams	Recruitment	Deaths	Total	Geometric Growth Rate (λ)	Instantaneous Growth Rate (r)
Feb 2015-Jan 2016 (Year 1)	23	1	1	1	15	5	36	1.38	0.322
Feb 2016-Jan 2017 (Year 2)	20	1	11	4	5	17	24	0.667	-0.405
Release (12 Feb 2015)-End of Study (20 Jan 2017)	23	1	1	1	20	22	24	0.92	-0.08

CHAPTER 2: ASSESSMENT OF GENETIC DIVERSITY AND DISEASE PREVALENCE OF TRANSLOCATED BIGHORN SHEEP IN THE DEADWOOD REGION OF THE BLACK HILLS, SOUTH DAKOTA

ABSTRACT

Bighorn sheep (*Ovis canadensis*) historically inhabited the Black Hills region of South Dakota, but the species was extirpated from the area in the early 1900s. Several reintroductions have taken place in the central and southern regions of the Black Hills. We translocated 26 bighorn sheep from Alberta, Canada to the Deadwood Region of the Black Hills. Our objectives were to assess genetic diversity and disease prevalence of translocated bighorn sheep in the Deadwood region of the Black Hills of South Dakota. We calculated an overall population observed heterozygosity (H_O) of 0.71 (SE=0.06) and an expected heterozygosity (H_E) of 0.64 (SE=0.05). *Mycoplasma ovipneumoniae* was not detected in samples from any bighorn sheep at capture, but 11 of 19 (57.9%) mortalities documented during the study were classed as pneumonia related and tested positive for the *M. ovi* pathogen. A single strain of *M. ovi*, unique to the Deadwood bighorn sheep herd, was present among samples. Bacterium isolated from samples obtained at capture included *Bibersteinia trehalosi*, Beta hemolytic *B. trehelosi*, *Mannheimia* sp., and *Trueperella pyogenes*. Selenium analysis, resulted in an average selenium ratio of 0.46 µg/g (Min=0.28 µg/g, Max=0.61 µg/g). Our results indicate that the translocated Deadwood bighorn sheep herd contracted a bacterium responsible for the pneumonia die-off from a source not currently occupying the Black Hills region.

INTRODUCTION

Prior to human colonization of North America, bighorn sheep (*Ovis canadensis*) were relatively abundant, numbering in the millions, and occupied habitats across the western United States, Canada, and Mexico (Buechner 1960). Bighorn sheep are an ecologically sensitive species, with many factors affecting their wilderness habitat

(Buechner 1960, Zimmerman 2008). Human impacts in the form of uncontrolled harvest, introduced disease from domestic sheep (*Ovis aries*), introduced forage competition from domestic livestock, reduced and fragmented habitat, and loss of movement corridors led to major declines in bighorn sheep populations in the late 19th century through the mid-20th century (Buechner 1960, Douglas and Leslie 1999, Beecham et al. 2007). Increasing domestic sheep populations have been negatively correlated with decreasing bighorn sheep populations; bighorn population declines resulted from the transfer of scabies (*Sarcoptes scabiei*) in the early 1900's and the transfer of pneumonia in more recent decades through interactions with domestic sheep (Smith 1954, Buechner1960, Foreyt 1990, Coggins 2002, George et al. 2008, Wehausen et al. 2011). Transmission of the pneumonia complex between individuals and species usually involves nose-to-nose contact, but transmission also has been documented when contact is made with infected fecal remains or equipment (Blaisdell 1972, Foreyt and Jessup 1982, Onderka et al. 1988, Foreyt 1990, Wehausen et al. 2011).

The pneumonia complex includes a number of causative diseases including lungworms *(Protostrongylus* spp.) and bacteria (*Mannheimia haemolytica, Bibersteinia trehalosi, Mycoplasma ovipneumoniae*; Besser et al. 2012) that become mortality agents affecting bighorn sheep when present in conjunction with other stressors (e.g., poor nutrition and extreme climate; Onderka and Wishart 1984, Foreyt 1990, Besser et al. 2012). *Mycoplasma ovipneumoniae* has been documented in pneumonic sheep from multiple bighorn sheep populations that have experienced large-scale die-offs; the presence of *Mycoplasma ovipneumoniae* in a bighorn sheep population may indicate that pneumonia exists within the herd (Besser et al. 2012). Plowright et al. (2013) documented that surviving ewes become immune to the effects of these pathogens, but that immunity is not transferred to lambs. Cassirer and Sinclair (2007) noted that pneumonia caused 43% of mortalities of adult bighorn sheep occupying Hells Canyon, Idaho, Oregon, and Washington. They designated pneumonia-caused mortality as the primary factor limiting population growth of bighorn sheep.

In South Dakota, bighorn sheep historically inhabited the Black Hills region, but the species was extirpated from the area in the early 1900s (Seton 1929, Zimmerman 2008, Witte and Gallagher 2012, Parr 2015). South Dakota Department of Game, Fish and Parks (SDGFP) began reintroductions to the state in the 1960s, with successful restorations occurring in Badlands National Park and the central and southern regions of the Black Hills, including Custer State Park, Spring Creek, Rapid Creek, Sheridan Lake, Hells Canyon, and Elk Mountain areas (Zimmerman 2008, SDGFP 2013, Parr 2015). Since the mid-1900s, many State and Federal wildlife management agencies have attempted numerous bighorn sheep reintroductions to the species' historic ranges with varying levels of success (Berger 1990, Singer et al. 2000, Hedrick 2014, Parr 2015). Reintroductions via translocations are executed in localized areas where the species has been completely extirpated or where remnant populations require augmentations to increase abundance or genetic diversity to remain viable (Buechner 1960, Zimmerman 2008).

To expand bighorn sheep restoration in the Black Hills, we translocated 26 bighorn sheep from the Luscar Mine near Hinton, Alberta, Canada to the Deadwood region of the northern Black Hills. In an effort to evaluate a critical large mammal translocation, our objectives were to: assess genetic diversity and disease prevalence of translocated bighorn sheep in the Deadwood region of the Black Hills of South Dakota.

STUDY AREA

Bighorn sheep were initially captured in Alberta, Canada and translocated to our study area, the Deadwood region, located in the northern Black Hills in western South Dakota, USA (44°20'56.55''N, -103°42'28.64''W) (Fig. 1). This area encompasses approximately 8,177 ha of public (5,203 ha) and private (2,974 ha) land and is located immediately adjacent to the Deadwood, Lead, and Central City communities in Lawrence County, South Dakota (SDGFP 2013). Elevations range from 1,073 to 2,209 m above mean sea level. The Deadwood region of the Black Hills occurs within the central core of the Blacks Hills, which is typified by canyons, mountain peaks, and broad valleys (Hoffman and Alexander 1987). Soils of the region include limestones, dolomites, and sandstones of Paleozoic origin (Hoffman and Alexander 1987). This region of the Black Hills receives more precipitation in the form of snow (156 cm) and is cooler (-5 C) than more southern areas within the Black Hills (Hoffman and Alexander 1987, NOAA 2017).

Ponderosa pine (*Pinus ponderosa*) is the dominant overstory tree species of the region; it occurs in monotypic stands and is intermixed with small stands of quaking aspen (*Populus tremuloides*) and paper birch (*Betula papyrifera*) (Mcintosh 1949, Orr 1959, Thilenius 1972, Richardson and Petersen 1974, Hoffman and Alexander 1987). Common plant species include Kentucky bluegrass (*Poa pratensis*), timothy (*Phleum pretense*), smooth brome (*Bromus inermis*), sedges (*Carex* spp.), western wheatgrass (*Pascopyrum smithii*), prairie dropseed (*Sporobolus heterolepis*), fleabane (*Erigeron* spp.) and yarrow (*Achillea* spp.) (Uresk et al. 2009). Additional ungulate species occupying the study area included mule deer (*Odocoileus hemionus*), white-tailed deer (*O. virginianus*), and elk (*Cervus elaphus*). Potential species known to predate on bighorn sheep occurring in the study area include mountain lions (*Puma concolor*; Smith et al. 2014, Wilckens et al. 2016), coyotes (*Canis latrans*), bobcats (*Lynx rufus*; Parr et al. 2014), bald eagles (*Haliaeetus leucocephalus*), and golden eagles (*Aquila chrysaetos*).

METHODS

Translocation and Data Collection

In February 2015, we (i.e., SDGFP and South Dakota State University [SDSU] personnel) traveled to Hinton, Alberta, Canada to capture and transport bighorn sheep to South Dakota. Two sites within the Luscar Mine were baited with alfalfa (*Medicago sativa*) hay for one week prior to our capture date. On 10 February 2015, modified 18 m x 18 m electromagnetic drop-nets were constructed over bait sites, and the following morning nets were used to capture 26 bighorn sheep (Jedrzejewski and Kamler 2004). Adult male bighorn sheep were aged based on horn annuli (Geist 1966) and adult females were aged via tooth eruption and wear (Hemming 1969, Krausman and Bowyer 2003). Twenty-one adult females and 1 adult male bighorn sheep were fitted with store-on-board global positioning system (GPS; Model 2110D; 154-155 MHz) radio collars (Advanced Telemetry Systems, Isanti, MN, USA). Two adult female bighorn sheep were fitted with very high frequency (VHF; Model 2520B; 154-155 MHz) radio collars (Advanced Telemetry Systems, Isanti, MN, USA). One female bighorn lamb and 1 male bighorn lamb were fitted with very high frequency (VHF; Model M4200M; 154-155 MHz) expandable break-away radio collars (Advanced Telemetry Systems, Isanti, MN, USA).

Ear tags were attached to each individual bighorn sheep for future identification in the field. We collected blood samples and swabbed nasal and pharyngeal passages for disease testing; swab and blood samples were sent to Washington Animal Disease Diagnostic Laboratory (WADDL) to test for the presence of *Mycoplasma ovipneumoniae* (*M. ovi*) and pathogens related to pneumonia; blood samples were sent to The Holmes Research Centre, University of Idaho for selenium analysis; collected serum used to test for *Brucella ovis, B. abortus, B. suis*, PI-3, bovine viral diarrhea virus, and *Bacillus thuringiensis* was sent to USDA APHIS National Veterinary Services Laboratories; blood for DNA extraction and analysis was sent to the University of Alberta. We also administered a pneumonia vaccine (IM and intranasally) to all bighorn sheep individuals. All capture and handling methods were approved by the South Dakota State University Institutional Animal Care and Use Committee (Approval No. 14-096A).

Translocated bighorn sheep were released approximately 3.5 km southwest of Deadwood, South Dakota on private land. All radio-collared bighorn sheep were located a minimum of 5 times per week post-release between February-August 2015 and May-July 2016, and a minimum of 3-4 times per week September 2015-April 2016 and August-December 2016 using a hand-held directional antenna and portable receiver (model RA-23K, Telonics, Inc., Mesa, AZ, USA). Mortality events were generally located within 12 hours of receiving mortality signals from collars; in the event bighorn carcasses were decayed or scavenged beyond recognition, samples were not collected. Upon finding bighorn sheep mortalities, we documented observations, extracted blood samples when possible, and carcasses were transported to SDGFP laboratory in Rapid City, South Dakota where necropsy and cause of death were determined. The respiratory tract, including the lungs and trachea, were sent to the WADDL in Pullman, Washington where comprehensive testing for pneumonia strains was conducted.

Data Analysis

Mycoplasma ovipneumoniae sampled from 2 selected bighorn sheep mortalities were strain typed at WADDL. The translocated Deadwood bighorn sheep strains were compared to strains sampled from the Custer State Park bighorn sheep herd in the southern Black Hills of South Dakota using the Clustal Omega Multiple Sequence Alignment tool (http://www.ebi.ac.uk/Tools/msa/clustalo/). Sixteen *M. ovi* samples from the Black Hills of South Dakota, including 2 samples from the translocated Deadwood bighorn sheep herd, 1 sample from the Custer State Park bighorn sheep herd, 1 sample from the Spring Creek bighorn sheep herd, 1 sample from a mountain goat (*Oreamnos americanus*) in Battle Creek, and 11 samples from domestic sheep from several different flocks, were used to create a neighbor joining tree in FigTree 1.4.3 (http://tree.bio.ed.ac.uk/software/figtree/) of 4-locus strain type data to compare between populations (Fig. 2).

Genomic DNA from blood and tissue samples was extracted with a Dneasy Tissue Kit (Qiagen Inc., Valencia, CA). DNA from hair samples was extracted with the Dneasy Tissue Kit. Polymerase chain reaction (PCR) volumes (10µl) contained 1.0-3.0µl DNA, 1x reaction buffer (Applied Biosystems, Foster City, CA), 2.0 mM MgC12, 200µM of each dNTP, 1 µM reverse primer, 1 µM dye-labeled forward primer, 1.5 mg/ml BSA, and 1U Taq polymerase (Applied Biosystems, Foster City, California). The PCR cycling profiles were conducted according to published references and PCR products run in a 6.5% acrylamide gel and visualized on a LI-COR DNA analyzer (LI-

COR Biotechnology, Lincoln NE). Genomic DNA samples (*n*=21) were analyzed using 13 microsatellite markers: *BM1225, BM4505, BMC1222, FCB266, MAF209, MAF36, MAF64, MAF65, OarAE16, OarCP26, Rt9, TGLA122, TGLA387*. Descriptive statistics for the microsatellite results were calculated using GenAlEx (Peakall and Smouse 2006) and GenePop (Raymond and Roussel 1995) software programs; we calculated observed (H_O) and expected (H_E) heterozygosity, allelic diversity (A), effective alleles (A_E), and tested for deviations from Hardy-Weinberg equilibrium (HWE).

RESULTS

The enzyme-linked immunosorbent assay (ELISA) method was used to test 26 total blood serum samples, resulting in a 0% (0/26 bighorn sheep) *Mycoplasma ovipneumoniae* detection rate (2 March 2015). Antibody detections for all originally captured bighorn sheep also were below 40% (Antibody not detected). Nasal swab samples for captured bighorn sheep were tested for *M. ovi*, using a culture of the nasal swabs, resulting in a 0% detection rate (0/24), with 2 of 26 samples considered indeterminate (16 February 2015). WADDL utilized pharyngeal swabs sampled at capture to run a bacteriology assessment on all captured bighorn sheep; bacterium isolated included *Bibersteinia trehalosi,* Beta hemolytic *B. trehelosi, Mannheimia* sp., and *Trueperella pyogenes* (19 February 2015) (Table 1). Selenium analysis, resulted in an average selenium ratio of 0.46 µg/g (Min=0.28 µg/g, Max=0.61 µg/g) (3 March 2015). Of the 26 bighorn sheep serum samples analyzed for diseases, 2 of 26 tested positive for bovine parainfluenza virus-3 (7.69%), while all other results for each disease were negative among all bighorn sheep.

We documented 19 mortalities within the translocated Deadwood bighorn sheep herd from February 2015-January 2017. One adult ram was euthanized due to contact with domestic sheep; however, results from WADDL showed that *M. ovi* was not detected, nor were antibodies (I=21.86%), in any samples. Eleven of the 19 mortalities (57.89%) within the translocated Deadwood bighorn sheep herd were classed as pneumonia related. Three bighorn sheep ewes were euthanized after showing pneumonic symptoms. Disease results from WADDL confirmed the presence of *M. ovi* in samples from each of the 3 mortality/euthanization events. Carcasses of 8 bighorn sheep mortalities were sampled and results from WADDL confirmed the presence of *M. ovi*. *M. ovi*, that was discovered from selected mortality samples (*n*=2) of the translocated Deadwood bighorn sheep herd, was strain typed and confirmed that a single strain was present among samples. This strain was then compared with strains documented in existing Black Hills bighorn sheep, domestic sheep, and mountain goat populations in which *M. ovi* occurred; the strain differed from those previously found in the Black hills (Fig. 2).

We successfully genotyped and analyzed 21 unique samples collected from the translocated Deadwood bighorn sheep herd. We calculated an overall population observed heterozygosity (H_O) of 0.71 (SE=0.06) and an expected heterozygosity (H_E) of 0.64 (SE=0.05). Heterozygosity per locus ranged from 0.10-0.95. Number of alleles per locus (A) ranged from 2-7 (Mean=5.23, SE=0.44) and average number of effective alleles (A_E) was 3.19 (SE=0.32) (Table 2). We found a single deviation from HWE at locus *BMC1222* (P=0.04).

DISCUSSION

Our results indicated that individual bighorn sheep in the translocated Deadwood bighorn sheep herd were carriers, at the time of capture (10 February 2015), of multiple bacteria strains that have been implicated in pneumonia epidemics (Besser et al. 2012). However, at capture none of the 26 translocated bighorn sheep tested positive for *Mycoplasma ovipneumoniae*. Besser et al. (2012) found that *M. ovi* was the leading candidate as the primary etiologic agent for pneumonia and it was found in >95% of individual bighorn sheep individuals (8 different bighorn sheep herds) involved in epizootics. A Deadwood bighorn sheep herd pneumonia event began 29 October 2016, resulting in 11 pneumonia related mortalities. This die-off resulted in 57.89% of all mortalities during the study period (Feb 2015-Jan 2017). All 11 pneumonia related mortalities were tested for *M. ovi*, resulting in a 100% detection rate. Tests for strain typing indicated that selected samples (n=2) of translocated Deadwood bighorn sheep differed from strains previously discovered within populations of bighorn sheep, domestic sheep, and mountain goats occupying varying regions of the Black Hills. This finding has lead us to the hypothesis that the translocated Deadwood bighorn sheep herd may have contracted the bacterium from a source not currently occupying the Black Hills region; possibly a livestock trailer hauling domestic sheep came in close proximity to bighorn sheep foraging in ditches along a main road; and thus, transmitting the disease without direct contact. However, because the exact etiologic agent of pneumonia has not been widely agreed upon (Parr 2015), other possibilities of contact, with various bacteria species, are plausible.

Selenium plays a large role in the immunity of animals (Hefnawy and Tórtora-Pérez 2010), including bighorn sheep. Puls (1994) described a range of 0.13-0.23 µg/g as an approximation of adequate levels of selenium in blood serum of Rocky Mountain bighorn sheep, but normal ranges can be influenced by specific habitat types and populations. The translocated Deadwood bighorn sheep herd had an average selenium blood serum ratio of 0.46 µg/g, with a range of 0.28-0.61 µg/g. These results indicate that at capture, the translocated Deadwood bighorn sheep herd had higher than adequate levels of selenium, but lower levels than Parr (2015) found (0.54-1.42 µg/g, mean=0.83 µg/g) in herds occupying the Elk Mountain region of the Black Hills. The high range of selenium levels in bighorn sheep in the Elk Mountain region of the Black Hills is likely due to high selenium levels found in western South Dakota soils, where vertical transmission of selenium likely takes place (Rosenfeld and Beath 1964, Parr 2015).

Heterozygosity is an important measure of allelic pairing at specific loci and indicates recent breeding history, while allelic diversity or richness, is an indicator of the number of alleles found at specific loci on chromosomes (Whittaker et al. 2004, Parr 2015). Our overall translocated Deadwood bighorn sheep population results of H_O=0.71 (SE=0.06) and H_E=0.64 (SE=0.05) showed high levels of heterozygosity and allelic diversity (A=5.23, SE=0.44) at capture (Table 2). When our results are compared to previous bighorn sheep studies in South Dakota (Zimmerman 2008, Parr 2015), Oregon, and Nevada (Whittaker et al. 2004), heterozygosity and allelic diversity levels for transplanted bighorn sheep were higher than previously recorded (Table 3). However, the comparison is indirect due to differing loci sampled during each study, but heterozygosity and allelic diversity differences are still important to note. Because genetic data were not sampled from neonates during our study period to observe transfer of alleles to offspring, we do not know the continued state of heterozygosity. The pneumonia associated die-off that occurred towards the end of the study period may have greatly diminished the heterozygosity levels within remaining individuals (n=24) of the translocated Deadwood bighorn sheep herd.

MANAGEMENT IMPLICATIONS

Due to the lack of *Mycoplasma ovipneumoniae* present in the translocated Deadwood bighorn sheep herd at release, and the subsequent pneumonia die-off year 2 of the study, we recommend SDGFP more thoroughly investigate and sample domestic sheep and goats near and surrounding the area occupied by the herd. If a source for the specific strain of *M. ovi* found within the Deadwood bighorn sheep mortalities is located, removal or additional safeguards may prevent future contact and transmission. Additional vaccines, as they become available, should be given to domestic sheep, domestic goats, and bighorn sheep in the area. Even with the limited number of individuals initially captured, heterozygosity and genetic diversity for the translocated bighorn sheep was relatively high, so at this time founder effect is only a minor concern. We also recommend future genetic, disease, and selenium sampling of the Deadwood bighorn sheep herd to assess overall health of the population.

ACKNOWLEDGEMENTS

Financial support for this project was provided by Federal Aid to Wildlife Restoration administered through South Dakota Department of Game, Fish and Parks (Study Number 7556). We thank South Dakota Department of Game, Fish and Parks, Civil Air Patrol, Deadwood Police Department, Lawrence County Sheriff's Office, and private property owners in the Deadwood area for their assistance and property access. We thank B. Juarez for their assistance with data analyses. We thank T. Haffley, K. Cudmore, J. Doyle, J. Clark, and C. Werdel for their assistance with monitoring, capturing, and euthanizing bighorn sheep during the study period.

LITERATURE CITED

Beecham, J. J., C. P. Collins, and T. D. Reynolds. 2007. Rocky Mountain bighorn sheep (*Ovis canadensis*): A Technical Conservation Assessment. http://www.fs.fed.us/r2/projects/scp/assessments/rockymountainbighornsheep.pdf (accessed 2/27/2017).

Berger, J. 1990. Persistence of different-sized populations: an empirical assessment of rapid extinctions in bighorn sheep. Conservation Biology 4:91-98.

Besser, T. E., M. Highland, K. Baker, E. F. Cassirer, N. J. Anderson, J. M. Ramsey, K. Mansfield, D. L. Bruning, P. Wolff, J.B. Smith, and J. A. Jenks. 2012. A comparative study of the etiology of eight epizootics of bronchopneumonia affecting free-ranging bighorn sheep. Emerging Infectious Diseases 18:406-414.

Blaisdell, J. A. 1972. Progress report—lava beds bighorn re-establishment. In: Desert Bighorn Council 1972 Transactions, Desert Bighorn Council, Tucson, Arizona. 5-7 April, C. Hansen, Las Vegas, Nevada, pp. 84-87.

Buechner, H. K. 1960. The bighorn sheep in the United States, its past, present, and future. Wildlife Monographs 4:3-174.

Cassirer, E. F., and A. R. E. Sinclair. 2010. Dynamics of pneumonia in a bighorn sheep metapopulation. Journal of Wildlife Management 71: 1080-1088.

Coggins VL. 2002. Rocky Mountain bighorn sheep/domestic sheep and domestic goat interactions: a management prospective. In: Proceedings of the thirteenth biennial symposium of the Northern Wild Sheep and Goat Council, Northern Wild Sheep and Goat Council, Rapid City, South Dakota. 23-27 April, G. Brundige, Cody, Wyoming, pp. 165-174.

Douglas, C. L., and D. M. Leslie, Jr. 1999. Management of bighorn sheep. Pages 238-262 in R. Valdez and P. R. Kraus man, editors. Mountain sheep of North America. The University of Arizona Press, Tucson, Arizona, USA.

Foreyt W. J. and D. A. Jessup. 1982. Fatal pneumonia of bighorn sheep following association with domestic sheep. Journal of Wildlife Diseases 18:163-168.

Foreyt, W. J. 1990. Pneumonia in bighorn sheep: effects of *Pasteurella haemolytica* from domestic sheep: effects on survival and long-term reproduction. Biennial Symposium of the North American Wild Sheep and Goat Council 7:92-101.

Geist, V. 1966. Validity of horn segment counts in aging bighorn sheep. Journal of Wildlife Management 30:634-635.

George, J. L., D. J. Martin, P. M. Lukacs, and M.W. Miller. 2008. Epidemic *Pasteurellosis* in a bighorn sheep population coinciding with the appearance of a domestic sheep. Journal of Wildlife Disease 44:388-403.

Hedrick, P. W. 2014. Conservation genetics and the persistence and translocation of small populations: bighorn sheep populations as examples. Animal Conservation 17:106-114.

Hefnawy, A. E. G., and J. L. Tórtora-Pérez. 2010. The importance of selenium and the effects of its deficiency in animal health. Small Ruminant Research 89:185-192.

Hemming, J. E. 1969. Cemental deposition, tooth succession, and horn development as criteria of age in dall sheep. Journal of Wildlife Management 33:552-558.

Hoffman, G. R., and R. R. Alexander. 1987. Forest vegetation of the Black Hills National Forest of South Dakota and Wyoming: a habitat type classification. USDA

Research Paper RM-276. Rocky Mountain Forest and Range Experiment Station, Fort Collins, Colorado. 48pp.

Jedrzejewski, W., and J. F. Kamler. 2004. Modified drop-net for capturing ungulates. Wildlife Society Bulletin 32:1305-1308.

Krausman P. R., and R. T. Bowyer. 2003. Mountain sheep (*Ovis canadensis* and *O. dalli*). In: Feldhamer GA, Thompson BC, Chapman JA, editors. Wild mammals of North America: biology, management, and conservation. 2nd Ed. Johns Hopkins University press, Baltimore, Maryland, pp. 1095-1115.

Mcintosh, A. C. 1949. A botanical survey of the Black Hills of South Dakota. Black Hills Engineer 28:1-74.

National Oceanic and Atmospheric Administration. 2017. Data Tools: 2010 Normals. <www.ncdc.noaa.gov>. Accessed 10 January 2017.

Onderka D. K., S. A. Rawluk, and W.D. Wishart. 1988. Susceptibility of Rocky Mountain bighorn sheep and domestic sheep to pneumonia induced by bighorn and domestic livestock strains of Pasteurella haemolytica. Canadian Journal of Veterinary Research 52:439-444.

Orr, H. K. 1959. Precipitation and streamflow in the Black Hills. USDA Research Station Paper 44. Rocky Mountain Forest and Range Experiment Station, Fort Collins, Colorado. 25pp.

Parr, B. L., J. Kanta, J. Sandrini, D. J. Thompson, and J. A. Jenks. 2014. Bobcat predation on bighorn lamb in the western Black Hills of South Dakota. The Prairie Naturalist 46:41-43.

Parr, B. L. 2015. Population parameters of a bighorn sheep herd inhabiting the Elk Mountain region of South Dakota and Wyoming. M.S. Thesis, South Dakota State University, Brookings. 148pp.

Plowright, R. K., K. Manlove, E. F. Cassirer, P. C. Cross, T. E. Besser, and P. J. Hudson. 2013. Use of exposure history to identify patterns of immunity to pneumonia in bighorn sheep (*Ovis canadensis*). Plos ONE 8: e61919.

Puls, R. 1994. Mineral levels in animal health. Diagnostic data. Sherpa International. British Columbia, Canada.

Richardson, A.H., and L. E. Peterson. 1974. History and management of South Dakota deer. South Dakota Department of Game, Fish and Parks Public Bulletin No. 5. Pierre, South Dakota. 113pp.

Rosenfeld, I. and O.A. Beath. 1964. Selenium geobotany, biochemistry, toxicity and nutrition. Academic Press, New York, USA.

Seton, E. T. 1929. Lives of game animals. Doubleday, Doran and Co., Inc., New York Volume 4:441-501.

Singer, F. J., C. M. Papouchis, and K. K. Symonds. 2000. Translocations as a tool for restoring populations of bighorn sheep. Restoration Ecology 8:6-13.

Smith, D. R. 1954. The bighorn sheep in Idaho: its status, life history, and management. Idaho Department of Fish and Game Wildlife Bulletin Number 1, Boise, Idaho, 154 pp.

Smith, J. B., J. A. Jenks, T. W. Grovenburg, and R. W. Klaver. 2014. Disease and predation: sorting out causes of a bighorn sheep (*Ovis canadensis*) decline. Plos ONE 9: e88271.

South Dakota Department of Game, Fish and Parks. 2013. Action Plan for Management of bighorn sheep in South Dakota. Available: http://gfp.sd.gov/wildlife/management/plans. Accessed 27 February 2017.

Thilenius, J. F. 1972. Classification of deer habitat in the ponderosa pine forest of the Black Hills, South Dakota. USDA Forest Service Research Papers RM-91. Fort Collins, Colorado. 28pp.

Uresk, D. W., D. E. Mergen, and T. A. Benzon. 2009. Monitoring meadows with a modified Robel pole in the northern Black Hills, South Dakota. The Prairie Naturalist 41:121-125.

Wehausen J. D., S. T. Kelley, and R.R. Ramey II. 2011. Domestic sheep, bighorn sheep, and respiratory disease: A review of the experimental evidence. California Fish and Game 97:7-24.

Whittaker, D. G., S. D. Ostermann, and W. M. Boyce. 2004. Genetic variability of reintroduced California bighorn sheep in Oregon. Journal of Wildlife Management 68:850-859

Wilckens, D. T., J. B. Smith, S. A. Tucker, D. J Thompson, and J. A. Jenks. 2016. Mountain lion (*Puma concolor*) feeding behavior in the recently recolonized Little Missouri Badlands, North Dakota. Journal of Mammalogy 97:373-385.

Witte, S. S., and M. V. Gallagher. 2012. The North American Journals of Prince Maximilian of Wied. University of Oklahoma Press, Norman, Oklahoma, USA. Volume 3, September 1833-August 1834.

Zimmerman, T. J. 2008. Evaluation of an augmentation of Rocky Mountain bighorn sheep at Badlands National Park, South Dakota. Ph.D. Dissertation, South Dakota State University, Brookings. 139pp.

Figure 1. The translocated Deadwood bighorn sheep study area, located in the northern Black Hills of South Dakota, USA.

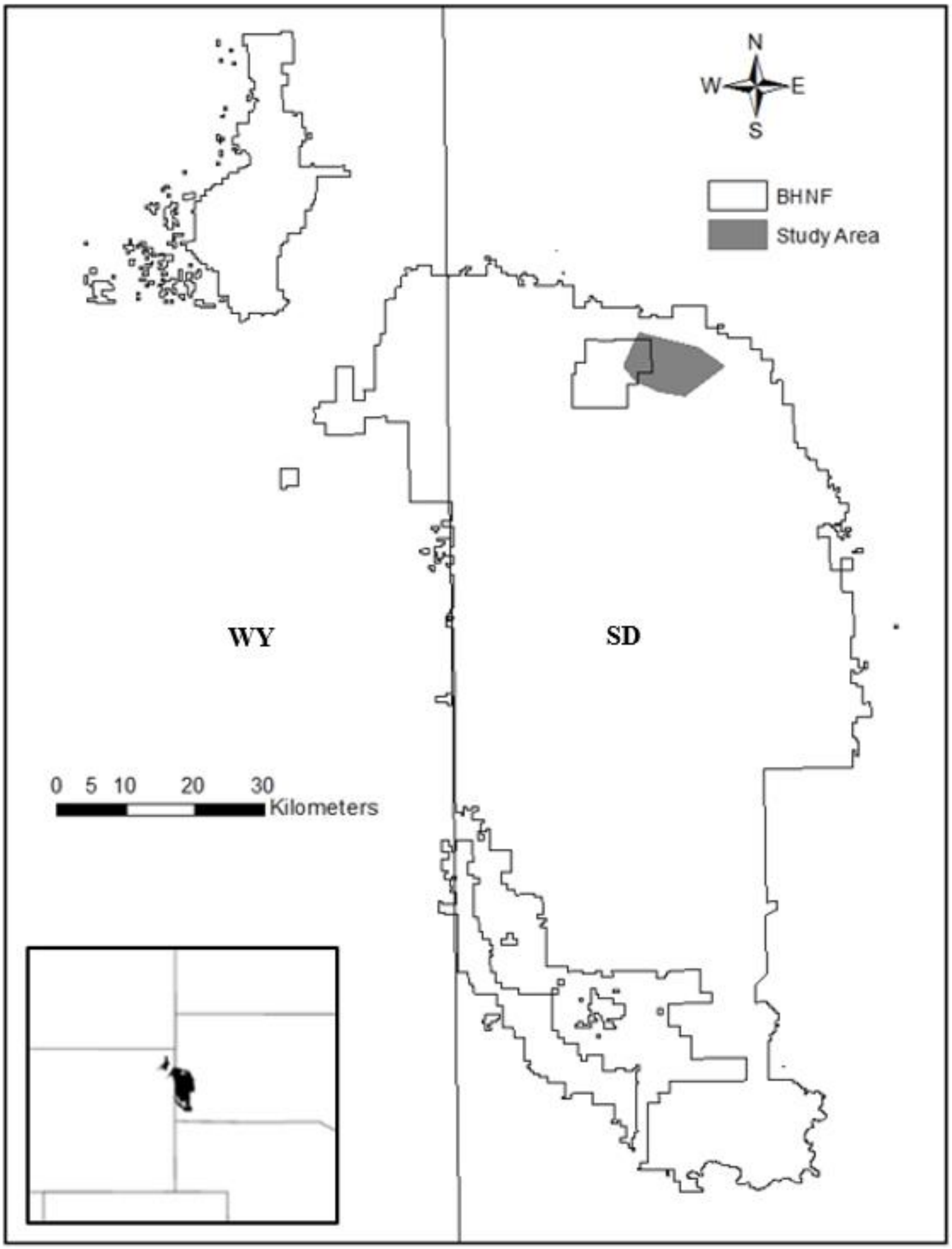


Figure 2. Neighbor joining tree of 4-locus *Mycoplasma ovipneumoniae* strain types illustrating diversity among Black Hills South Dakota populations created using FigTree 1.4.3 (http://tree.bio.ed.ac.uk/software/figtree/). Strain difference=horizontal line distance; identical strains connected by vertical line. Numbers and letters following "Domestic sheep" indicate flock and sheep number. BH numbers following "Deadwood Bighorn Sheep" are unique identification numbers.

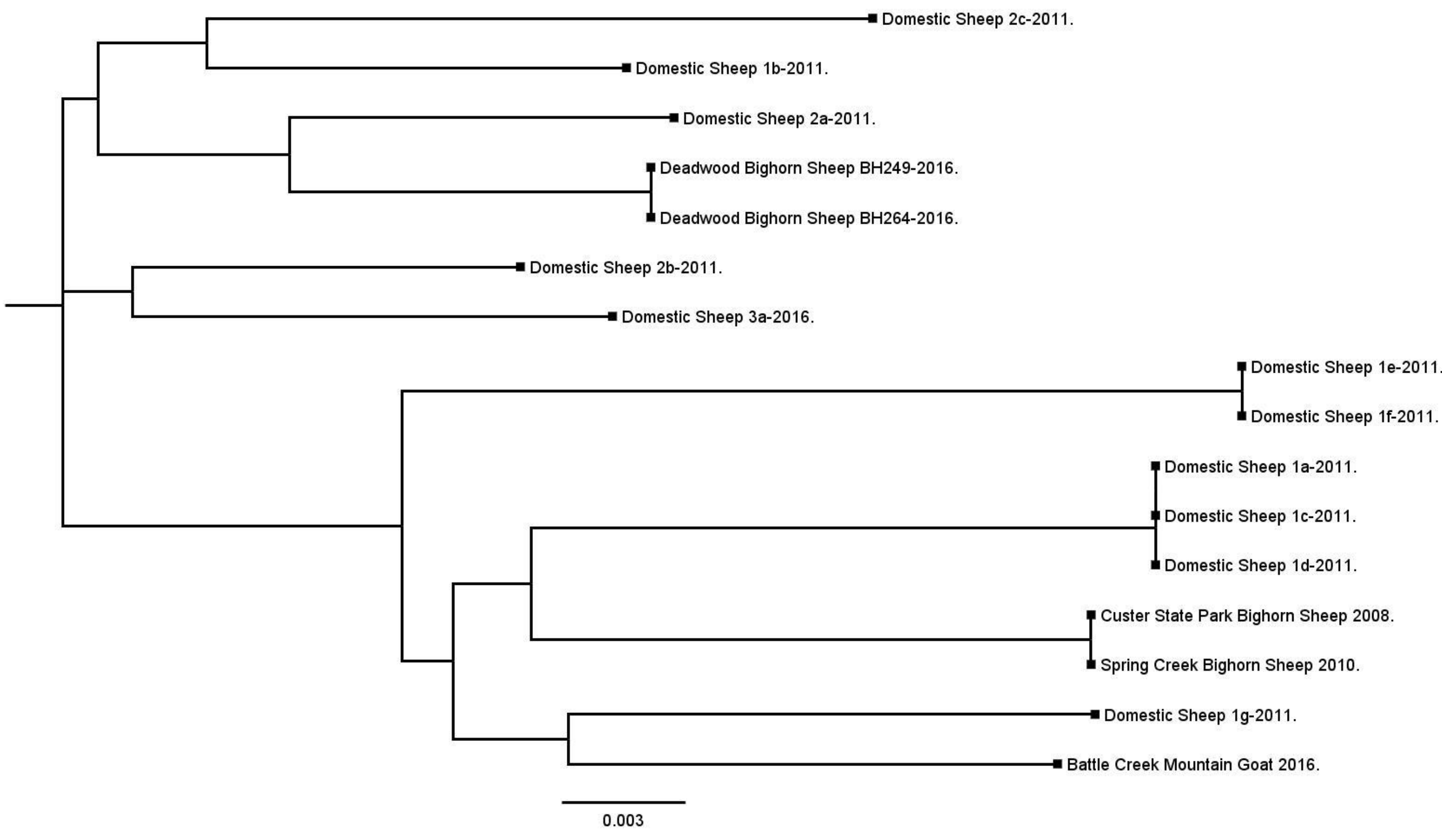


Table 1. Frequency and prevalence (%) of various pathogens in translocated Deadwood bighorn sheep sampled at capture 12 February 2015.

	Mycoplasma ovipneumoniae	*Bibersteinia trehalosi*	Beta hemolytic *B. trehelosi*	*Mannheimia* sp.	*Trueperella pyogenes*
Deadwood Bighorn Sheep (*n*=26)	0	20 (76.92%)	6 (23.08%)	3 (11.54%)	1 (3.85%)

Table 2. Summary of genetic variation in the translocated Deadwood bighorn sheep herd population. N=number of samples, A=number of alleles per locus (allelic diversity), A_E=number of effective alleles per locus, H_O=observed heterozygosity, and H_E=expected heterozygosity.

Locus	**N**	**A**	**A_E**	**H_O**	**H_E**
BM1225	21	5	3.89	0.81	0.74
BM4505	21	4	2.43	0.76	0.59
BMC1222	21	2	1.21	0.10	0.17
FCB266	21	4	2.58	0.62	0.61
MAF209	21	4	2.71	0.76	0.63
MAF36	21	4	3.14	0.91	0.68
MAF64	21	7	4.18	0.76	0.76
MAF65	21	5	4.01	0.81	0.75
OarAE16	21	7	5.80	0.95	0.83
OarCP26	21	7	3.79	0.86	0.74
Rt9	21	6	3.12	0.76	0.68
TGLA122	21	7	2.01	0.43	0.50
TGLA387	21	6	2.58	0.67	0.61
Mean	***21.00***	***5.23***	***3.19***	***0.71***	***0.64***
SE	***0.00***	***0.44***	***0.32***	***0.06***	***0.05***

Table 3. A compilation of four studies comparing population size (N), year sampled, observed heterozygosity (H_O), average number of alleles (A), and effective number of alleles (A_E).

Population	N	Year	H_O*	A*	A_E*	Source
Deadwood, SD	21	2015	0.71	5.23	3.19	This Paper
Elk Mountain, SD	100	2013	0.59	4.33	2.55	Parr 2015
Badlands National Park, SD	83-101	1992	0.51	4.20	2.23	Zimmerman 2008
Badlands National Park, SD	71-72	1996	0.54	3.20	2.1	Zimmerman 2008
Badlands National Park, SD	66	1998	0.50	3.20	2.03	Zimmerman 2008
Badlands National Park, SD	67	2004	0.47	2.20	1.66	Zimmerman 2008
Hart Mountain, OR	270	1999	0.31	2.22	Unk	Whittaker et al. 2004
Aldrich Mountain, OR	205	1998	0.28	2.22	Unk	Whittaker et al. 2004
John Day River, OR	310	1999	0.36	2.44	Unk	Whittaker et al. 2004
Steens Mountain, OR	185	1999	0.29	2.22	Unk	Whittaker et al. 2004
Leslie Gulch, OR	125	1999	0.29	2.33	Unk	Whittaker et al. 2004
Santa Rosa Mountains, NV	295	2000	0.53	3.78	Unk	Whittaker et al. 2004

*Comparisons of H_O, A, and A_E are indirect due to differing loci sampled between studies

CHAPTER 3: MOVEMENT PATTERNS POST-RELEASE OF TRANSLOCATED BIGHORN SHEEP IN THE DEADWOOD REGION OF THE BLACK HILLS, SOUTH DAKOTA

ABSTRACT

Bighorn sheep (*Ovis canadensis*) historically inhabited the Black Hills region of South Dakota, but the species was extirpated from the area in the early 1900s. Several reintroductions have taken place in the central and southern regions of the Black Hills. We translocated 26 bighorn sheep from Alberta, Canada to the Deadwood Region of the Black Hills. Our objectives were to evaluate movement patterns post-release of translocated bighorn sheep in the translocated Deadwood bighorn sheep herd. We utilized 3 types of home-range analyses; adaptive kernel (95% mean=42.07 km^2), minimum convex polygon (MCP) (95% mean=108.53 km^2), and Brownian Bridge Movement Models (BBMM) (95% mean=15.90 km^2). Year 1 home-range sizes (95% BBMM mean=24.77 km^2) were larger than year 2 (95% BBMM mean=5.29 km^2) home-range sizes. Travel distances also were larger in year 1 (mean=431.80 km) than year 2 (368.77 km). Our results indicate that after an acclimation period, which included individual dispersal, the translocated Deadwood bighorn sheep herd settled into smaller home-ranges near the release site.

INTRODUCTION

Prior to human colonization of North America, bighorn sheep (*Ovis canadensis*) were relatively abundant, numbering in the millions, and occupied habitats across the western United States, Canada, and Mexico (Buechner 1960). Bighorn sheep are an ecologically sensitive species, with many factors affecting their wilderness habitat (Buechner 1960, Zimmerman 2008). Human impacts in the form of uncontrolled harvest, introduced disease from domestic sheep (*Ovis aries*), introduced forage competition from domestic livestock, reduced and fragmented habitat, and loss of movement corridors led to major declines in bighorn sheep populations in the late 19th century through the mid-20th century (Buechner 1960, Douglas and Leslie 1999, Beecham et al. 2007).

Bighorn sheep (*Ovis canadensis*) are gregarious as a species, but segregate sexually; males can occupy habitats with higher predator (i.e., coyotes [*Canis latrans*]) densities and forage quality, whereas females occupy habitats closer to water sources and generally occur in larger social groups than do males (Geist 1971, Bleich et al. 1997). Pregnant ewes migrate between two distinct range types prior to lambing (May-June); moving from low elevation winter ranges with high forage quality, to high elevation lambing ranges with lower forage quality to avoid predation on newborn lambs (Festa-Bianchet 1988). Home range can be defined as an area in which an individual animal conducts its normal activities such as mating, gathering food, and caring for young (Burt 1943). Female bighorn sheep learn home ranges from maternal bands and may stay with their mothers for up to 6 years (Geist 1971, Festa-Bianchet 1988). Male bighorn sheep remain with their mothers from 1-4 years before searching out adult ram bands and forming their own home ranges (Geist 1971, Festa-Bianchet 1988). Escape terrain, including rocky outcrops and slopes ≥40 degrees (Zimmerman 2008), is a critical habitat attribute for bighorn sheep. At Badlands National Park, Zimmerman (2008) found resident and introduced bighorn sheep were, on average, <150 m from escape terrain, resulting in linear home ranges that were closely associated with badland formations. Because of the association between bighorn sheep and escape terrain, home ranges were best evaluated using three-dimensional analyses (Walter et al. 2013).

In South Dakota, bighorn sheep historically inhabited the entire Black Hills region, but the species was extirpated from the area in the early 1900s (Seton 1929, Zimmerman 2008, Witte and Gallagher 2012, Parr 2015). South Dakota Department of Game, Fish and Parks (SDGFP) began reintroductions to the state in the 1960s, with successful restorations occurring in Badlands National Park and the central and southern regions of the Black Hills, including Custer State Park, Spring Creek, Rapid Creek, Sheridan Lake, Hells Canyon, and Elk Mountain areas (Zimmerman 2008, SDGFP 2013, Parr 2015). Since the mid-1900s, many State and Federal wildlife management agencies have attempted numerous bighorn sheep reintroductions to the species' historic ranges with varying levels of success (Berger 1990, Singer et al. 2000a, Hedrick 2014, Parr 2015). Reintroductions via translocations are executed in localized areas where the species has been completely extirpated or where low species' populations require increased abundance or genetic diversity to remain viable (Buechner 1960, Zimmerman 2008).

Evaluating large mammal translocations is critical, due to expected initial mortality post-release, relatively low number of individuals initially translocated, unproven habitat capability, potential for predation, and time necessary for acclimation. Results of many reintroductions and translocations are inadequately detailed, leaving stakeholders without an understanding of project benefits and challenges (Gogan 1990, Zimmerman 2008). Bighorn sheep translocations should be vigorously evaluated to provide information on carrying capacity, post-release pioneering, habitat selection, and home range to help increase translocation success (Douglas and Leslie 1999, Zimmerman 2008). The Deadwood area of the northern Black Hills was vacant of bighorn sheep, but was deemed potentially suitable for a reintroduction, based on habitat suitability models and a qualitative assessment of topography, forage, and water (SDGFP 2013). However, despite a prerelease evaluation of the release site, no information was available regarding historical use of the area by bighorn sheep (SDGFP 2013).

Traditionally, there have been 3 methods, with different variations, of estimating home range size for ungulates including bighorn sheep; minimum convex polygon (MCP) (Krausman et al. 1989), fixed and adaptive kernel (Worton 1989), and Brownian Bridge Movement Models (BBMM) (Zimmerman 2008, Jacques et al. 2009, Kie et al. 2010, Wilckens 2014, Parr 2015). MCP home ranges are becoming a method of the past, due to the method's tendency to overestimate true home ranges (Getz and Wilmers 2004, Kie et al.2010, Wilckens 2014, Parr 2015). Fixed and adaptive kernel methods are utilized due to their nonparametric nature and ability to produce consistent results (Worton 1989, Kie et al. 2010, Schuler et al. 2014, Parr 2015). With GPS collar technology becoming more prominent in wildlife research, BBMM are increasingly used because of BBMM's ability to delineate true areas of use and define exploratory movements (Kie et al. 2010, Walter et al. 2011, Wilckens 2014, Parr 2015).

Northern populations of bighorn sheep rarely disperse or colonize new areas once home-ranges are established (Singer et al. 2000, Zimmerman 2008). However, young rams may disperse as a function of the pursuit of breeding advantages, while young ewes seldom disperse due to their tendency to "adopt the home-ranges of the females that raised them" (Geist 1971, Zimmerman 2008). Dispersal by bighorn sheep into unfamiliar or inhospitable habitat may increase an individual's susceptibility to predation, stress, or malnutrition (Van Vuren 1998, Zimmerman 2008). Expeditious establishment of home-ranges near the reintroduction site, with minimal dispersion from suitable terrain, will maximize survivability of translocated bighorn sheep (Van Vuren 1998, Zimmerman 2008).

To expand bighorn sheep restoration in the Black Hills, we translocated 26 bighorn sheep from the Luscar Mine near Hinton, Alberta, Canada to the Deadwood region of the northern Black Hills. In an effort to evaluate a critical large mammal translocation, our objectives were to: evaluate movement patterns post-release of translocated bighorn sheep in the translocated Deadwood bighorn sheep herd.

STUDY AREA

Bighorn sheep were initially captured in Alberta, Canada and translocated to our study area, the Deadwood region, located in the northern Black Hills in western South Dakota, USA (44°20'56.55"N, -103°42'28.64"W) (Fig. 1). This area encompasses approximately 8,177 ha of public (5,203 ha) and private (2,974 ha) land and is located immediately adjacent to the Deadwood, Lead, and Central City communities in Lawrence County, South Dakota (SDGFP 2013). Elevations range from 1,073 to 2,209 m above mean sea level. The Deadwood region of the Black Hills occurs within the central core of the Blacks Hills, which is typified by canyons, mountain peaks, and broad valleys (Hoffman and Alexander 1987). Soils of the region include limestones, dolomites, and sandstones of Paleozoic origin (Hoffman and Alexander 1987). This region of the Black Hills receives more precipitation in the form of snow (156 cm) and is cooler (-5 C) than more southern areas within the Black Hills (Hoffman and Alexander 1987, NOAA 2017).

Ponderosa pine (*Pinus ponderosa*) is the dominant overstory tree species of the region; it occurs in monotypic stands and is intermixed with small stands of quaking aspen (*Populus tremuloides*) and paper birch (*Betula papyrifera*) (Mcintosh 1949, Orr 1959, Thilenius 1972, Richardson and Petersen 1974, Hoffman and Alexander 1987). Common plant species include Kentucky bluegrass (*Poa pratensis*), timothy (*Phleum pretense*), smooth brome (*Bromus inermis*), sedges (*Carex* spp.), western wheatgrass (*Pascopyrum smithii*), prairie dropseed (*Sporobolus heterolepis*), fleabane (*Erigeron* spp.) and yarrow (*Achillea* spp.) (Uresk et al. 2009). Additional ungulate species occupying the study area included mule deer (*Odocoileus hemionus*), white-tailed deer (*O. virginianus*), and elk (*Cervus elaphus*). Potential species known to predate on bighorn sheep occurring in the study area include mountain lions (*Puma concolor*; Smith et al. 2014, Wilckens et al. 2016), coyotes (*Canis latrans*), bobcats (*Lynx rufus*; Parr et al. 2014), bald eagles (*Haliaeetus leucocephalus*), and golden eagles (*Aquila chrysaetos*).

METHODS

Translocation and Data Collection

In February 2015, we (i.e., SDGFP and SDSU personnel) traveled to Hinton, Alberta, Canada to capture and transport bighorn sheep to South Dakota. Two sites within the Luscar Mine were baited with alfalfa (*Medicago sativa*) hay for one week prior to our capture date. On 10 February 2015, modified 18 m x 18 m electromagnetic drop-nets were constructed over bait sites, and the following morning nets were used to capture 26 bighorn sheep (Jedrzejewski and Kamler 2004). Adult male bighorn sheep were aged based on horn annuli (Geist 1966) and adult females were aged via tooth eruption and wear (Hemming 1969, Krausman and Bowyer 2003). Twenty-one adult female bighorn sheep and 1 adult male bighorn sheep were fitted with store-on-board global positioning system (GPS; Model 2110D; 154-155 MHz) radio collars (Advanced

Telemetry Systems, Isanti, MN, USA). Two adult female bighorn sheep were fitted with very high frequency (VHF; Model 2520B; 154-155 MHz) radio collars (Advanced Telemetry Systems, Isanti, MN, USA). One female bighorn lamb and 1 male bighorn lamb were fitted with very high frequency (VHF; Model M4200M; 154-155 MHz) expandable break-away radio collars (Advanced Telemetry Systems, Isanti, MN, USA).

Ear tags were attached to each individual bighorn sheep for future identification in the field. We collected blood samples and swabbed nasal and pharyngeal passages for disease testing; swab and blood samples were sent to Washington Animal Disease Diagnostic Laboratory (WADDL) to test for the presence of *Mycoplasma ovipneumoniae* (*M. ovi*) and pathogens related to pneumonia; blood samples were sent to The Holmes Research Centre University of Idaho for selenium analysis; collected serum used to test for *Brucella ovis*, *B. abortus*, *B. suis*, PI-3, bovine viral diarrhea virus, and *Bacillus thuringiensis* was sent to USDA APHIS National Veterinary Services Laboratories; blood for DNA extraction and analysis was sent to the University of Alberta. We also administered a pneumonia vaccine (IM and intranasally) to all bighorn sheep individuals. All capture and handling methods were approved by the South Dakota State University Institutional Animal Care and Use Committee (Approval No. 14-096A).

Translocated bighorn sheep were released approximately 3.5 km southwest of Deadwood, South Dakota on private land. All radio-collared bighorn sheep were located a minimum of 5 times per week post-release between February 2015-August 2015 and May 2016-July 2016, and a minimum of 3-4 times per week September 2015-April 2016 and August 2016-December 2016 using a hand-held directional antenna and portable receiver (model RA-23K, Telonics, Inc., Mesa, AZ, USA). GPS collars fitted on live bighorn sheep released automatically after ~700 days and were recovered in the field, while GPS collars fitted on bighorn sheep mortalities were recovered at mortality sites; satellite location and time data were offloaded from GPS collars into ArcMap 10.3.1 (Environmental Systems Research Institute, Redlands, California, USA).

Data Analysis

Lambing locations were observed while in the field, and later assessed by isolating GPS locations from the lambing period (May-June) in ArcGIS 10.3.1 (Environmental Systems Research Institute, Redlands, California, USA).

GPS locations for 22 translocated bighorn sheep were entered into a Geographic Information System (UTM datum Zone 13N, NAD83 projection) and converted into shapefiles (Zimmerman 2008). The Home-Range Tools Analysis Extension (Rodgers et al. 2005) was added to ArcGIS 10.3.1 (Environmental Systems Research Institute, Redlands, California, USA) and used to calculate 95%, and 50% volume contours simultaneously using non-parametric adaptive kernel estimators (Worton 1989, Zimmerman 2008). Volume contours were manually entered, while default resolution grids and bandwidth were used (Zimmerman 2008). All contours (e.g., 95%, 50%) were determined using the same smoothing parameter. A minimum convex polygon (MCP) (95%) was created using a fixed mean in the Home-Range Tools Analysis Extension (Rodgers et al. 2005) in ArcGIS 10.3.1 for comparison of year 1 and year 2 time periods. Individual 95% and 50% Home-Range Tools Analysis Extension home-ranges were combined using the “union” tool in ArcGIS 10.3.1 (Environmental Systems Research Institute, Redlands, California, USA) to determine entire area utilized as home-range by the Deadwood bighorn sheep herd.

We calculated 99%, 95%, and 50% Brownian Bridge Movement Models (BBMM) home range contours using the "BBMM" package in Program R (Nielson et al. 2013, Parr 2015). We used a maximum time-lag of 180 minutes to exclude any nonconsecutive locations and a cell size of 100 m for data collected from February 2015-January 2017. Contour polygons were converted to shapefiles and mapped in ArcGIS 10.3.1 (Environmental Systems Research Institute, Redlands, California, USA) to evaluate locations and home ranges for each individual bighorn sheep. Individual 99%, 95%, and 50% BBMM home-ranges were combined using the "union" tool in ArcGIS 10.3.1 (Environmental Systems Research Institute, Redlands, California, USA) to determine the area utilized as home-range by the Deadwood bighorn sheep herd. We isolated year 1 (Feb 2015-Jan 2016) and year 2 (Feb 2016-Jan 2017) locations for individual bighorn sheep to calculate 99%, 95%, and 50% BBMM home-ranges to compare between time periods.

Movement for each individual bighorn sheep, isolating only locations obtained from year 1 (Feb 2015-Jan 2016) and year 2 (Feb 2016-Jan 2017) time periods, was plotted using the "move" package in Program R; movement statistics (i.e., travel distance, maximum distance, minimum distance) also were derived. Visual and statistical (travel distance) comparisons were made between the separate time periods to test the hypothesis that translocated Deadwood bighorn sheep herd would pioneer significantly more in year 1 than year 2.

RESULTS

Immediately post-release (12 February 2015), the translocated Deadwood bighorn sheep dispersed in all directions from the release site. Through the first 2-3 weeks, individual bighorn sheep were observed 16 km South, 18 km West, 17 km North, and 12 km East of the release site. After analyzing the location data in ArcGIS 10.3.1, it was found that 1 adult female bighorn sheep traveled 62 km South before returning back North to the release site. This pioneering behavior by multiple individual bighorn sheep continued for 3-4 months post-release until the lambing period (May-June) began. During the lambing period, pregnant ewes sought out rugged, isolated areas within, and outside of the study area. Two lambing areas were identified in the field and confirmed with GPS locations uploaded into ArcGIS 10.3.1 (Fig. 2). These lambing areas were utilized in both May-June 2015 and May-June 2016.

Of the 26 bighorn sheep originally translocated, 22 were fitted with GPS store-on-board collars at capture. One adult female bighorn sheep died due to capture stress shortly after release (6 March 2015), resulting in too few GPS locations to be utilized in analyses. Two subadults that were fitted with expandable lamb collars were chemically immobilized and lamb collars were replaced with new GPS store-on-board adult collars (14 October 2015, 4 April 2016). Collars released ~15 January 2017, and 22 of 23 were successfully retrieved; one collar was left in the field as it was irretrievable, located on the side a high cliff face.

Overall 95% adaptive kernel home ranges, using Home-Range Tools Analysis Extension (Rodgers et al. 2005), resulted in a mean home-range size of 42.07 km^2 (n=22, SE=10.38). The smallest home-range size using this analysis was 3.53 km^2, while the largest home-range size was 200.74 km^2. The combined home-ranges for 95% adaptive kernel home-range calculations was 269.21 km^2 (Fig. 3). Overall 50% adaptive kernel home ranges, using Home-Range Tools Analysis Extension (Rodgers et al. 2005), resulted in a mean home-range size of 4.3 km^2 (*n*=22, SE=0.91) (Figure 3). The smallest home-range size using this analysis was 0.49 km^2, while the largest home-range size was 18.28 km^2. The combined home-range for 50% adaptive kernel home-range calculations was 24.52 km^2. The mean 95% minimum convex polygon (MCP), using Home-Range Tools Analysis Extension (Rodgers et al. 2005), was 108.53 km^2 (*n*=22, SE=36.36, Min=20.24 km^2, Max=713.70 km^2). The mean 95% MCP for year 1 was 163.50 km^2 (*n*=22, SE=65.35, Min=0.92 km^2, Max=1,150.60 km^2), while the mean MCP for year 2 was 23.81 km^2 (*n*=19, SE=2.66, Min=3.02 km^2, Max=36.19 km^2). The combined home-range for 95% MCP was 783.73 km^2, while the combined MCP home-range for year 1 was 1,217.74 km^2 and 56.46 km^2 for year 2 (Figure 4).

The 99% Brownian Bridge Movement Models (BBMM) home range analysis resulted in a mean home-range size of 61.77 km^2 (*n*=22, SE=16.20, Min=8.82 km^2, Max=328.64 km^2). The combined home-ranges for 99% BBMM analysis was 446.62 km^2 (Figure 5). The 95% BBMM mean home-range size was 15.90 km^2 (*n*=22, SE=4.20, Min=2.12 km^2, Max=79.63 km^2). The combined home-ranges for 95% BBMM analysis was 102.83 km^2 (Figure 5). The 50% BBMM mean home-range size was 0.17 km^2 (*n*=22, SE=0.04, Min=0.04 km^2, Max=0.76 km^2). The combined home-ranges for 50% BBMM analysis was 1.18 km^2 (Figure 5). Mean home-range sizes for year 1 (99% BBMM=76.59 km^2, 95% BBMM=24.77 km^2, 50% BBMM=0.21 km^2) were larger than those for year 2 (99% BBMM=16.22 km^2, 95% BBMM=5.29 km^2, 50% BBMM=0.21 km^2). The combined home-ranges for year 1 BBMM (99% BBMM=569.26 km^2, 95% BBMM=187.33 km^2, 50% BBMM=1.72 km^2) also were larger than those for year 2

BBMM (99% BBMM=56.78 km^2, 95% BBMM=14.22 km^2, 50% BBMM=0.58 km^2) (Figure 6).

Only 4 GPS collars were recovered from bighorn sheep that survived the entire study period (Feb 2015-Jan 2017), which allowed comparisons between year 1 and year 2 movement data. Mean travel distance for year 1 was 431.80 km, while mean travel distance for year 2 was 368.77 km. BH223 (bighorn sheep identification number) traveled a total distance of 339.68 km in year 1 and 384.44 km in year 2 (Fig. 5), resulting in 46.9% of total travel occurring in year 1. BH232 (bighorn sheep identification number) traveled a total distance of 444.46 km in year 1 and 318.72 km in year 2 (Fig. 6), resulting in 58.2% of total travel occurring in year 1. BH233 (bighorn sheep identification number) traveled a total distance of 600.27 km in year 1 and 340.07 km in year 2 (Fig. 7), resulting in 63.8% of total travel occurring in year 1. BH239 (bighorn sheep identification number) traveled a total distance of 342.78 km in year 1 and 431.85 km in year 2 (Fig. 8), resulting in 44.3% of total travel occurring in year 1.

DISCUSSION

Established bighorn sheep herds may be migratory, occupying multiple (3-6) distinct home-ranges throughout the year (Geist 1971, Festa-Bianchet 1986, Parr 2015). The translocated Deadwood bighorn sheep herd was not observed as migratory; they did not utilize separate distinct ranges during summer and winter seasons. However, the only adult male bighorn sheep that was originally translocated did show signs of differing movement during the summer, but was euthanized, due to potential contact with domestic sheep, ending data collection; this type of movement by adult rams has been documented by DeCesare and Pletscher (2006) and Parr (2015). Seasonal movement was observed during the lambing season, which has been seen in a previous Black Hill's bighorn sheep study (Parr 2015). During the lambing period, ewes tend to utilize habitat with less nutritious areas that include cliffs and large amounts of escape terrain than throughout the remainder of the year (Geist 1971, Leslie and Douglas 1979). The pioneering behavior, searching for appropriate habitat over long distances in the first few months post-release, was expected prior to home-range establishment (Bleich et al. 1996, Kissell 1996, Singer et al. 2000b). We saw the indication of pioneering and subsequent home-range establishment between years when utilizing MCP and BBMM analyses for each time period. These data reinforce observations made in the field during those time periods.

Our 50% and 95% adaptive kernel mean home-range sizes (4.3 km^2 and 42.07 km^2) were much smaller in area when compared to fixed kernel home-range size (14.38 km^2 and 94.30 km^2) of Parr (2015), who conducted a similar study on bighorn sheep in the Black Hills. However, Zimmerman (2008) utilized 95% adaptive and fixed kernel home-range analyses in her Badlands National Park (South Dakota) bighorn sheep study, finding mean home-range sizes of 15.5 km^2 (Adaptive kernel) and 16.1 km^2. Zimmerman (2008) also analyzed 50% adaptive (mean=3.1 km^2) and fixed kernel (mean=1.8 km^2) home-range. Our 50% and 95% adaptive kernel mean home-range sizes fall between results from these 2 similar South Dakota studies.

Previous studies on bighorn sheep utilizing MCP to determine home-range size (Leslie and Douglas 1979, Seegmiller and Ohmart 1981, Krausman et al. 1989, Zimmerman 2008) resulted in mean home-range sizes (mean of summer, winter, male, and female home-ranges) of 5.65 km^2, 12.30 km^2, 23.48 km^2, and 16.30 km^2, respectively, which were much smaller than our overall mean 95% MCP home-range size of 108.53 km^2. However, when we isolated only year 2 locations, our year 2 mean 95% MCP home-range size of 23.81 km^2 was similar to the findings of Leslie and Douglas (1979), Seegmiller and Ohmart (1981), Krausman et al. (1989), and Zimmerman (2008). It is important to note that our MCP analysis included areas not observed in the field as areas of use by bighorn sheep.

When comparing BBMM of Parr's (2015) study and this study, we see a similar comparison; Parr's (2015) 95% BBMM ranged from 15.68 km^2-42.06 km^2, while our 95% BBMM mean home-range size was much smaller (15.90 km^2). As Parr (2015) indicated, their limited location data may have overestimated true home-range size (Horne et al. 2007, Sawyer et al. 2009, Walter et al. 2011). Our smaller home-range size may be due to large numbers of GPS locations (*n*=57,026), origin of the translocated bighorn sheep, or differing terrain and habitat capabilities of the 2 study areas.

We utilized and compared 3 different home-range models, finding vastly different areas with each. Our mean 95% MCP estimated the greatest area of home-range (108.53 km^2), followed by 50% and 95% adaptive kernel estimates (4.3 km^2 and 42.07 km^2), and 50%, 95%, and 99% BBMM estimates (0.17 km^2, 15.90 km^2, and 61.77 km^2). However, after isolating only year 2 locations, our 95% MCP (23.81 km^2) and 95% BBMM (5.29 km^2) means are much more similar than for the entire study period. Based on previous research (Kie et al. 2010, Walter et al. 2011, Wilckens 2014, Parr 2015) and our comparisons between each method, we believe that the most accurate home-range estimate for the translocated Deadwood bighorn sheep herd was the 95% BBMM when using only year 2 locations. This model was deemed the most accurate based on field observations and visual analysis of locations within ArcGIS 10.3.1; it encompassed much of the same area as the year 2 95% MCP, but excluded areas of little or no observed use by bighorn sheep (Figure 12). The model also excluded the early pioneering locations and encompassed the areas that were most utilized by the Deadwood herd.

Having only 4 originally fitted GPS collars record data for the entire study period gave us a small sample size to work with when comparing movement from year 1 to year 2. However, the plotted movement models created with the “move” package in Program R allowed us to visually examine distances and movement patterns of the 4 individuals. The total distance traveled for each time period may not be significant statistically, but when looking at each set of plots we can visually see striking differences. For each of the 4 sets of plots, year 1 showed more excursions away from a centrally located mass of location points than did year 2. This supports our hypothesis that after an acclimation period, the translocated Deadwood bighorn sheep herd would settle into a smaller home-range near the release site.

MANAGEMENT IMPLICATIONS

The Deadwood bighorn sheep herd may require a smaller home-range size than do other bighorn sheep herds in the Black Hills. Immediate pioneering post-release of translocated bighorn sheep should be expected in future reintroductions. The lambing areas outlined in Figure 2 will most likely continue to be utilized by the Deadwood bighorn sheep herd on a yearly/seasonal basis. As much of the home range is near or overlapping major roads and communities, it would be beneficial to managers to campaign for slower speed limits and increase the visibility/frequency of bighorn sheep crossing signs. We recommend continued monitoring of the Deadwood bighorn sheep herd to assess whether movement patterns and home-ranges remain the same, or if migration begins to occur. It may also benefit managers to begin evaluating home-range size and movements after pioneering behavior slows or ceases; beginning year 2 post-release of translocated bighorn sheep.

ACKNOWLEDGEMENTS

Financial support for this project was provided by Federal Aid to Wildlife Restoration administered through South Dakota Department of Game, Fish and Parks (Study Number 7556). We thank South Dakota Department of Game, Fish and Parks, Civil Air Patrol, Deadwood Police Department, Lawrence County Sheriff's Office, and private property owners in the Deadwood area for their assistance and property access. We thank J. Smith and B. Simpson for their assistance with data analyses. We thank T. Haffley, K. Cudmore, J. Doyle, J. Clark, and C. Werdel for their assistance with monitoring, capturing, and euthanizing bighorn sheep during the study period.

LITERATURE CITED

Beecham, J. J., C. P. Collins, and T. D. Reynolds. 2007. Rocky Mountain bighorn sheep (*Ovis canadensis*): A Technical Conservation Assessment. http://www.fs.fed.us/r2/projects/scp/assessments/rockymountainbighornsheep.pdf (accessed 2/27/2017).

Benkobi, L., D. W. Uresk, G. Schenbeck, and R. M. King. 2000. Protocol for monitoring standing crop in grasslands using visual obstruction. Journal of Range Management 53:627-633.

Berger, J. 1990. Persistence of different-sized populations: an empirical assessment of rapid extinctions in bighorn sheep. Conservation Biology 4:91-98.

Bleich, V. C., J. D. Wehausen, R. R. Ramey II, and J. L. Rechel. 1996. Metapopulation theory and mountain sheep: implication for conservation. Pages 353–373 in D. R. McCullough, editor. Metapopulations and Wildlife Conservation. Island Press, Washington, D.C.

Bleich, V. C, R. T. Bowyer, and J. D. Weyhausen. 1997. Sexual segregation in mountain sheep: resources or predation? Wildlife Monographs 134:1-50.

Buechner, H. K. 1960. The bighorn sheep in the United States, its past, present, and future. Wildlife Monographs 4:3-174.

Burt, W.H. 1943. Territoriality and home range concepts as applied to mammals. Journal of Mammalogy 24:346-352.

DeCesare, N. J., and D. H. Pletscher. 2006. Movements, connectivity, and resource selection of Rocky Mountain bighorn sheep. Journal of Mammalogy 87:531-538.

Douglas, C. L., and D. M. Leslie, Jr. 1999. Management of bighorn sheep. Pages 238-262 in R. Valdez and P. R. Krausman, editors. Mountain sheep of North America. The University of Arizona Press, Tucson, Arizona, USA.

Festa-Bianchet, M. 1988. Seasonal range selection in bighorn sheep: conflicts between forage quality, forage quantity, and predator avoidance. Oecologia 75:580-586.

Geist V. 1966. Validity of horn segment counts in aging bighorn sheep. Journal of Wildlife Management 30:634-635.

Geist, V. 1971. Mountain sheep: a study in behavior and evolution. University of Chicago Press, Chicago, Illinois, USA.

Getz, W. M., and C. C. Wilmers. 2004. A local nearest-neighbor convex-hull construction of home ranges and utilization distributions. Ecography 27:489-505.

Gogan, P. J. P. 1990. Considerations in the reintroduction of native mammalian species to restore natural ecosystems. Natural Areas Journal 10:210–217.

Hedrick, P. W. 2014. Conservation genetics and the persistence and translocation of small populations: bighorn sheep populations as examples. Animal Conservation 17:106-114.

Hemming, J. E. 1969. Cemental deposition, tooth succession, and horn development as criteria of age in dall sheep. Journal of Wildlife Management 33:552-558.

Hoffman, G. R., and R. R. Alexander. 1987. Forest vegetation of the Black Hills National Forest of South Dakota and Wyoming: a habitat type classification. USDA Research Paper RM-276. Rocky Mountain Forest and Range Experiment Station, Fort Collins, Colorado. 48pp.

Horne, J. E., E. O. Garton, S. M. Krone, and J. S. Lewis. 2007. Analyzing animal movements using Brownian bridges. Ecology 88:2354-2363.

Jacques, C. N., J. A. Jenks, C. S. Deperno, J. D. Sievers, T. W. Grovenburg, T. J. Brinkman, C. C. Swanson, and B. A. Stillings. 2009. Evaluating ungulate mortality associated with helicopter net-gun captures in the northern Great Plains. Journal of Wildlife Management 73:1282–1291.

Jedrzejewski, W. and J. F. Kamler. 2004. Modified drop-net for capturing ungulates. Wildlife Society Bulletin 32:1305-1308.

Kie, J. G., J. Matthiopoulos, J. Fieberg, R.A. Powell, F. Cagnacci, M.S. Mitchell, J.M. Gaillard, and P.R. Moorcroft. 2010. The home-range concept: are traditional estimators still relevant with modern telemetry technology? Philosophical Transactions of the Royal Society B 365:2221-2231.

Kissell, R. E. 1996. Competitive interactions among bighorn sheep, feral horses and mule deer in Bighorn Canyon National Recreation Area. Ph. D. Dissertation. Montana State University, Bozeman, MT.

Krausman P. R., B. D. Leopold, R. F. Seegmiller, and S.G. Torres. 1989. Relationships between desert bighorn sheep and habitat in western Arizona. Wildlife Monograph 102:1–66.

Krausman, P. R. and R. T. Bowyer. 2003. Mountain sheep (*Ovis canadensis* and *O. dalli*). In: Feldhamer GA, Thompson BC, Chapman JA, editors. Wild mammals of North America: biology, management, and conservation. 2nd Ed. Johns Hopkins University press, Baltimore, Maryland, pp. 1095-1115.

Leslie, D. M., and C. L. Douglas. 1979. Desert bighorn sheep of the river mountains, Nevada. Wildlife Monograph 66: 1-56.

Mcintosh, A. C. 1949. A botanical survey of the Black Hills of South Dakota. Black Hills Engineer 28:1-74.

Nielson, R.M., H. Sawyer, and T. L. McDonald. 2013. BBMM: Brownian bridge movement models. http://CRAN.R-project.org/package=BBMM. Accessed January 2017.

National Oceanic and Atmospheric Administration. 2017. Data Tools: 2010 Normals. <www.ncdc.noaa.gov>. Accessed 10 January 2017.

Orr, H. K. 1959. Precipitation and streamflow in the Black Hills. USDA Station Paper 44. Rocky Mountain Forest and Range Experiment Station, Fort Collins, Colorado. 25pp.

Parr, B. L., J. Kanta, J. Sandrini, D. J. Thompson, and J. A. Jenks. 2014. Bobcat predation on bighorn lamb in the western Black Hills of South Dakota. The Prairie Naturalist 46:41-43.

Parr, B. L. 2015. Population parameters of a bighorn sheep herd inhabiting the Elk Mountain region of South Dakota and Wyoming. M.S. Thesis, South Dakota State University, Brookings. 148pp.

Richardson, A.H., and L. E. Peterson. 1974. History and management of South Dakota deer. South Dakota Department of Game, Fish and Parks Public Bulletin No. 5. Pierre, South Dakota. 113pp.

Rodgers, A. R., A. P. Carr, L. Smith, and J. G. Kie. 2005. HRT: Home-range tools for ArcGIS. Ontario Ministry of Natural Resources, Centre for Northern Forest

Ecosystem Research, Thunder Bay, Ontario, Canada, Roy, J. L., and L. R. Irby. 1994. Augmentation of a bighorn sheep herd in southwest Montana. Wildlife Society Bulletin 22:470–478.

Sawyer, H., M. J. Kauffman, R. M. Nielson, and J. S. Horne. 2009. Identifying and prioritizing ungulate migration routes for landscape-level conservation. Ecology Applications 19:2016-2025.

Schuler, K.L., G.M. Schroeder, J.A. Jenks, and J.G. Kie. 2014. Ad hoc smoothing parameter performance in kernel estimates of GPS-derived home ranges. Wildlife Biology 20:259-266.

Seegmiller, R. F., and R. D. Ohmart. 1981. Ecological relationships of feral burros and desert bighorn sheep. Wildlife Monograph 78:1-58.

Seton, E. T. 1929. Lives of game animals. Doubleday, Doran and Co., Inc., New York Volume 4:441-501.

Singer, F. J., C. M. Papouchis, and K. K. Symonds. 2000a. Translocations as a tool for restoring populations of bighorn sheep. Restoration Ecology 8:6-13.

Singer, F. J., V. C. Bleich, and M. A. Gudorf. 2000b. Restoration of bighorn sheep metapopulations in and near western national parks. Restoration Ecology 8:14-24.

Smith, J. B., J. A. Jenks, T. W. Grovenburg, and R. W. Klaver. 2014. Disease and predation: sorting out causes of a bighorn sheep (*Ovis canadensis*) decline. Plos ONE 9: e88271.

South Dakota Department of Game, Fish and Parks. 2013. Action plan for management of bighorn sheep in South Dakota. Available: http://gfp.sd.gov/wildlife/management/plans. Accessed 27 February 2017.

Thilenius, J. F. 1972. Classification of deer habitat in the ponderosa pine forest of the Black Hills, South Dakota. USDA Forest Service Research Paper RM-91. Fort Collins, Colorado. 28pp.

Uresk, D. W., D. E. Mergen, and T. A. Benzon. 2009. Monitoring meadows with a modified Robel pole in the northern Black Hills, South Dakota. The Prairie Naturalist 41:121-125.

Van Vuren, D. 1998. Mammalian dispersal and reserve design. Pages 369-393 in T. Caro, editor. Behavioral ecology and conservation biology. Oxford University Press, New York, USA.

Walter, W. D., J. W. Fischer, S. Baruch-Mordo, and K. C. VerCauteren. 2011. What is the proper method to delineate home range of an animal using today's advanced GPS telemetry systems: the initial step. USDA National Wildlife Research Center. Staff Publications, Paper 1375. 19pp.

Walter, W. D., J. W. Fischer, T. J. Frink, S. E. Hygnstrom, J. A. Jenks, and K. C. VerCeauteren. 2013. Topographic home range of large mammals: is planimetric home range still a viable method? The Prairie Naturalist 45:21-27.

Wilckens, D. 2014. Ecology of mountain lions *(Puma concolor*) in the North Dakota Badlands: population dynamics and prey use. Thesis, South Dakota State University, Brookings, South Dakota. 92 p.

Wilckens, D. T., J. B. Smith, S. A. Tucker, D. J Thompson, and J. A. Jenks. 2016. Mountain lion (*Puma concolor*) feeding behavior in the recently recolonized Little Missouri Badlands, North Dakota. Journal of Mammalogy 97:373-385.

Witte, S. S., and M. V. Gallagher. 2012. The North American Journals of Prince Maximilian of Wied. University of Oklahoma Press, Norman, Oklahoma, USA. Volume 3, September 1833-August 1834.

Worton, B.J. 1989. Kernel methods for estimating the utilization distribution in home range studies. Ecology 70:164-168.

Zimmerman, T. J. 2008. Evaluation of an augmentation of Rocky Mountain bighorn sheep at Badlands National Park, South Dakota. Ph.D. Dissertation, South Dakota State University, Brookings. 139pp.

Figure 1. The translocated Deadwood bighorn sheep study area, located in the northern Black Hills of South Dakota, USA.

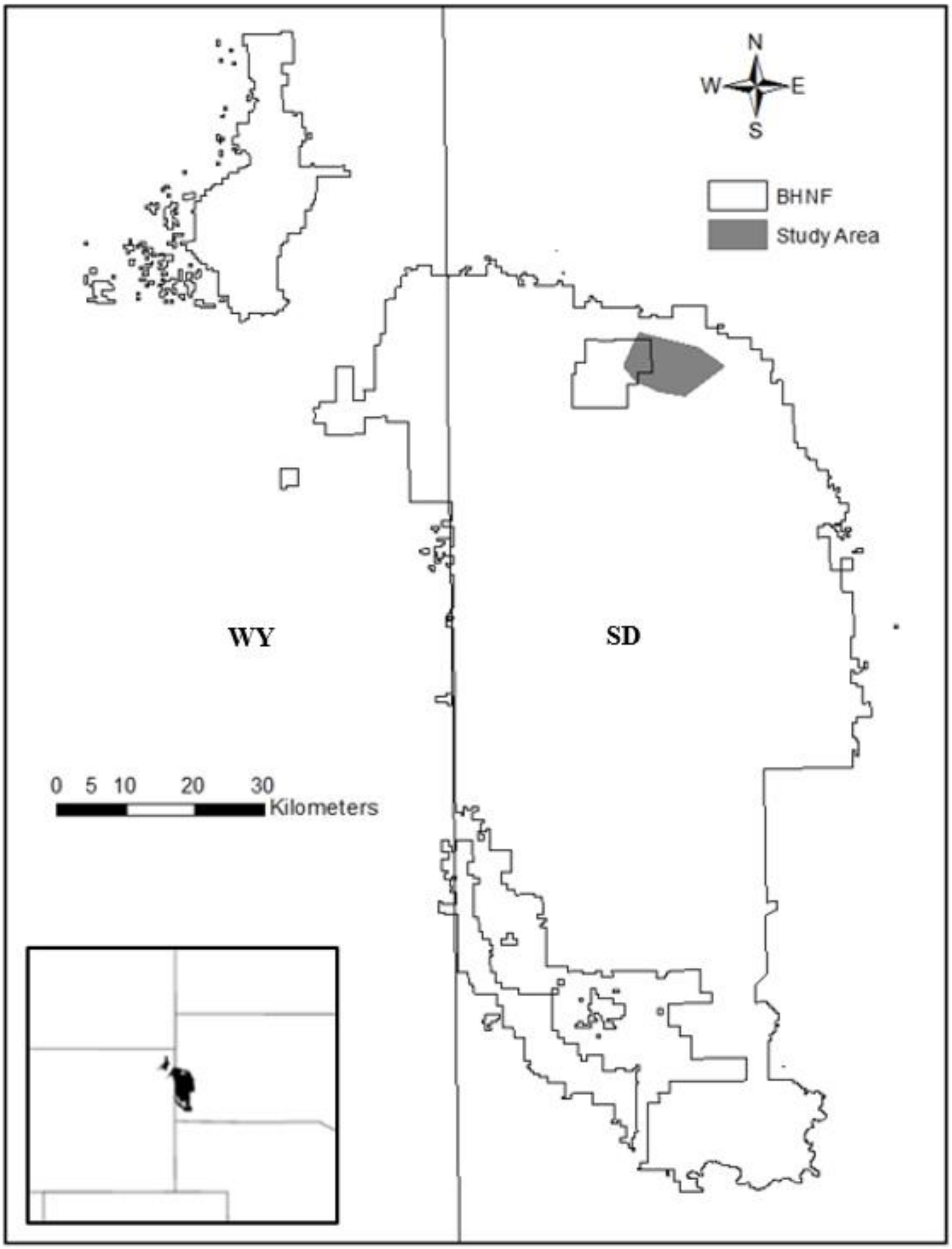


Figure 2. Lambing areas utilized by the translocated Deadwood bighorn sheep herd, located in the northern Black Hills of South Dakota, USA.

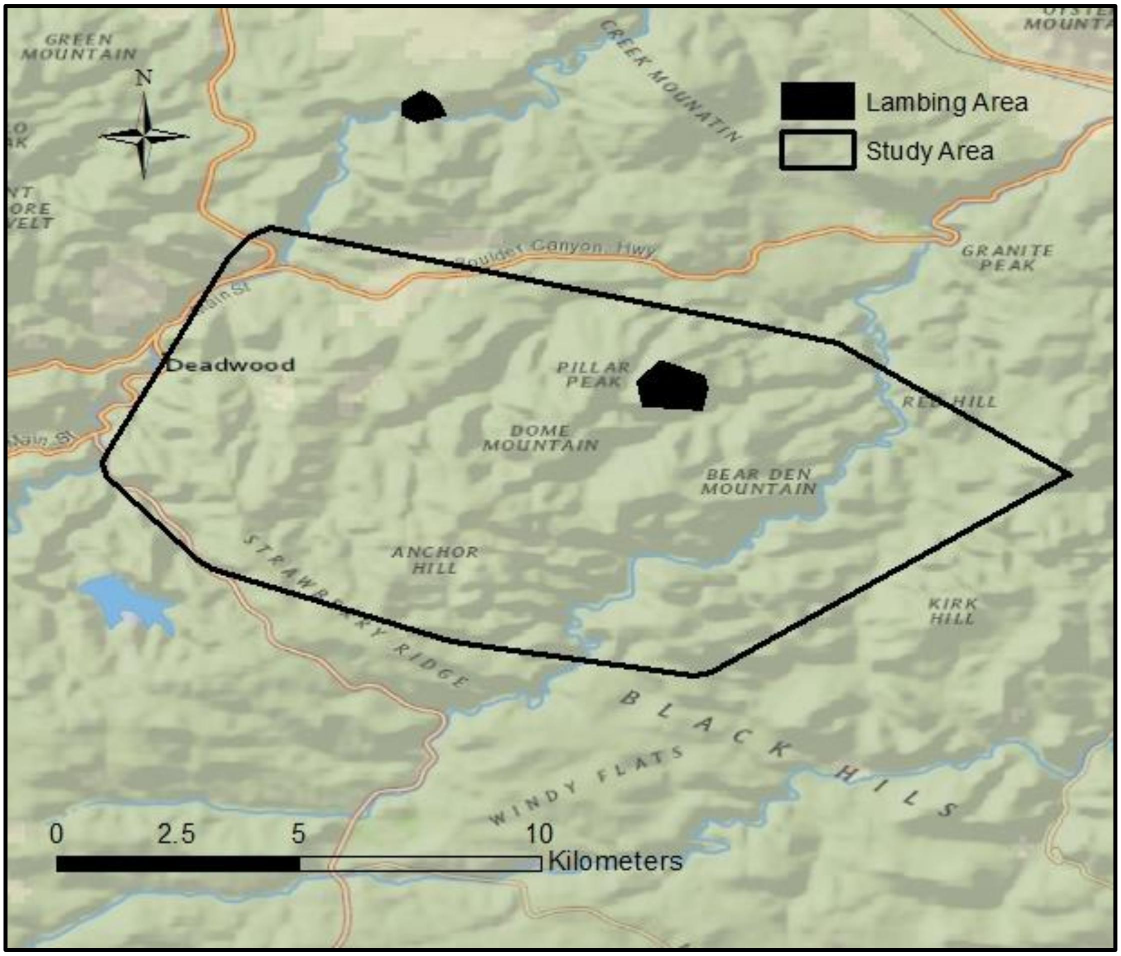


Figure 3. Combined home-ranges for 95% (269.21 km^2) and 50% (24.52 km^2) adaptive kernel home-range analysis generated using Home-Range Tools Analysis Extension (Rodgers et al. 2005).

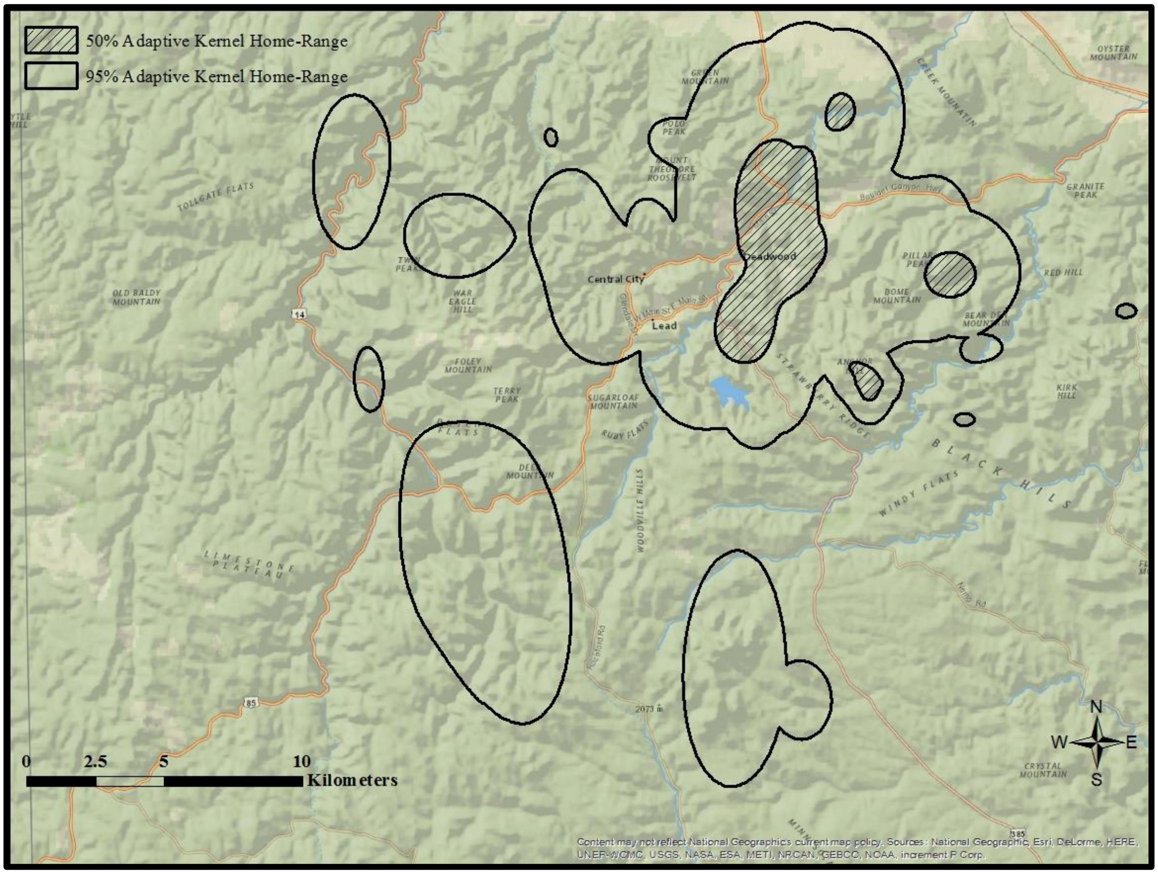


Figure 4. Combined home-ranges for 95% MCP (783.73 km^2), 95% MCP year 1 (1217.74 km^2), and 95% MCP year 2 (56.46 km^2).

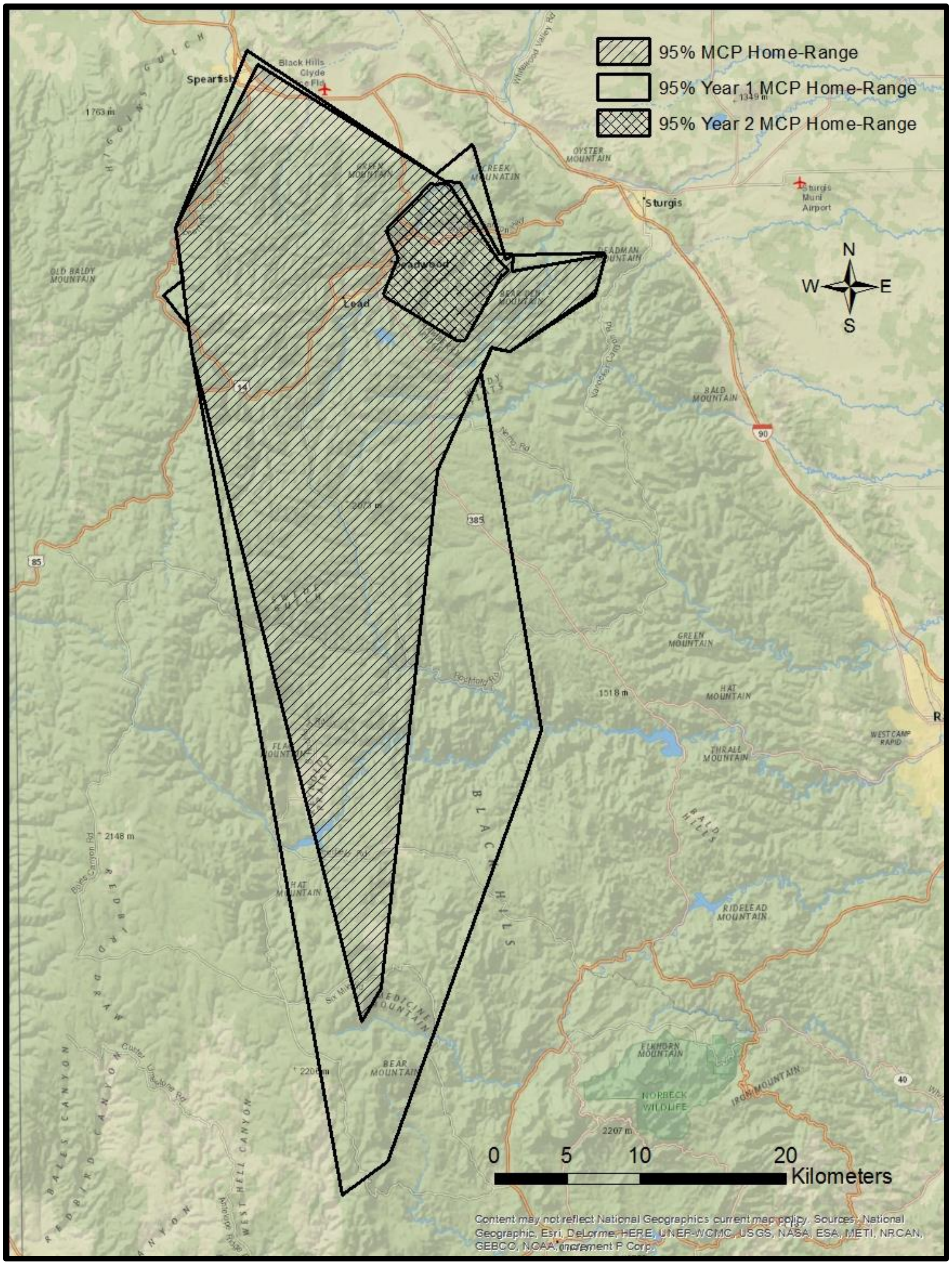


Figure 5. Combined home-ranges for 99% BBMM (446.62 km^2), 95% BBMM (102.83 km^2), and 50% BBMM (1.18 km^2).

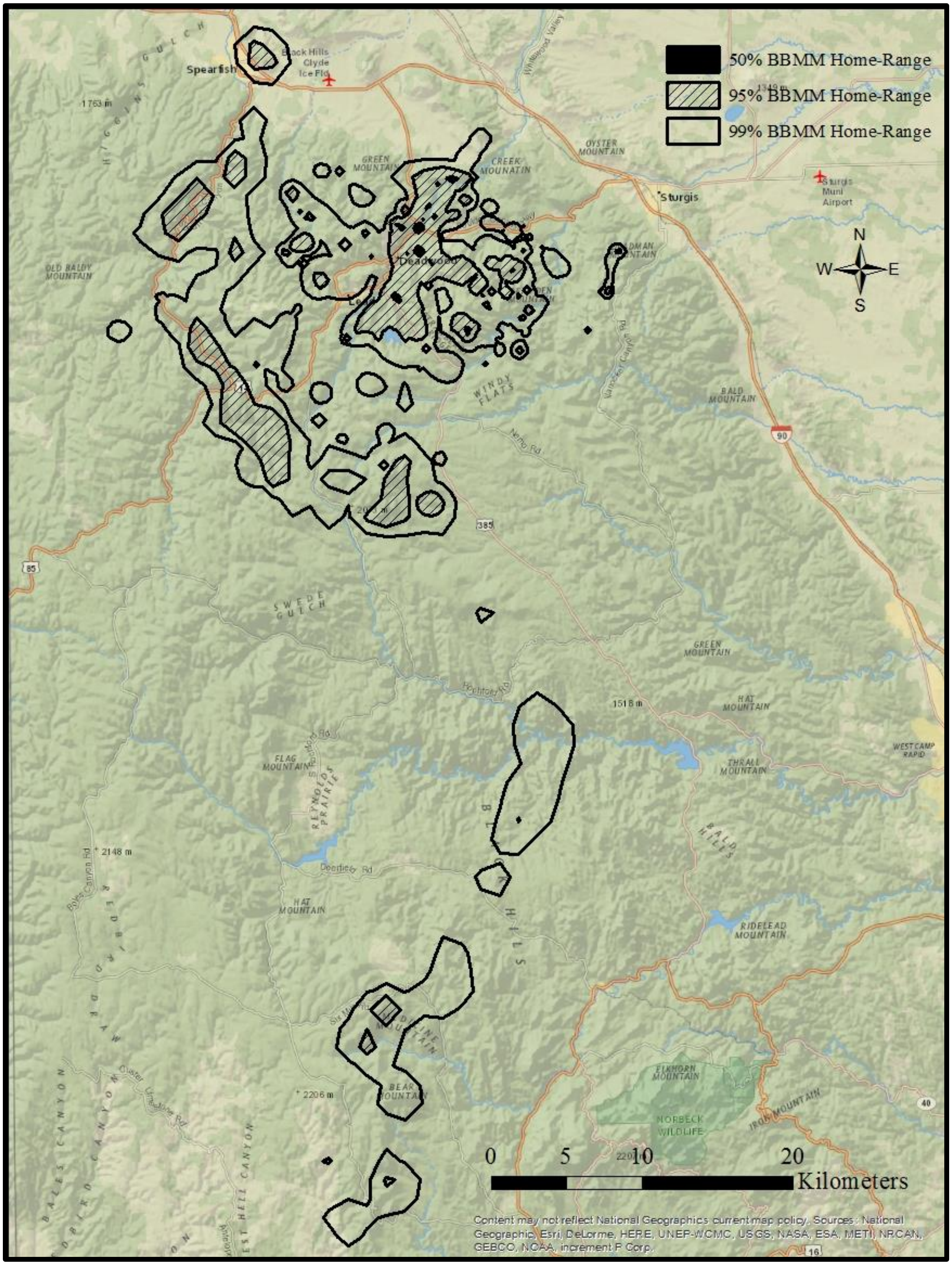


Figure 6. Combined home-ranges for year 1 99% BBMM (569.26 km^2), 95% BBMM (187.33 km^2), and 50% BBMM (1.72 km^2).

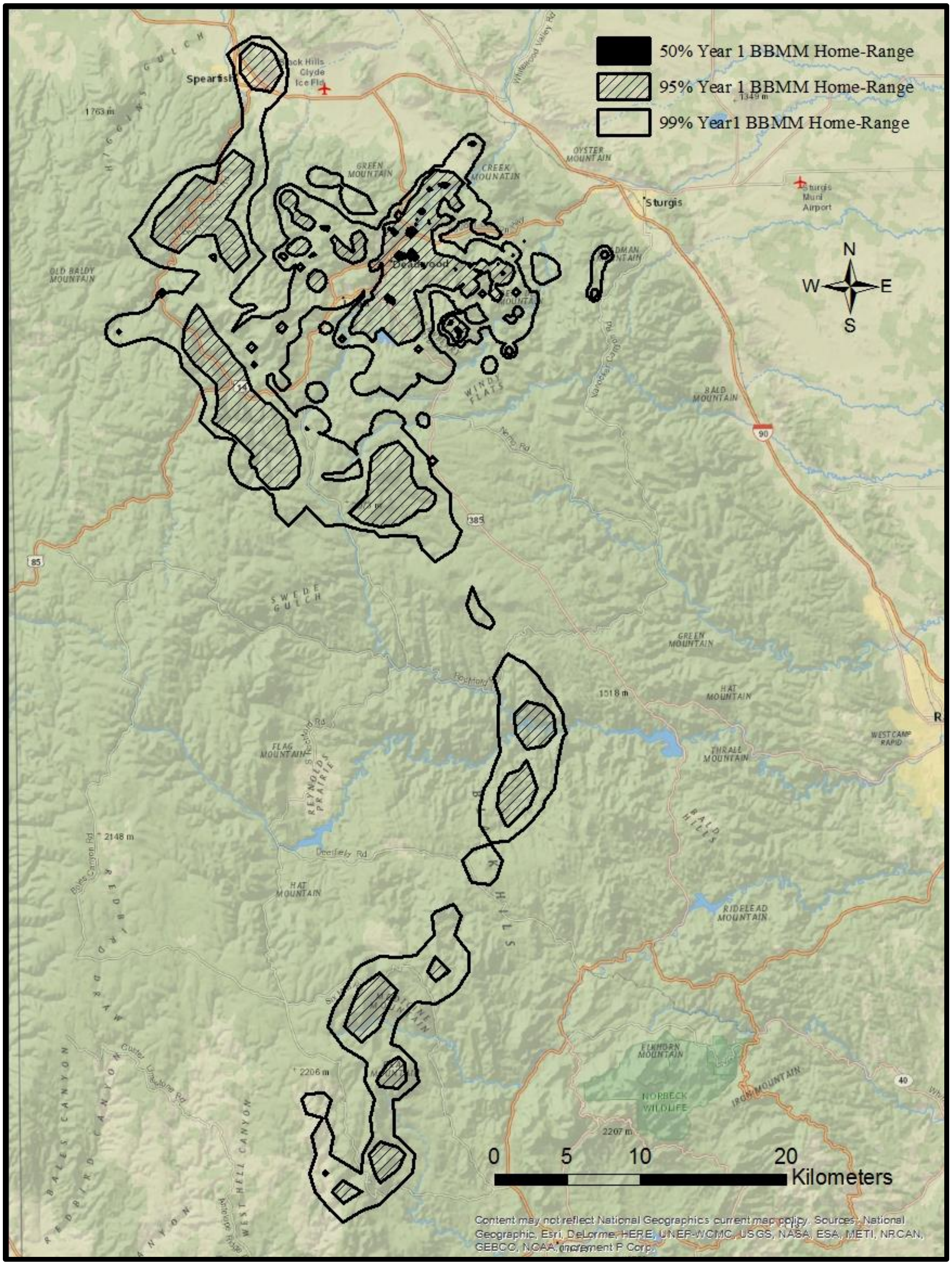


Figure 7. Combined home-ranges for year 2 99% BBMM (56.78 km^2), 95% BBMM (14.22 km^2), and 50% BBMM (0.58 km^2).

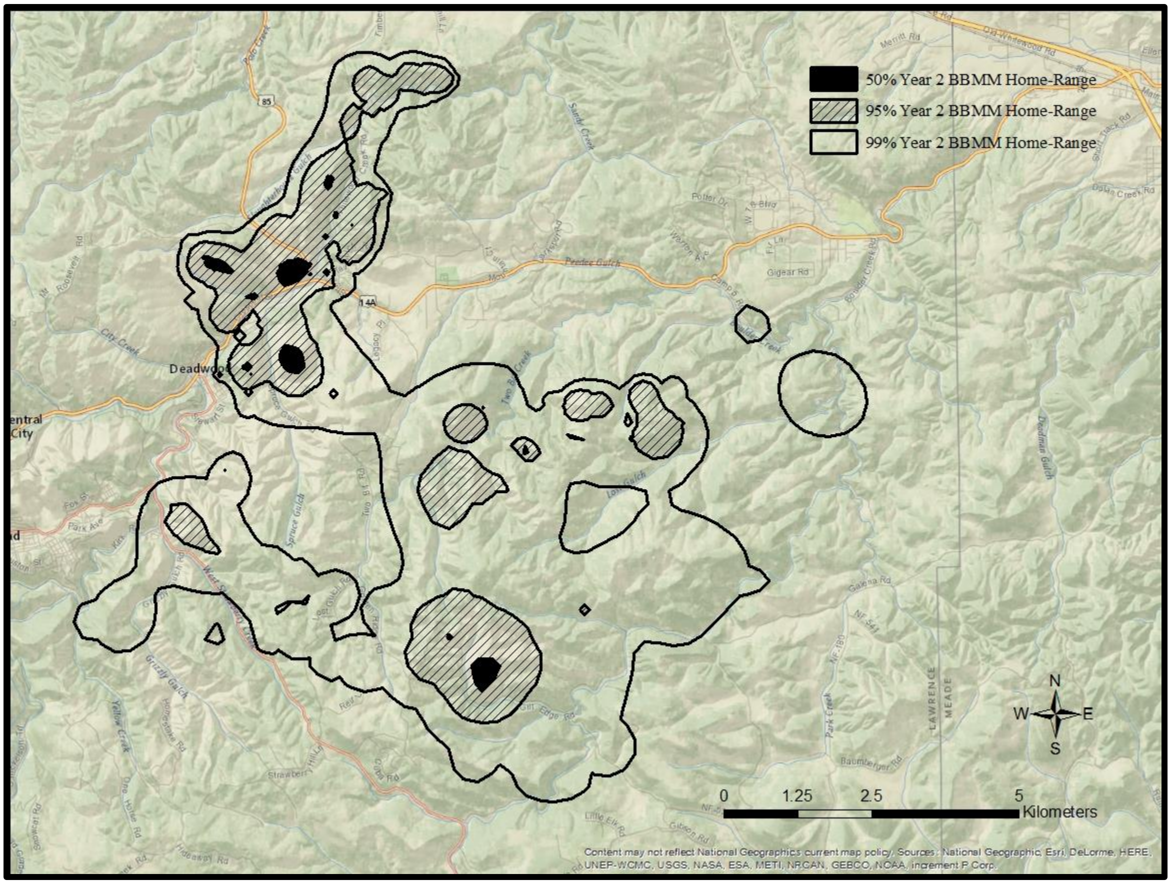


Figure 8. Movement comparison of year 1 (Green) and year 2 (Red) of BH223, via the "move" package in Program R.

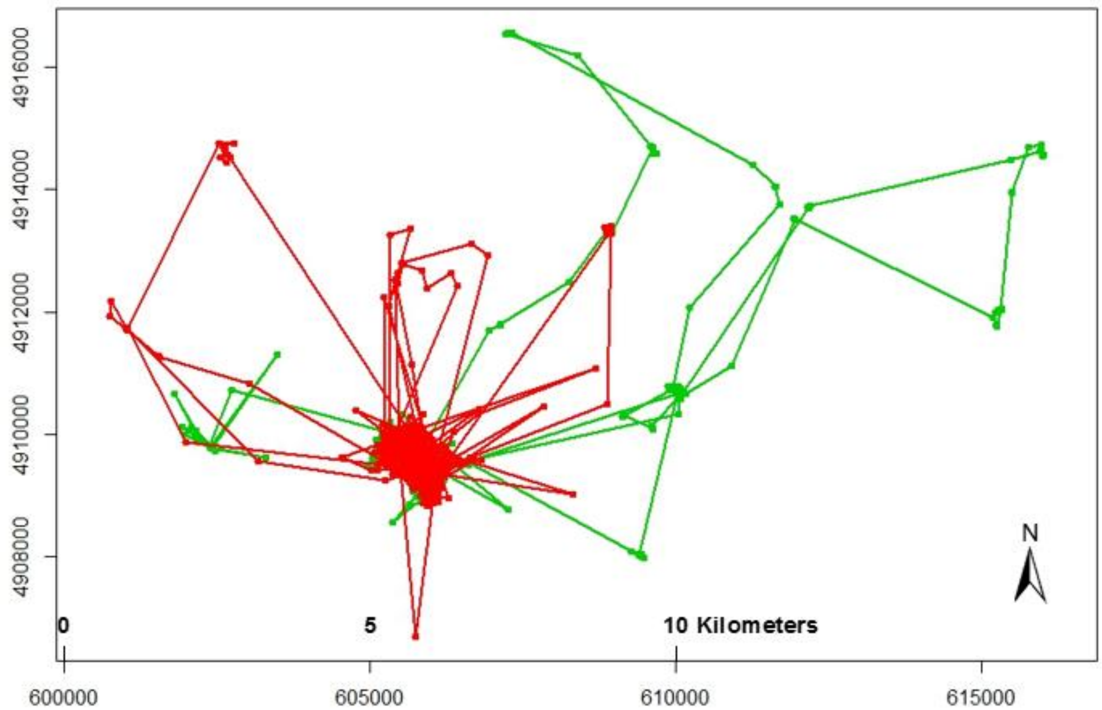


Figure 9. Movement comparison of year 1 (Green) and year 2 (Red) of BH232, via the "move" package in Program R.

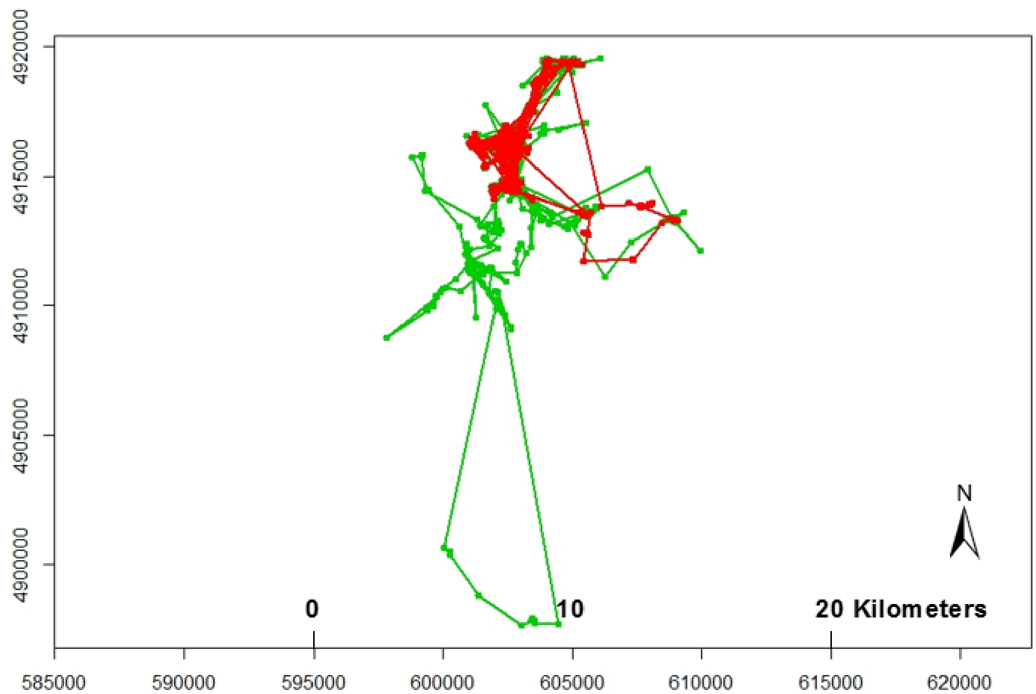


Figure 10. Movement comparison of year 1 (Green) and year 2 (Red) of BH233, via the "move" package in Program R.

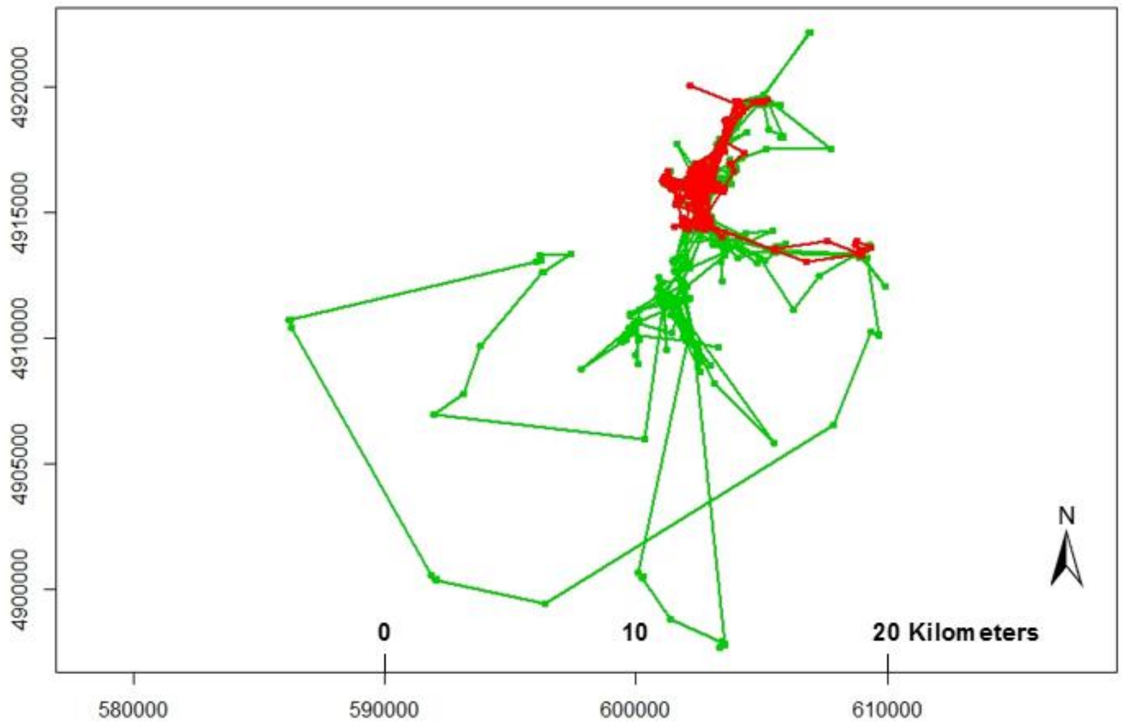


Figure 11. Movement comparison of year 1 (Green) and year 2 (Red) of BH239, via the "move" package in Program R.

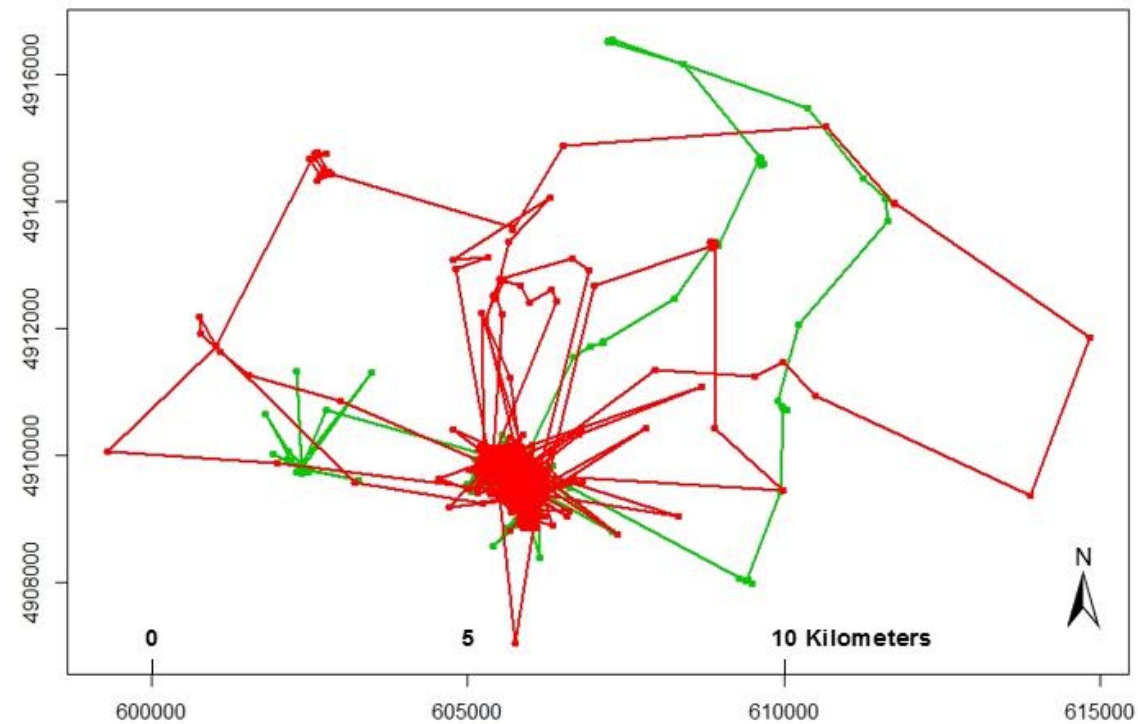
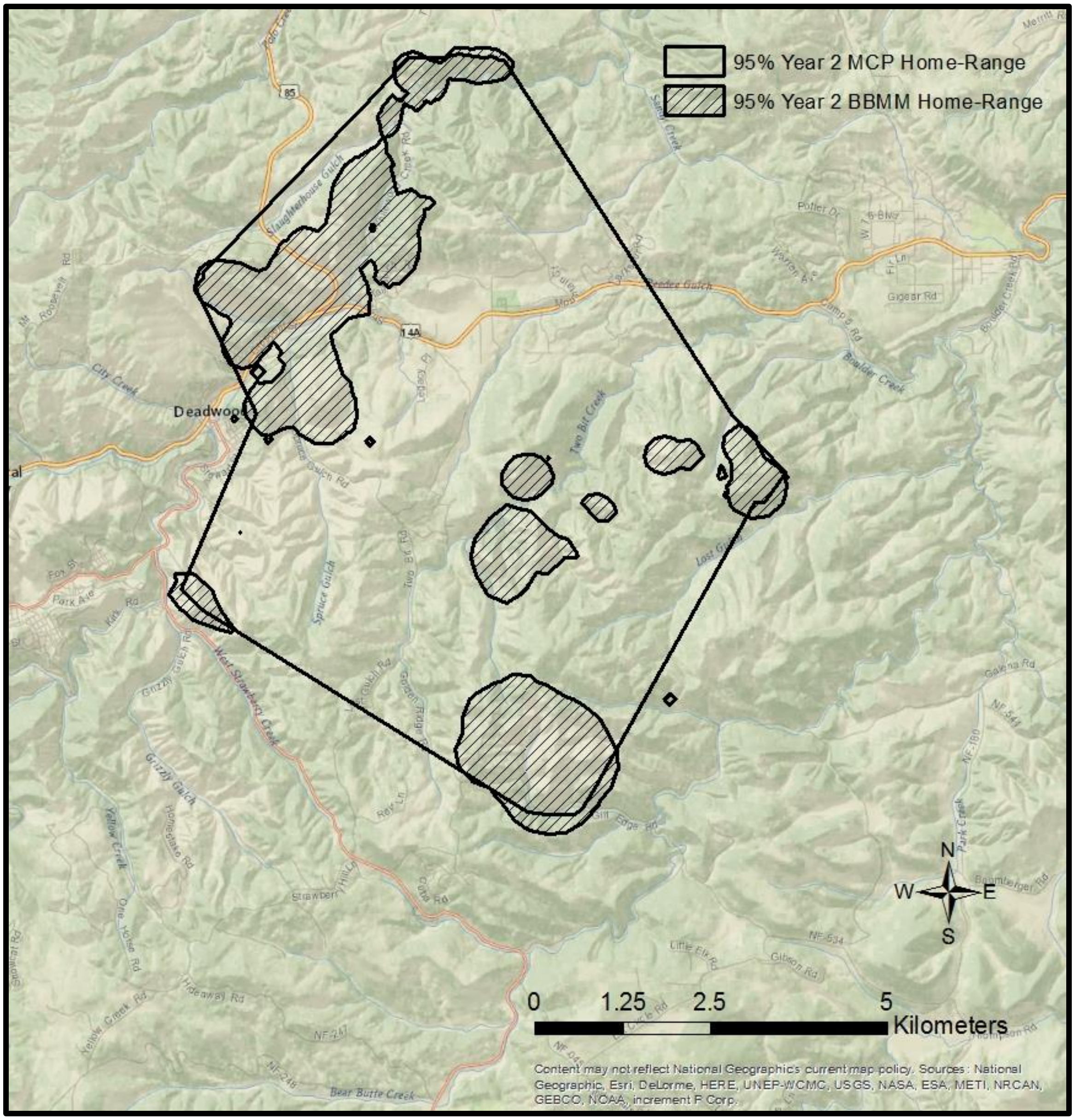


Figure 12. Comparison of combined year 2 95% BBMM home-range (14.22 km^2) and combined year 2 95% MCP home-range (56.46 km^2).



CHAPTER 4: EVALUATION OF 3RD-ORDER HABITAT SELECTION AND ESTIMATION OF HERBACEOUS BIOMASS AT FORAGING SITES POST-RELEASE OF TRANSLOCATED BIGHORN SHEEP IN THE DEADWOOD REGION OF THE BLACK HILLS, SOUTH DAKOTA

ABSTRACT

Bighorn sheep (*Ovis canadensis*) historically inhabited the Black Hills region of South Dakota, but the species was extirpated from the area in the early 1900s. Several reintroductions have taken place in the central and southern regions of the Black Hills. We translocated 26 bighorn sheep from Alberta, Canada to the Deadwood Region of the Black Hills. Our objectives were to evaluate 3rd-order habitat selection and estimate herbaceous biomass at foraging sites post-release of the translocated Deadwood bighorn sheep herd. The relationship between VOR's and herbaceous biomass (n=78) was significant (r^2=0.62). Herbaceous biomass ranged from 302.07 kg/ha to 2,487.43 kg/ha. Foraging sites were typically located in areas with little overstory tree canopy cover (mean= 8.41%, SE=1.85), short distance to escape terrain (mean= 24.00 m, SE=3.21), and little woody debris (mean= 0.25 kg/ha, SE=0.07). Individual bighorn sheep selected habitat types at varying levels, but barren habitat was the most positively selected, while forest habitat was universally avoided. Individual bighorn sheep selected elevations at varying levels, but 1,000-1,300 m and 1,900-2,200 m elevations were almost universally avoided. Overall bighorn sheep selection was neutral for slope degrees of 60-80, positive for slope degrees of 20-40 and 40-60, and negative for slope degrees of 0-20. Our results indicated that bighorn sheep in the Deadwood Region avoided forested habitat, preferred barren, shrubland, and grassland habitats, and preferred slopes from 20-60 degrees. The Deadwood Region had sufficient herbaceous biomass to support the newly established bighorn sheep herd.

INTRODUCTION

Prior to human colonization of North America, bighorn sheep (*Ovis canadensis*) were relatively abundant, numbering in the millions, and occupied habitats across the western United States, Canada, and Mexico. (Buechner 1960). Bighorn sheep are an ecologically sensitive species, with many factors affecting their wilderness habitat (Buechner 1960, Zimmerman 2008). Human impacts in the form of uncontrolled harvest, introduced disease from domestic sheep (*Ovis aries*), introduced forage competition from domestic livestock, reduced and fragmented habitat, and loss of movement corridors led to major declines in bighorn sheep populations in the late 19th century through the mid-20th century (Buechner 1960, Douglas and Leslie 1999, Beecham et al. 2007).

Bighorn sheep are gregarious as a species, but segregate sexually; males can occupy habitats with higher predator densities (i.e., coyotes [*Canis latrans*]) and forage quality, whereas females occupy habitats closer to water sources and generally occur in larger social groups than do males (Geist 1971, Bleich et al. 1997). Pregnant ewes migrate between two distinct range types prior to lambing (May-June); moving from low elevation winter ranges with high forage quality to high elevation lambing ranges with lower forage quality to avoid predation on newborn lambs (Festa-Bianchet 1988). Home range can be defined as an area in which an individual animal conducts its normal activities such as mating, gathering food, and caring for young (Burt 1943). Female bighorn sheep learn home ranges from maternal bands and may associate with their mothers their first 6 years of life (Geist 1971, Festa-Bianchet 1988). Escape terrain, including rocky outcrops and slopes ≥40 degrees (Zimmerman 2008), is a critical habitat attribute for bighorn sheep. At Badlands National Park, Zimmerman (2008) found resident and introduced bighorn sheep were, on average, <150 m from escape terrain, resulting in linear home ranges that were closely associated with badland formations. Because of the association between bighorn sheep and escape terrain, home ranges were best evaluated using three-dimensional analyses (Walter et al. 2013).

In South Dakota, bighorn sheep historically inhabited the entire Black Hills region, but the species was extirpated from the area in the early 1900s (Seton 1929, Zimmerman 2008, Witte and Gallagher 2012, Parr 2015). South Dakota Department of Game, Fish and Parks (SDGFP) began reintroductions of bighorn sheep to the state in the 1960s, with successful restorations occurring in Badlands National Park and the central and southern regions of the Black Hills, including Custer State Park, Spring Creek, Rapid Creek, Sheridan Lake, Hells Canyon, and Elk Mountain (Zimmerman 2008, SDGFP 2013, Parr 2015). Since the mid-1900s, many State and Federal wildlife management agencies have attempted hundreds of bighorn sheep reintroductions to the species' historic ranges with varying levels of success (Berger 1990, Singer et al. 2000, Hedrick 2014, Parr 2015). Reintroductions via translocations are executed in localized areas where the species has been completely extirpated or where low species' populations require increased abundance or genetic diversity to remain viable (Buechner 1960, Zimmerman 2008). Evaluating large mammal translocations is critical, due to expected initial mortality post-release, relatively low number of individuals initially translocated, unproven habitat capability, potential for predation, and time necessary for acclimation. Results of many reintroductions and translocations are inadequately detailed, leaving stakeholders without an understanding of project benefits and challenges (Gogan 1990, Zimmerman 2008). Bighorn sheep translocations should be vigorously evaluated to provide information on carrying capacity, post-release pioneering, habitat selection, and home range to help increase translocation success (Douglas and Leslie 1999, Zimmerman 2008). The Deadwood area of the northern Black Hills was vacant, but was deemed potentially suitable for a reintroduction, based on habitat suitability models and a qualitative assessment of topography, forage, and water (SDGFP 2013). However, despite a prerelease evaluation of the release site, no information was available regarding historical use of the area by bighorn sheep (SDGFP 2013). We assumed that post release, animal movements would be related to habitat pioneering prior to home range establishment.

Third-order habitat selection relates to how the habitat components within the home range are utilized (i.e., areas used for foraging) (Krausman 1999). Bighorn sheep primarily forage on grasses and forbs (Chapman and Feldhamer 1982), but under some circumstances may consume a relatively high percentage of browse (Rominger et al. 1988). Previous studies evaluating bighorn sheep diets, show that a variety of grasses, forbs, and shrubs were important during different times of the year (Miller and Gaud 1989, Wikeem and Pitt 1992, Wagner and Peek 2006). Forage production and quality can both be limiting factors to bighorn sheep population growth (Stelfox 1976).

Open vegetation, few water barriers, and rugged terrain are correlated with successful colonization of reintroduced bighorn sheep (Singer et al. 2000, Zimmerman 2008). Bighorn sheep generally avoid densely forested habitats due to increased predation risk (Geist 1971, Zimmerman 2008). Habitat suitability is dependent on a balance between predator avoidance (i.e., escape terrain), sufficient forage resources, and adequate shelter from environmental conditions (Owen-Smith 2003, Zimmerman 2008).

Douglas and Leslie (1999) recommended that translocated animals be released in habitats they are familiar with and thus, similar to their originally occupied area (Zimmerman 2008).

To expand bighorn sheep restoration in the Black Hills, we translocated 26 bighorn sheep from the Luscar Mine near Hinton, Alberta, Canada to the Deadwood region of the northern Black Hills. In an effort to evaluate a critical large mammal translocation, our objectives were to: evaluate 3rd-order habitat selection and estimate herbaceous biomass at foraging sites post-release of the translocated Deadwood bighorn sheep herd.

STUDY AREA

Bighorn sheep were initially captured in Alberta, Canada and translocated to our study area, the Deadwood region, located in the northern Black Hills in western South Dakota, USA (44°20'56.55"N, -103°42'28.64"W) (Fig. 1). This area encompasses approximately 8,177 ha of public (5,203 ha) and private (2,974 ha) land and is located immediately adjacent to the Deadwood, Lead, and Central City communities in Lawrence County, South Dakota (SDGFP 2013). Elevations range from 1,073 to 2,209 m above mean sea level. The Deadwood region of the Black Hills occurs within the central core of the Blacks Hills, which is typified by canyons, mountain peaks, and broad valleys (Hoffman and Alexander 1987). Soils of the region include limestones, dolomites, and sandstones of Paleozoic origin (Hoffman and Alexander 1987). This region of the Black Hills receives more precipitation in the form of snow (156 cm) and is cooler (-5 C) than more southern areas within the Black Hills (Hoffman and Alexander 1987, NOAA 2017).

Ponderosa pine (*Pinus ponderosa*) is the dominant overstory vegetation of the region; it occurs in monotypic stands and is intermixed with small stands of quaking aspen (*Populus tremuloides*) and paper birch (*Betula papyrifera*) (Mcintosh 1949, Orr 1959, Thilenius 1972, Richardson and Petersen 1974, Hoffman and Alexander 1987). Common plant species include Kentucky bluegrass (*Poa pratensis*), timothy (*Phleum pretense*), smooth brome (*Bromus inermis*), sedges (*Carex* spp.), western wheatgrass (*Pascopyrum smithii*), prairie dropseed (*Sporobolus heterolepis*), fleabane (*Erigeron* spp.) and yarrow (*Achillea* spp.) (Uresk et al. 2009). Additional ungulate species occupying the study area included mule deer (*Odocoileus hemionus*), white-tailed deer (*O. virginianus*), and elk (*Cervus elaphus*). Potential species known to predate on bighorn sheep occurring in the study area include mountain lions (*Puma concolor*; Smith et al. 2014, Wilckens et al. 2016), coyotes (*Canis latrans*), bobcats (*Lynx rufus*; Parr et al. 2014), bald eagles (*Haliaeetus leucocephalus*), and golden eagles (*Aquila chrysaetos*).

METHODS

Translocation and Data Collection

In February 2015, we (i.e., SDGFP and South Dakota State University [SDSU] personnel) traveled to Hinton, Alberta, Canada to capture and transport bighorn sheep to South Dakota. Two sites within the Luscar Mine were baited with alfalfa (*Medicago sativa*) hay for one week prior to our capture date. On 10 February 2015, modified 18 m x 18 m electromagnetic drop-nets were constructed over bait sites, and the following morning nets were used to capture 26 bighorn sheep (Jedrzejewski and Kamler 2004). Adult male bighorn sheep were aged based on horn annuli (Geist 1966) and adult females were aged via tooth eruption and wear (Hemming 1969, Krausman and Bowyer 2003).

Twenty-one adult female bighorn sheep and 1 adult male bighorn sheep were fitted with store-on-board global positioning system (GPS; Model 2110D; 154-155 MHz) radio collars (Advanced Telemetry Systems, Isanti, MN, USA). Two adult female bighorn sheep were fitted with very high frequency (VHF; Model 2520B; 154-155 MHz) radio collars (Advanced Telemetry Systems, Isanti, MN, USA). One female bighorn lamb and 1 male bighorn lamb were fitted with very high frequency (VHF; Model M4200M; 154-155 MHz) expandable break-away radio collars (Advanced Telemetry Systems, Isanti, MN, USA). Ear tags were attached to each individual bighorn sheep for future identification in the field. We drew blood samples and swabbed nasal and pharyngeal passages for disease testing; swab and blood samples were sent to Washington Animal Disease Diagnostic Laboratory (WADDL) to test for *Mycoplasma ovipneumoniae* (*M. ovi*) and pathogens related to pneumonia, blood samples were sent to The Holmes Research Centre University of Idaho for selenium analysis, blood for DNA extraction and analysis was sent to the University of Alberta, and serum to test for *Brucella ovis*, *Brucella abortus*, *Brucella suis*, PI-3, bovine viral diarrhea, and *Bacillus thuringiensis* was sent to USDA APHIS National Veterinary Services Laboratories. We also administered a pneumonia vaccine (IM and intranasally) to all captured bighorn sheep. All capture and handling methods were approved by the South Dakota State University Institutional Animal Care and Use Committee (Approval No. 14-096A).

Translocated bighorn sheep were released approximately 3.5 km southwest of Deadwood, South Dakota on private land. All radio-collared bighorn sheep were located a minimum of 5 times per week post-release between February 2015-August 2015 and May 2016-July 2016, and a minimum of 3-4 times per week September 2015-April 2016 and August 2016-December 2016 using a hand-held directional antenna and portable receiver (model RA-23K, Telonics, Inc., Mesa, AZ, USA). GPS collars fitted on live bighorn sheep released automatically after ~700 days and were recovered in the field, while GPS collars fitted on bighorn sheep mortalities were recovered at mortality sites; satellite location and time data were offloaded from GPS collars into ArcMap 10.3.1 (Environmental Systems Research Institute, Redlands, California, USA).

Vegetation sampling occurred during summer year 1 (June 2015-August 2015, *n*=30) and year 2 (June 2016-August 2016, *n*=50). Vegetative characteristics were collected along 100-m transects centered at observed foraging sites; transects were oriented along topographical contours. Overstory canopy cover was recorded at 1-m intervals along transects using a GRS densitometer (Geographic Resource Solutions, Arcata, CA, USA) (*n*=100) (Stumpf 1993). Percent understory cover of total herbaceous cover, grass, forbs, and shrubs was estimated in 0.1 m^2 quadrats (Daubenmire 1959) at 3-m intervals along transects (*n*=30). Aspect was recorded via a Silva Ranger CL15 compass (Johnson Outdoors Gear, Inc. Binghamton, NY); percent slope was estimated along this same gradient with a Silva Ranger CL15 clinometer (Johnson Outdoors Gear, Inc. Binghamton, NY, USA). Distance (m) to nearest escape cover (slope ≥40 degrees) was measured using a Nikon Prostaff 7 range finder (Nikon Corporation, Tokyo, Japan). Downed woody debris (kg/ha) was interpolated using a pictorial guide (Simmons 1982). A modified Robel pole marked with alternating colors at 1.27-cm increments (Robel et al. 1970, Benkobi et al. 2000) was used to characterize visual obstruction from vegetation at bighorn sheep foraging locations. Visual obstruction was collected at 10-m intervals (*n* =10) from foraging sites. The Robel pole was placed 4 m from investigators and estimation of VOR (*n*=4) was collected by viewing the pole while kneeled at a height of 1 m (one in each cardinal direction) (Robel et al. 1970). Standing herbage was clipped to ground level within 0.25 m^2 circular plots centered at stations and located 40 and 80 m from foraging sites (*n*=4). Vegetation was oven dried at 60º C for 48 hours and weighed to nearest 0.1 g.

Data Analysis

Robel pole measurements were correlated with dried herbaceous biomass to estimate standing herbage expressed as kg•ha^{-1} (Uresk and Benzon 2007, Uresk et al. 2009). All VOR's and clipped herbage were averaged by transect. Relationships between VOR and herbaceous biomass were analyzed using linear regression with 90% prediction intervals. Probability plots were created and examined graphically for normality of residuals. We utilized linear regression with the "glm()" function in Program R version 3.3.3 (R Development Core Team 2014) (Program R Version 3.3.3, 2017, www.r-project.org/, accessed 10 Jan 2017), with significance set at $\alpha = 0.10$.

Non-hierarchical cluster analysis (ISODATA) was used (transect means, VOR, and clipped herbage) to develop standing herbage resource categories for guidelines to evaluate grazing for allotments and pastures as it pertained to bighorn sheep management (Ball and Hall 1967, del Morel 1975, Lehman et al. 2017). Resource categories used for standing herbage included short, intermediate, and tall. Minimum and maximum thresholds for each category were computed using 95% confidence intervals (CI). VOR's and kg/ha were standardized to give equal weight for analyses (individual data subtracted from the sample mean/standard deviation). The estimated number of transects to achieve estimates within 20% of the mean with an 80% confidence level were evaluated on the regression variance (Cochran 1977).

We calculated 99% Brownian Bridge Movement Model (BBMM) home range contours using the “BBMM” package in Program R (Nielson et al. 2013, Parr 2015). We used a maximum time-lag of 180 minutes to exclude any nonconsecutive locations and a cell size of 100 m for data collected from February 2015-January 2017. Contour polygons were converted to shapefiles and mapped in ArcGIS 10.3.1 (Environmental Systems Research Institute, Redlands, California, USA) to evaluate locations and home range for individual bighorn sheep. The “Clip” tool in ArcGIS 10.3.1 was used to include only individual bighorn sheep locations that fell within each individual 99% BBMM contour. The “Create Random Points” tool in ArcGIS 10.3.1 was used to create an equal number of random points, comparable to individual collar locations, for each bighorn sheep within 99% BBMM contours. The “Extract Values to Points” tool in ArcGIS 10.3.1 was used to create fields for each point that reflected values for land cover (NLCD2011), elevation, and slope.

Resource selection was evaluated using a design III analysis (α=0.10) to determine whether selection was positive, negative, or neutral for habitat categories using individual habitat use and availability (Manly et al. 2002). Program R version 3.3.3 (http://www.r-project.org/) with the adehabitat library (Calenge 2006) was used to calculate selection ratios and chi square tests were used to assess deviation from random use of microhabitat types. Microhabitats were combined into 5 categories: developed (Open space development, low intensity development, medium intensity development, high intensity development, pasture/hay, and cultivated crops), barren (areas of bedrock, desert pavement, scarps, talus, slides, volcanic material, glacial debris, sand dunes, strip mines, gravel pits and other accumulations of earthen material with vegetation accounting for less than 15% of total cover), forest (deciduous forest, evergreen forest, and mixed forest), shrubland (areas dominated by shrubs ≥20% of total cover), and grassland (areas dominated by graminoid or herbaceous vegetation ≥80% of total cover) (NLCD2011). Selection of habitat was indicated if selection ratios ($\hat{w}$) differed significantly from 1; positively or negatively (Manly et al. 2002). The same analysis was then implemented with respect to elevation (Categories included 1000-1300 m, 1300-1600 m, 1600-1900 m, and 1900-2200 m) and slope (Categories included 0-20 degrees, 20-40 degrees, 40-60 degrees, and 60-80 degrees).

RESULTS

A total of 24 adult bighorn sheep (*n*= 23 ewes, *n*= 1 ram) was included in our analyses, resulting in 80 summer foraging sites measured during 2 separate study periods (June 2015-August 2015, *n*=30; June 2016-August 2016, *n*=50). The relationship between Visual Obstruction Readings (VOR) and herbaceous biomass was significant, but not sufficiently predictive (r^2=0.58; $F_{1,78}$=105.974, P<0.01). Transects with >30% shrub cover, based on understory cover estimates, were removed (Lehman et al. 2017), resulting in 78 foraging sites, which improved our regression fit (r^2=0.62; $F_{1,76}$=125.427, P<0.01) (Figure 2). Cluster analyses (ISODATA) based on transect means for VOR's and clipped herbage resulted in 3 distinct minimum-variance VOR categories (short, intermediate, and tall). Herbaceous biomass ranged from 302.07 kg/ha to 2,487.43 kg/ha across short (Bands= 0.87-2.56), intermediate (Bands= 2.57-5.27), and tall (Bands= 5.28-10.26) categories utilizing cluster analysis with 95% CI at 80 foraging sites (Table 1).

Foraging sites were typically located in areas with little overstory tree canopy cover (mean= 8.41%, SE=1.85), short distance to escape terrain (mean= 24.00 m, SE=3.21), and little woody debris (mean= 0.25 kg/ha, SE=0.07) (Table 2).

The most abundant habitat types available within areas encompassed by 99% Brownian Bridge Movement Models (BBMM) for bighorn sheep (*n*=19 [*n*=3 were removed due to limited location data]) was forest, followed by grassland, shrubland, developed, and barren habitats. The highest percentage of habitat used, based on bighorn sheep locations, was grassland, followed by forest, barren, shrubland, and developed habitats (Table 3). We determined, utilizing design III analyses, that bighorn sheep were not using resources in the same proportion as available habitat (X^2= 37,955.77; df= 72; P<0.001). Throughout the study period (Feb 2015-Jan 2017), overall bighorn sheep selection was neutral for developed habitat, positive for barren, shrubland, and grassland habitats, and negative for forest habitat (Table 4 and Figure 3). Individual bighorn sheep selected habitat types at varying levels, but barren habitat was the most positively selected, while forest habitat was universally avoided (Figure 3).

Bighorn sheep were not using elevations in the same proportions as available elevations (X^2= 13,993.89; df= 42; P<0.001). Throughout the study period (Feb 2015-Jan 2017), overall bighorn sheep selection was neutral for elevations of 1,300-1,600 m and 1,600-1900 m, and negative for elevations of 1,000-1,300 m and 1,900-2,200 m (Table 5 and Figure 4). Individual bighorn sheep selected elevations at varying levels, but 1,000-1,300 m and 1,900-2,200 m elevations were almost universally avoided (Figure 4).

We also determined bighorn sheep were not using slope in the same proportion as available slopes (X^2=infinite; df= 49; P<0.001). Throughout the study period (Feb 2015-

Jan 2017), overall bighorn sheep selection was neutral for slope degrees of 60-80, positive for slope degrees of 20-40 and 40-60, and negative for slope degrees of 0-20 (Table 6 and Figure 5).

DISCUSSION

Bighorn sheep diets can vary by geographic location and sex, but are typically comprised of grasses, forbs, and shrubs (Valdez and Krausman 1999, Schroeder et al. 2010). Our bighorn sheep study population selected foraging areas with little overstory canopy cover and minimal distance to escape terrain, along with ample available forage in the form of grasses, forbs, and shrubs, in descending order; results correspond with previous studies (Valdez and Krausman 1999, Lehman et al. 2017). When our results are compared to those of Lehman et al. (2017), we found that our VOR's and standing herbage were lower across all band categories; short, intermediate, and tall. Our lower herbaceous biomass results may be due to the differences in regions of the Black Hills; Lehman et al. (2017) conducted their study in the southern Black Hills of South Dakota, while our study was located in the northern Black Hills of South Dakota, which receives more precipitation in the form of snow (156 cm) and is cooler (-5 C) than the southern Black Hills (Hoffman and Alexander 1987). Once we removed foraging sites with greater than 30% shrub cover, the modified Robel pole was adequate at predicting herbaceous biomass (r^2=0.63), similar to previous studies using the same methods; r^2=0.65 (Lehman et al. 2017) and r^2=0.80 (Uresk and Benzon 2007, Uresk et al. 2009).

Evaluating use of habitat categories by bighorn sheep is important to management because resource use is dependent on resources available within a given habitat (Hobbs and Hanley 1990, Robling 2011). The Grizzly Gulch fire of June 2002 near Deadwood, South Dakota burned 4,690 hectares over 13 days, clearing a large expanse of overstory canopy cover. DeCesare and Pletscher (2006) found that areas of high-visibility, such as "grasslands and high-severity burned forests were generally preferred" by bighorn sheep. However, as of 2011 (NLCD2011), 55.59% of available habitat within our BBMM home ranges was comprised of forest habitat and accounted for the highest percentage of available habitat. Our study population of bighorn sheep actively avoided the forest habitat type, which supported Geist's (1971) observations of bighorn sheep avoiding forested habitats to avoid predators. Large 90% CI's ($\hat{w}$ values <1 and >1) resulted in selection for developed habitat types as inconclusive, so we interpreted the results as neutral. Shrubland and grassland habitats were considered positively selected with lower and upper 90% CI's greater than $\hat{w}$ of 1, but it was found that the most actively selected habitat type selected was barren. Barren habitat types may be positively selected because of their close association with escape terrain; escape terrain has been described as rocky outcrops or slopes ≥40 degrees (Zimmerman 2008), and barren habitat is described as areas of bedrock, desert pavement, scarps, talus, slides, volcanic material, glacial debris, sand dunes, strip mines, gravel pits and other accumulations of earthen material with vegetation accounting for less than 15% of total cover (NLCD2011). Escape terrain is a critical habitat attribute for bighorn sheep utilized to escape predation (Geist 1971, Zimmerman 2008).

Wide 90% CI's limited determination of selection for elevation categories within BBMM home ranges for our study population of bighorn sheep. Elevations of 1,600-1,900 m had a $\hat{w}$ value of 1.09 (showing positive selection), but upper and lower CI's of <1 and >1, resulting in our determination of neutral selection for that category. However, elevations of 1,000-1,300 m and 1,900-2,200 m were actively avoided with $\hat{w}$ values and their CI's much less than 1. Elevations of 1,000-1,300 m may have been avoided due to the fact that there is limited escape terrain associated with these elevations in the Deadwood region of the Black Hills of South Dakota. Our results for selection of slope ranges indicated that $\hat{w}$ values increase as slope increases. Our study population of bighorn sheep avoided slopes <20 degrees and positively selected slopes 20-40 and 40-60 degrees. This coincides closely with escape terrain (slopes ≥40 degrees) (Zimmerman 2008). The highest $\hat{w}$ value of 11 was for slopes 60-80 degrees, but the CI's were so wide (90% CI $\hat{w}$= -3.24 - 25.24) that we could not irrefutably claim that selection was positive.

The Luscar Mine near Hinton, Alberta, Canada (site of original capture) has elevation, slope, and habitat characteristics similar to the Deadwood region of the Black Hills, South Dakota (NRC 2017). The Luscar Mine elevation ranged from 1,415-2,550 m above mean sea level, while our study area elevation ranged from 1,073 to 2,209 m. Percentage of total area within the Luscar Mine included 23.1% from 1,300-1,600 m, 52.5% from 1,600-1,900 m, 16.8% from 1,900-2,200 m, and 7.6% from 2,200-2,550 m. Slopes in the Luscar Mine ranged from 0-74 degrees. Percentage of total area within the Luscar Mine included 77% from 0-20 degrees, 21.9% from 20-40 degrees, 0.6% from 40-60 degrees, and 0.5% from 60-80 degrees. Based on examination of satellite imagery and anecdotal evidence from our days spent within the Luscar Mine, the habitat characteristics (i.e., small amounts of overstory canopy cover, close proximity to escape terrain, areas of barren land, and areas of high quality forage) are analogous with the Deadwood region of the Black Hills, South Dakota. The similarities between the capture and release locations may justify the establishment of home ranges near the release location after an initial period (year 1) of dispersal into unsuitable habitats (i.e., densely forested areas).

MANAGEMENT IMPLICATIONS

We recommend SDGFP managers monitor forage availability for bighorn sheep using the modified Robel pole as a tool in the northern Black Hills. The relationship between VOR's and herbaceous biomass can be used as a reliable tool to monitor available forage for bighorn sheep. VOR categories (short, intermediate, and tall) provided useful guidelines for management of standing herbage to meet objectives. Our recommendation is to use the intermediate category (816.79 – 1,643.89 kg/ha herbaceous biomass) as a goal for bighorn sheep management. Utilizing short, intermediate, and tall VOR categories, wildlife managers can evaluate forage availability accurately and with little cost. Future reintroduction efforts should keep positive selection, and avoidance of forest habitat, of our study population in mind when finding suitable reintroduction areas; available slopes ≥40 degrees, available barren habitat, and open canopy cover.

ACKNOWLEDGEMENTS

Financial support for this project was provided by Federal Aid to Wildlife Restoration administered through South Dakota Department of Game, Fish and Parks (Study Number 7556). We thank South Dakota Department of Game, Fish and Parks, Civil Air Patrol, Deadwood Police Department, Lawrence County Sheriff's Office, and private property owners in the Deadwood area for their assistance and property access. We thank J. Smith and B. Simpson for their assistance with data analyses. We thank T. Haffley, K. Cudmore, J. Doyle, J. Clark, and C. Werdel for their assistance with monitoring, capturing, and euthanizing bighorn sheep during the study period. We thank C. Neumann for assistance with Program R statistical analysis.

LITERATURE CITED

Ball, G. H., and D. J. Hall. 1967. A clustering technique for summarizing multivariate data. Behavioral Science. 12:153-155.

Beecham, J. J., C. P. Collins, and T. D. Reynolds. 2007. Rocky Mountain Bighorn Sheep (*Ovis canadensis*): A Technical Conservation Assessment. http://www.fs.fed.us/r2/projects/scp/assessments/rockymountainbighornsheep.pdf (accessed 2/27/2017).

Benkobi, L., D. W. Uresk, G. Schenbeck, and R. M. King. 2000. Protocol for monitoring standing crop in grasslands using visual obstruction. Journal of Range Management 53:627-633.

Berger, J. 1990. Persistence of different-sized populations: an empirical assessment of rapid extinctions in bighorn sheep. Conservation Biology 4:91-98.

Bleich, V. C, R. T. Bowyer, and J. D. Weyhausen. 1997. Sexual segregation in mountain sheep: resources or predation? Wildlife Monographs 134:1-50.

Buechner, H. K. 1960. The bighorn sheep in the United States, its past, present, and future. Wildlife Monographs 4:3-174.

Burt, W. H. 1943. Territoriality and home range concepts as applied to mammals. Journal of Mammalogy 24:346-352.

Calenge, C. 2006. The package “adehabitat” for R software: A tool for the analysis of space and habitat use by animals. Ecological Modelling 197:516-519.

Chapman, J. A., and G. A. Feldhamer. 1982. Wild mammals of North America: biology, management, and economics. Johns Hopkins University Press.

Cochran, W.G. 1977. Sampling techniques, 3rd ed. John Wiley and Sons, New York 428 pp.

Daubenmire, R. 1959. A canopy-coverage method of vegetational analysis. Northwest Science 33:43-64.

DeCesare, N. J., and D. H. Pletscher. 2006. Movements, connectivity, and resource selection of Rocky Mountain bighorn sheep. Journal of Mammalogy 87:531-538.

del Moral, R. 1975. Vegetation clustering by means of ISO DATA: revision by multiple discriminant analysis. Vegetation. 39:179-190.

Douglas, C. L., and D. M. Leslie, Jr. 1999. Management of bighorn sheep. Pages 238-262 in R. Valdez and P. R. Kraus man, editors. Mountain sheep of North America. The University of Arizona Press, Tucson, Arizona, USA.

Festa-Bianchet, M. 1988. Seasonal range selection in bighorn sheep: conflicts between forage quality, forage quantity, and predator avoidance. Oecologia 75:580-586.

Geist V. 1966. Validity of horn segment counts in aging bighorn sheep. Journal of Wildlife Management 30:634-635.

Geist, V. 1971. Mountain sheep: a study in behavior and evolution. University of Chicago Press, Chicago, Illinois, USA.

Gogan, P. J. P. 1990. Considerations in the reintroduction of native mammalian species to restore natural ecosystems. Natural Areas Journal 10:210–217.

Hedrick, P. W. 2014. Conservation genetics and the persistence and translocation of small populations: bighorn sheep populations as examples. Animal Conservation 17:106-114.

Hemming JE. 1969. Cemental deposition, tooth succession, and horn development as criteria of age in Dall sheep. Journal of Wildlife Management 33:552-558.

Hobbs, N. T., and T. A. Hanley. 1990. Habitat evaluation: Do use/availability data reflect carrying capacity? Journal of Wildlife Management 54:515-522.

Hoffman, G. R., and R. R. Alexander. 1987. Forest vegetation of the Black Hills National Forest of South Dakota and Wyoming: a habitat type classification. USDA Research Paper RM-276. Rocky Mountain Forest and Range Experiment Station, Fort Collins, Colorado. 48pp.

Jedrzejewski, W. and J. F. Kamler. 2004. Modified drop-net for capturing ungulates. Wildlife Society Bulletin 32:1305-1308.

Krausman, P. R. 1999. Some basic principles of habitat use. Grazing Behavior of Livestock and Wildlife 70:85-90.

Krausman P. R. and R. T. Bowyer. 2003. Mountain sheep (*Ovis canadensis* and *O. dalli*). In: Feldhamer GA, Thompson BC, Chapman JA, editors. Wild mammals of North America: biology, management, and conservation. 2nd Ed. Johns Hopkins University press, Baltimore, Maryland, pp. 1095-1115.

Lehman, C. P., T. M. Gingery, K. D. Kaskie, and D. W. Uresk. 2017. Characterizing bighorn sheep foraging sites using the modified Robel pole in the southern Black Hills of South Dakota. In Press.

Manly, B. F. J., L. L. McDonald, D. L. Thomas, T. L. McDonald, and W. P. Erickson. 2002. Resource selection by animals: statistical design and analysis for field studies. Second edition. Kluwer Academic Publishers, Dordrecht, The Netherlands.

Mcintosh, A. C. 1949. A botanical survey of the Black Hills of South Dakota. Black Hills Engineer 28:1-74.

Miller, G. D., and W. S. Gaud. 1989. Composition and variability of desert bighorn sheep diets. The Journal of Wildlife Management 53:597-606

National Land Cover Database. 2011. https://www.mrlc.gov/nlcd2011.php. Accessed January 2017.

National Oceanic and Atmospheric Administration. 2017. Data Tools: 2010 Normals. <www.ncdc.noaa.gov>. Accessed 10 January 2017.

Natural Resources Canada. 2017. http://geogratis.gc.ca/site/eng/extraction. Accessed May 2017.

Nielson, R.M., H. Sawyer, and T.L. McDonald. 2013. BBMM: Brownian bridge movement models. http://CRAN.R-project.org/package=BBMM. Accessed January 2017.

Orr, H. K. 1959. Precipitation and streamflow in the Black Hills. USDA Research Station Paper 44. Rocky Mountain Forest and Range Experiment Station, Fort Collins, Colorado. 25pp.

Owen-Smith, N. 2003. Foraging behavior, habitat suitability, and translocation success, with special reference to large mammalian herbivores pp 93-109 in Animal behavior and wildlife conservation. M. Festa-Bianchet and M. Apollonio, editors. Island Press, Washington, D.C., USA. 380 pp.

Parr, B. L., J. Kanta, J. Sandrini, D. J. Thompson, and J. A. Jenks. 2014. Bobcat predation on bighorn lamb in the western Black Hills of South Dakota. The Prairie Naturalist 46:41-43.

Parr, B. L. 2015. Population parameters of a bighorn sheep herd inhabiting the Elk Mountain region of South Dakota and Wyoming. M.S. Thesis, South Dakota State University, Brookings. 148pp.

Richardson, A.H., and L. E. Peterson. 1974. History and Management of South Dakota Deer. South Dakota Department of Game, Fish and Parks Public Bulletin No. 5. Pierre, South Dakota. 113pp.

Robel, R. J., J. N. Briggs, A. D. Dayton, and L. C. Hulbert. 1970. Relationships between visual obstruction measurements and weight of grassland vegetation. Journal of Range Management 23:295-297.

Rominger, E. M., A. R. Dale, and J. A. Bailey. 1988. Shrubs in the summer diet of Rocky Mountain bighorn sheep. The Journal of Wildlife Management 52:47-50.

Schroeder, C., T. R. Bowyer, V. Bleich, and T. Stephenson. 2010. Sexual segregation in Sierra Nevada bighorn sheep, *Ovis canadensis sierrae*: ramifications for conservation. Arctic, Antarctic, and Alpine Research. 42:4760-489.

Seton, E. T. 1929. Lives of game animals. Doubleday, Doran and Co., Inc., New York Volume 4:441-501.

Simmons, L. 1982. Photo series for quantifying forest residues in the Black Hills: Ponderosa pine type-spruce type. U.S. Forest Service, Rocky Mountain Region, Fort Collins, Colorado, USA.

Singer, F. J., C. M. Papouchis, and K. K. Symonds. 2000. Translocations as a tool for restoring populations of bighorn sheep. Restoration Ecology 8:6-13.

South Dakota Department of Game, Fish and Parks. 2013. Action Plan for Management of Bighorn Sheep in South Dakota. Available: http://gfp.sd.gov/wildlife/management/plans. Accessed 27 February 2017.

Stelfox, J. G. 1976. Range ecology of Rocky Mountain bighorn sheep. Canadian Wildlife Service Report Series Number 39.

Stumpf, K. A. 1993. The estimation of forest vegetation cover descriptions using a vertical densitometer. Joint Inventory and Biometrics Working Groups Session, Indianapolis, Indiana, USA.

Thilenius, J. F. 1972. Classification of deer habitat in the ponderosa pine forest of the Black Hills, South Dakota. USDA Forest Service Research Paper RM-91. Fort Collins, Colorado. 28pp.

Uresk, D. W., and T. A. Benzon. 2007. Monitoring with a modified Robel pole on meadows in the central Black Hills of South Dakota. Western North American Naturalist. 67:46-50.

Uresk, D. W., D. E. Mergen, and T. A. Benzon. 2009. Monitoring meadows with a modified Robel pole in the northern Black Hills, South Dakota. The Prairie Naturalist 41:121-125.

Valdez, R., and P. R. Krausman. 1999. Mountain Sheep of North America. University of Arizona Press, Tucson, AZ. 353 pp.

Wagner, G. D., and J. M. Peek. 2006. Bighorn sheep diet selection and forage quality in central Idaho. Northwest Science 80:246.

Walter, W. D., J. W. Fischer, T. J. Frink, S. E. Hygnstrom, J. A. Jenks, and K. C. VerCeauteren. 2013. Topographic home range of large mammals: is planimetric home range still a viable method? The Prairie Naturalist 45:21-27.

Wikeem, B. M., and M. D. Pitt. 1992. Diet of California bighorn sheep, *Ovis canadensis californiana*, in British Columbia: assessing optimal foraging habitat. Canadian Field-Naturalist 106:327-335.

Wilckens, D. 2014. Ecology of mountain lions (*Puma concolor*) in the North Dakota Badlands: population dynamics and prey use. Thesis, South Dakota State University, Brookings, South Dakota. 92 p.

Witte, S. S., and M. V. Gallagher. 2012. The North American Journals of Prince Maximilian of Wied. University of Oklahoma Press, Norman, Oklahoma, USA. Volume 3, September 1833-August 1834.

Zimmerman, T. J. 2008. Evaluation of an augmentation of Rocky Mountain bighorn sheep at Badlands National Park, South Dakota. Ph.D. Dissertation, South Dakota State University, Brookings. 139pp.

Figure 1. The translocated Deadwood bighorn sheep study area, located in the northern Black Hills of South Dakota, USA.

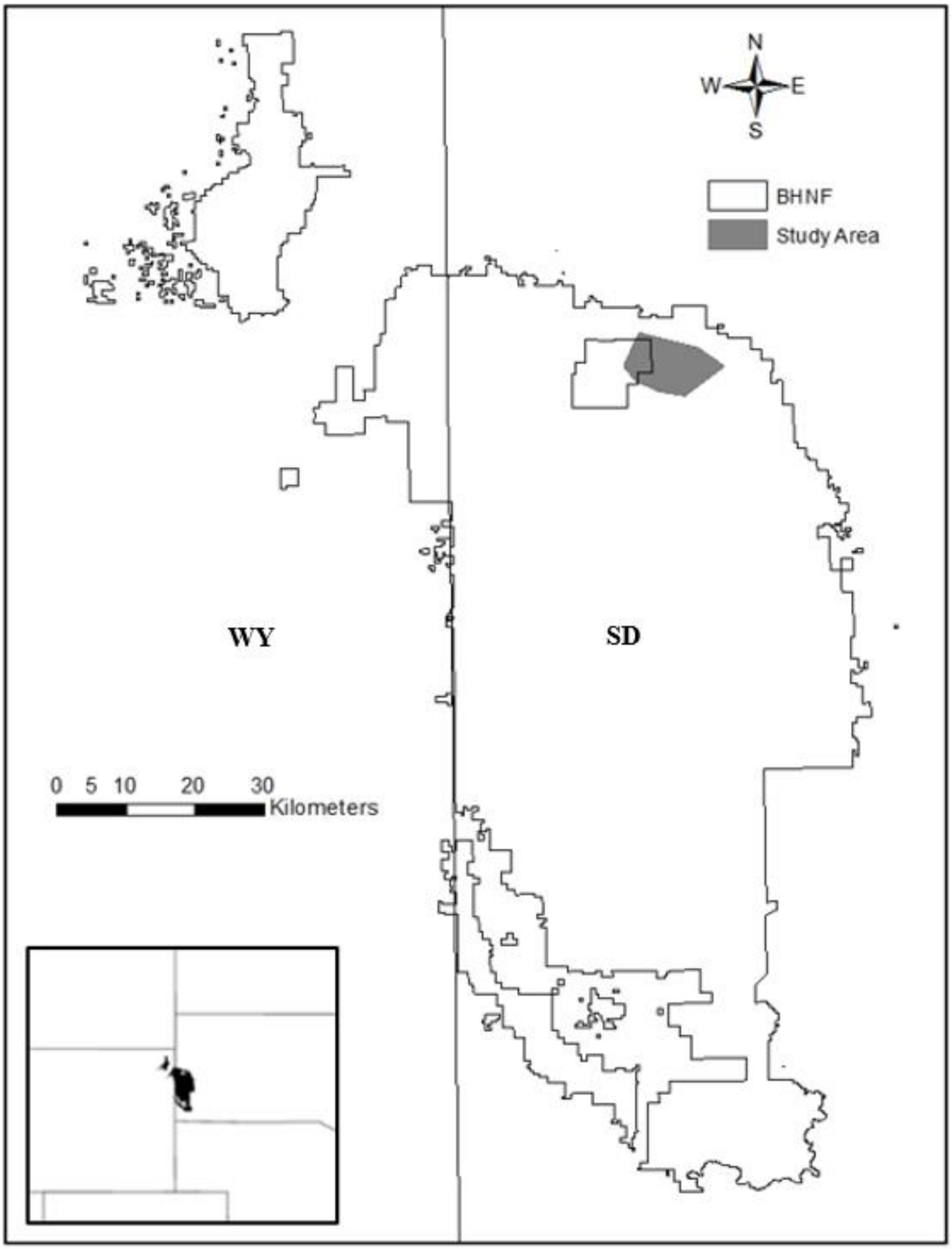


Figure 2. Regression relationship between Visual Obstruction Reading (VOR) bands and herbaceous biomass (kg•ha^{-1}). Transects with >30% understory shrub coverage, based on understory cover estimates, were removed resulting in *n*=78 transects in regression.

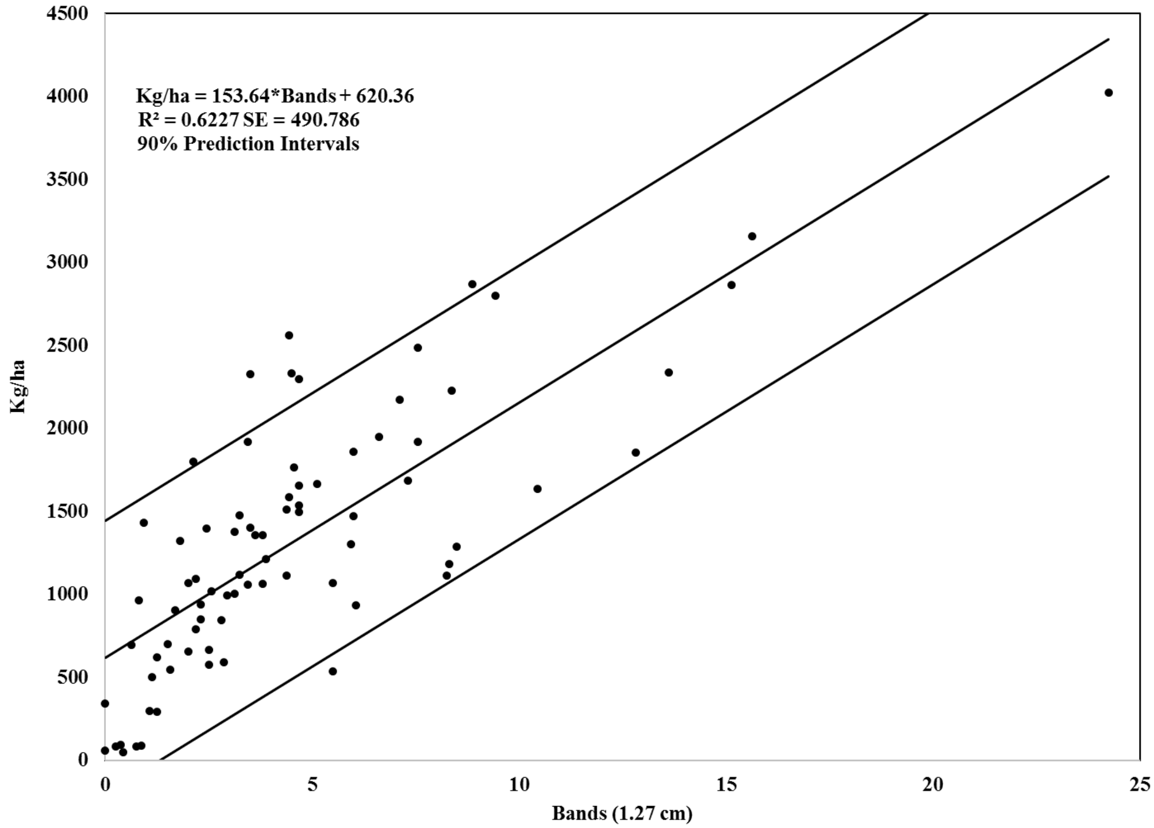
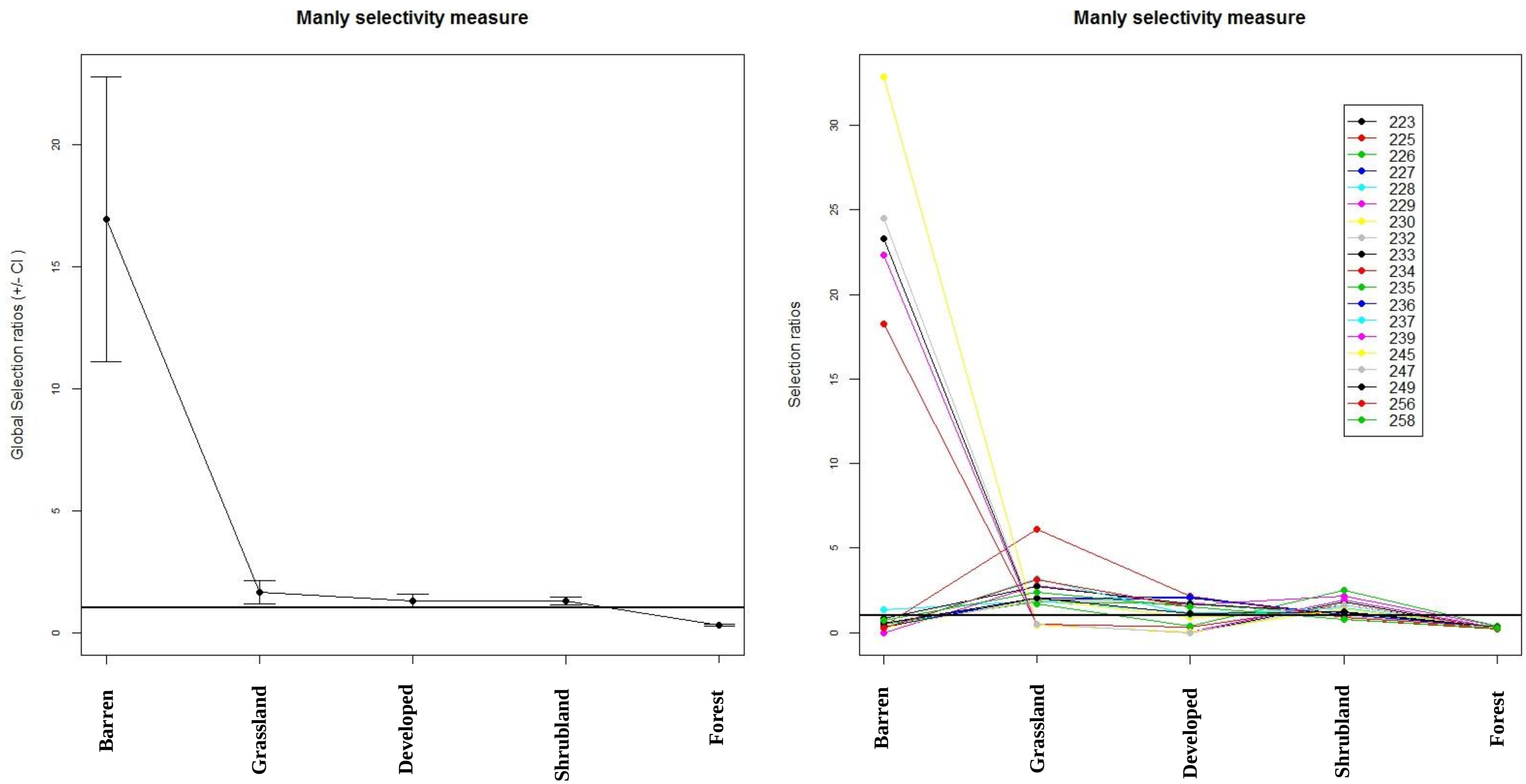
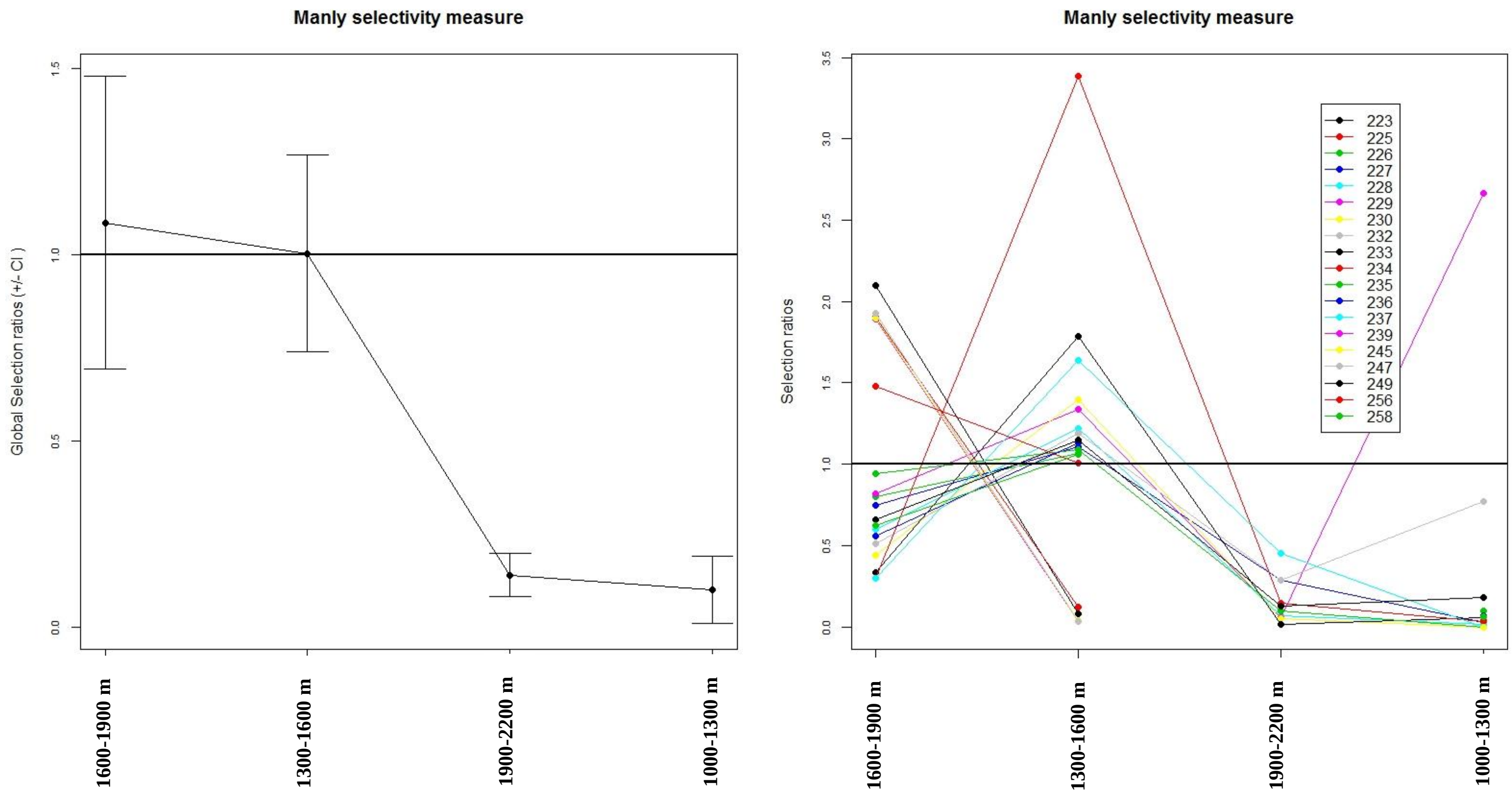


Figure 3. Habitat resource selection ratios during February 2015-January 2017 using design III (Manly et al. 2002) for overall herd and individual adult bighorn sheep (*n*=19) in the Deadwood region of the Black Hills of South Dakota.



*Colored points and vectors denote individual bighorn sheep identification numbers expressed in legend.

Figure 4. Elevation selection ratios during February 2015-January 2017 using design III (Manly et al. 2002) for overall herd and individual adult bighorn sheep (*n*=19) in the Deadwood region of the Black Hills of South Dakota.



*Colored points and vectors denote individual bighorn sheep identification numbers expressed in legend.

Figure 5. Slope selection ratios during February 2015-January 2017 using design III (Manly et al. 2002) for bighorn sheep herd (*n*=19) in the Deadwood region of the Black Hills of South Dakota. Individual bighorn sheep selection could not be graphed due to infinite selection ratio values.

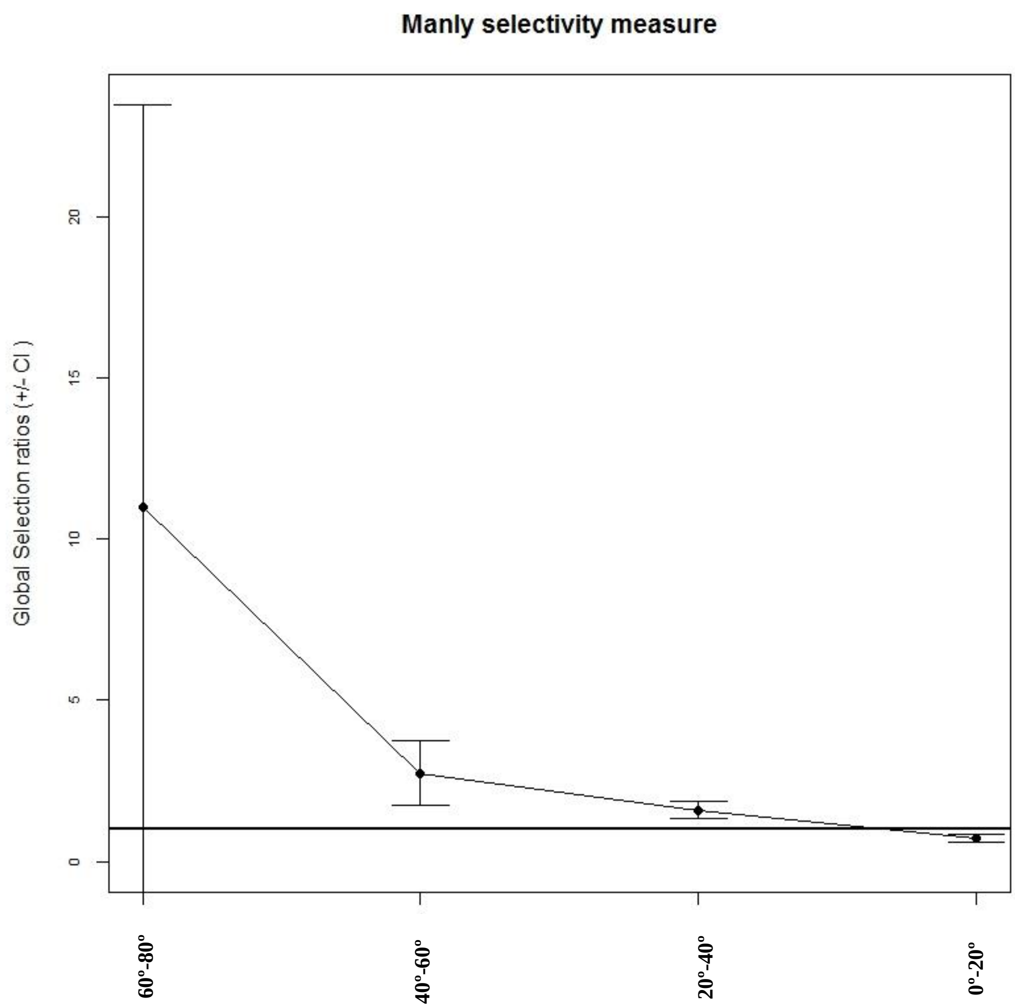


Table 1. Visual obstruction categories resulting from cluster analysis for short, intermediate, and tall bands (1.27 cm, 0.5 in) on a modified Robel pole with corresponding standing herbage (kg•ha^{-1}). Band represents Visual Obstruction Reading (VOR).

Category		Minimum	Mean	Maximum
Short (*n*=20)[a]	Band	0.87	1.43	2.56
	kg/ha[b]	302.07	413.25	816.78
Intermediate (*n*=34)	Band	2.57	3.73	5.27
	kg/ha	816.79	1185.63	1643.89
Tall (*n*=24)	Band	5.28	8.24	10.26
	kg/ha	1643.90	2256.54	2487.43

[a]Number of transects

[b]Kg/ha based on band-weight regression equation

Table 2. Characteristics of summer foraging sites for translocated bighorn sheep in the Deadwood region of the Black Hills, South Dakota, 2015-2017.

Variable	Mean	SE
Tree canopy cover (%)	8.41	1.85
Total understory cover (%)*	45.85	0.55
Understory grass cover (%)*	29.96	0.55
Understory forb cover (%)*	7.91	0.29
Understory shrub cover (%)*	4.21	0.30
Distance to escape terrain (m)	24.00	3.21
Slope (degrees)	14.61	0.94
Woody debris (kg/ha)	0.25	0.07
Herbaceous biomass (kg/ha)	1367.98	67.68
Visual obstruction readings (1.27 cm bands)	4.64	0.11

*Cover Classes (Percentages calculated using midpoint values):

1 = 0-5% midpoint of range 2.5%

2 = >5-25% midpoint of range 15%

3 = >25-50% midpoint of range 37.5%

4 = >50-75% midpoint of range 62.5%

5 = >75-95% midpoint of range 85%

6 = >95-100% midpoint of range 97.5%

Table 3. Resource availability and use encompassed by 99% Dynamic Brownian Bridge Movement Models for bighorn sheep (*n*=19) in the Deadwood region of the Black Hills of South Dakota, 2015-2017.

Habitat	Availability (%)	Use (%)
Developed*	4.06	5.29
Barren*	0.97	16.49
Forest*	55.59	16.57
Shrubland*	8.96	11.47
Grassland*	30.42	50.17

*Description of habitat classes from NLCD 2011.

***Developed** includes:
Developed, Open Space- areas with a mixture of some constructed materials, but mostly vegetation in the form of lawn grasses. Impervious surfaces account for less than 20% of total cover. These areas most commonly include large-lot single-family housing units, parks, golf courses, and vegetation planted in developed settings for recreation, erosion control, or aesthetic purposes.
Developed, Low Intensity- areas with a mixture of constructed materials and vegetation. Impervious surfaces account for 20% to 49% percent of total cover. These areas most commonly include single-family housing units.
Developed, Medium Intensity -areas with a mixture of constructed materials and vegetation. Impervious surfaces account for 50% to 79% of the total cover. These areas most commonly include single-family housing units.
Developed High Intensity-highly developed areas where people reside or work in high numbers. Examples include apartment complexes, row houses and commercial/industrial. Impervious surfaces account for 80% to 100% of the total cover.
Pasture/Hay-areas of grasses, legumes, or grass-legume mixtures planted for livestock grazing or the production of seed or hay crops, typically on a perennial cycle. Pasture/hay vegetation accounts for greater than 20% of total vegetation.
Cultivated Crops -areas used for the production of annual crops, such as corn, soybeans, vegetables, tobacco, and cotton, and also perennial woody crops such as orchards and vineyards. Crop vegetation accounts for greater than 20% of total vegetation. This class also includes all land being actively tilled.

***Barren** includes:
Barren Land (Rock/Sand/Clay) - areas of bedrock, desert pavement, scarps, talus, slides, volcanic material, glacial debris, sand dunes, strip mines, gravel pits and other accumulations of earthen material. Generally, vegetation accounts for less than 15% of total cover.

***Forest** includes:
Deciduous Forest- areas dominated by trees generally greater than 5 meters tall, and greater than 20% of total vegetation cover. More than 75% of the tree species shed foliage simultaneously in response to seasonal change.
Evergreen Forest- areas dominated by trees generally greater than 5 meters tall, and greater than 20% of total vegetation cover. More than 75% of the tree species maintain their leaves all year. Canopy is never without green foliage.
Mixed Forest- areas dominated by trees generally greater than 5 meters tall, and greater than 20% of total vegetation cover. Neither deciduous nor evergreen species are greater than 75% of total tree cover.

***Shrubland** includes:
Shrub/Scrub- areas dominated by shrubs; less than 5 meters tall with shrub canopy typically greater than 20% of total vegetation. This class includes true shrubs, young trees in an early successional stage or trees stunted from environmental conditions.

***Grassland** includes:
Grassland/Herbaceous- areas dominated by gramanoid or herbaceous vegetation, generally greater than 80% of total vegetation. These areas are not subject to intensive management such as tilling, but can be utilized for grazing.

Table 4. Manly's selection ratios for design III analysis on habitat types for bighorn sheep in the Deadwood region of the Black Hills of South Dakota, 2015-2017.

Habitat	$\hat{w}$	SE	90% Lower CI	90% Upper CI
Developed*	1.30	0.13	0.10	1.61
Barren*	16.93	2.84	10.33	23.54
Forest*	0.30	0.01	0.27	0.33
Shrubland*	1.28	0.08	1.10	1.46
Grassland*	1.65	0.24	1.10	2.20

*Description of habitat classes described in Table 3.

Table 5. Manly's selection ratios for design III analysis on elevation for bighorn sheep in the Deadwood region of the Black Hills of South Dakota, 2015-2017.

Elevation (m)	$\hat{w}$	SE	90% Lower CI	90% Upper CI
1000-1300	0.10	0.05	-0.003	0.20
1300-1600	1.00	0.13	0.70	1.30
1600-1900	1.09	0.20	0.64	1.54
1900-2200	0.14	0.03	0.07	0.21

Table 6. Manly's selection ratios for design III analysis on slope for bighorn sheep in the Deadwood region of the Black Hills of South Dakota, 2015-2017.

Slope (degrees)	$\hat{w}$	SE	90% Lower CI	90% Upper CI
0-20	0.72	0.06	0.58	0.86
20-40	1.60	0.14	1.28	1.91
40-60	2.73	0.51	1.58	3.89
60-80	11.00	6.35	-3.24	25.24

LITERATURE CITED

Ball, G. H., and D. J. Hall. 1967. A clustering technique for summarizing multivariate data. Behavioral Science. 12:153-155.

Beecham, J. J., C. P. Collins, and T. D. Reynolds. 2007. Rocky Mountain bighorn sheep (*Ovis canadensis*): A Technical Conservation Assessment. http://www.fs.fed.us/r2/projects/scp/assessments/rockymountainbighornsheep.pdf (accessed 2/27/2017).

Benkobi, L., D. W. Uresk, G. Schenbeck, and R. M. King. 2000. Protocol for monitoring standing crop in grasslands using visual obstruction. Journal of Range Management 53:627-633.

Berger, J. 1990. Persistence of different-sized populations: an empirical assessment of rapid extinctions in bighorn sheep. Conservation Biology 4:91-98.

Besser, T. E., M. Highland, K. Baker, E. F. Cassirer, N. J. Anderson, J. M. Ramsey, K. Mansfield, D. L. Bruning, P. Wolff, J.B. Smith, and J. A. Jenks. 2012. A comparative study of the etiology of eight epizootics of bronchopneumonia affecting free-ranging bighorn sheep. Emerging Infectious Diseases 18:406-414.

Blaisdell, J. A. 1972. Progress report—lava beds bighorn re-establishment. In: Desert Bighorn Council 1972 Transactions, Desert Bighorn Council, Tucson, Arizona. 5-7 April, C. Hansen, Las Vegas, Nevada, pp. 84-87.

Bleich, V. C., J. D. Wehausen, R. R. Ramey II, and J. L. Rechel. 1996. Metapopulation theory and mountain sheep: implication for conservation. Pages 353–373 in D. R. McCullough, editor. Metapopulations and Wildlife Conservation. Island Press, Washington, D.C.

Bleich, V. C, R. T. Bowyer, and J. D. Weyhausen. 1997. Sexual segregation in mountain sheep: resources or predation? Wildlife Monographs 134:1-50.

Buechner, H. K. 1960. The bighorn sheep in the United States, its past, present, and future. Wildlife Monographs 4:3-174.

Burt, W.H. 1943. Territoriality and home range concepts as applied to mammals. Journal of Mammalogy 24:346-352.

Calenge, C. 2006. The package “adehabitat” for R software: A tool for the analysis of space and habitat use by animals. Ecological Modelling 197:516-519.

Cassirer, E. F., and A. R. E. Sinclair. 2007. Dynamics of pneumonia in a bighorn sheep metapopulation. Journal of Wildlife Management 71: 1080-1088.

Cassirer, E. F., and A. R. E. Sinclair. 2010. Dynamics of pneumonia in a bighorn sheep metapopulation. Journal of Wildlife Management 71:1080-1088.

Chapman, J. A., and G. A. Feldhamer. 1982. Wild mammals of North America: biology, management, and economics. Johns Hopkins University Press.

Cochran, W.G. 1977. Sampling techniques, 3rd ed. John Wiley and Sons, New York 428 pp.

Coggins VL. 2002. Rocky Mountain bighorn sheep/domestic sheep and domestic goat interactions: a management prospective. In: Proceedings of the thirteenth biennial symposium of the Northern Wild Sheep and Goat Council, Northern Wild Sheep and Goat Council, Rapid City, South Dakota. 23-27 April, G. Brundige, Cody, Wyoming, pp. 165-174.

Cougar Management Guidelines Working Group. 2005. Cougar Management Guidelines 1st Edition. Wild Futures, Bainbridge Island, Washington, USA.

Daubenmire, R. 1959. A canopy-coverage method of vegetational analysis. Northwest Science 33:43-64.

DeCesare, N. J., and D. H. Pletscher. 2006. Movements, connectivity, and resource selection of Rocky Mountain bighorn sheep. Journal of Mammalogy 87:531-538.

Dekker, D. 2009. Declines of bighorn sheep, *Ovis canadensis*, on deteriorating winter range in Jasper national park, Alberta, 1981-2010. Canadian Field-Naturalist 123:157-164.

del Moral, R. 1975. Vegetation clustering by means of ISO DATA: revision by multiple discriminant analysis. Vegetation. 39:179-190.

Douglas, C. L., and D. M. Leslie, Jr. 1999. Management of bighorn sheep. Pages 238-262 in R. Valdez and P. R. Krausman, editors. Mountain sheep of North America. The University of Arizona Press, Tucson, Arizona, USA.

Festa-Bianchet, M. 1988. Seasonal range selection in bighorn sheep: conflicts between forage quality, forage quantity, and predator avoidance. Oecologia 75:580-586.

Foreyt, W. J. and D. A. Jessup. 1982. Fatal pneumonia of bighorn sheep following association with domestic sheep. Journal of Wildlife Diseases 18:163-168.

Forety, W. J. 1990. Pneumonia in bighorn sheep: effects of *Pasteurella haemolytica* from domestic sheep: effects on survival and long-term reproduction. Biennial Symposium of the North American Wild Sheep and Goat Council 7:92-101.

Geist V. 1966. Validity of horn segment counts in aging bighorn sheep. Journal of Wildlife Management 30:634-635.

Geist, V. 1971. Mountain sheep: a study in behavior and evolution. University of Chicago Press, Chicago, Illinois, USA.

George, J. L., D. J. Martin, P. M. Lukacs, and M.W. Miller. 2008. Epidemic *Pasteurellosis* in a bighorn sheep population coinciding with the appearance of a domestic sheep. Journal of Wildlife Disease 44:388-403.

Getz, W. M., and C. C. Wilmers. 2004. A local nearest-neighbor convex-hull construction of home ranges and utilization distributions. Ecography 27:489-505.

Gogan, P. J. P. 1990. Considerations in the reintroduction of native mammalian species to restore natural ecosystems. Natural Areas Journal 10:210–217.

Hedrick, P. W. 2014. Conservation genetics and the persistence and translocation of small populations: bighorn sheep populations as examples. Animal Conservation 17:106-114.

Hefnawy, A. E. G., and J. L. Tórtora-Pérez. 2010. The importance of selenium and the effects of its deficiency in animal health. Small Ruminant Research 89:185-192.

Hemming, J. E. 1969. Cemental deposition, tooth succession, and horn development as criteria of age in dall sheep. Journal of Wildlife Management 33:552-558.

Hobbs, N. T., and T. A. Hanley. 1990. Habitat evaluation: Do use/availability data reflect carrying capacity? Journal of Wildlife Management 54:515-522.

Hoffman, G. R., and R. R. Alexander. 1987. Forest vegetation of the Black Hills National Forest of South Dakota and Wyoming: a habitat type classification. USDA Research Paper RM-276. Rocky Mountain Forest and Range Experiment Station, Fort Collins, Colorado. 48pp.

Horne, J. E., E. O. Garton, S. M. Krone, and J. S. Lewis. 2007. Analyzing animal movements using Brownian bridges. Ecology 88:2354-2363.

Jacques, C. N., J. A. Jenks, C. S. Deperno, J. D. Sievers, T. W. Grovenburg, T. J.

Brinkman, C. C. Swanson, and B. A. Stillings. 2009. Evaluating ungulate mortality associated with helicopter net-gun captures in the northern Great Plains. Journal of Wildlife Management 73:1282–1291.

Jedrzejewski, W., and J. F. Kamler. 2004. Modified drop-net for capturing ungulates. Wildlife Society Bulletin 32:1305-1308.

Jenks, J. A. 2018. Mountain lions of the Black Hills; history and ecology. Johns Hopkins University Press, Baltimore.

Jorgenson, J. T., M. Festa-Bianchet, J. M. Gaillard, and W. D. Wishart. 1997. Effects of age, sex, disease, and density on survival of bighorn sheep. Ecology 78:1019-1032.

Kamler J. F., R. M. Lee, J. C. Devos, W. B. Ballard, and H. A. Whitlaw. 2002. Survival and cougar predation of translocated bighorn sheep in Arizona. Journal of Wildlife Management 66: 1267-1272.

Kie, J. G., J. Matthiopoulos, J. Fieberg, R.A. Powell, F. Cagnacci, M.S. Mitchell, J.M. Gaillard, and P.R. Moorcroft. 2010. The home-range concept: are traditional estimators still relevant with modern telemetry technology? Philosophical Transactions of the Royal Society B 365:2221-2231.

Kissell, R. E. 1996. Competitive interactions among bighorn sheep, feral horses and mule deer in Bighorn Canyon National Recreation Area. Ph. D. Dissertation. Montana State University, Bozeman, MT.

Krausman, P. R., B. D. Leopold, R. F. Seegmiller, and S.G. Torres. 1989. Relationships between desert bighorn sheep and habitat in western Arizona. Wildlife Monograph 102:1–66.

Krausman, P. R. 1999. Some basic principles of habitat use. Grazing Behavior of Livestock and Wildlife 70:85-90.

Krausman P. R. and R. T. Bowyer. 2003. Mountain sheep (*Ovis canadensis* and *O. dalli*). In:Feldhamer GA, Thompson BC, Chapman JA, editors. Wild mammals of North America: biology, management, and conservation. 2nd Ed. Johns Hopkins University press, Baltimore, Maryland, pp. 1095-1115.

Lehman, C. P., T. M. Gingery, K. D. Kaskie, and D. W. Uresk. 2017. Characterizing bighorn sheep foraging sites using the modified Robel pole in the southern Black Hills of South Dakota. In Press.

Leslie, D. M., and C. L. Douglas. 1979. Desert bighorn sheep of the river mountains, Nevada. Wildlife Monograph 66: 1-56.

Manly, B. F. J., L. L. McDonald, D. L. Thomas, T. L. McDonald, and W. P. Erickson. 2002. Resource selection by animals: statistical design and analysis for field studies. Second edition. Kluwer Academic Publishers, Dordrecht, The Netherlands.

Mcintosh, A. C. 1949. A botanical survey of the Black Hills of South Dakota. Black Hills Engineer 28:1-74.

McKinney, T., T. W. Smith, and J. C. deVos, Jr. 2006. Evaluation of factors potentially influencing a desert bighorn sheep population. Wildlife Monographs 164:1-36.

Miller, G. D., and W. S. Gaud. 1989. Composition and variability of desert bighorn sheep diets. The Journal of Wildlife Management 53:597-606.

National Land Cover Database. 2011. https://www.mrlc.gov/nlcd2011.php. Accessed January 2017.

National Oceanic and Atmospheric Administration. 2017. Data Tools: 2010 Normals. <www.ncdc.noaa.gov>. Accessed 10 January 2017.

Natural Resources Canada. 2017. http://geogratis.gc.ca/site/eng/extraction. Accessed May 2017.

Nielson, R.M., H. Sawyer, and T. L. McDonald. 2013. BBMM: Brownian bridge movement models. http://CRAN.R-project.org/package=BBMM. Accessed January 2017.

Onderka, D. K., and W. D. Wishart. 1984. A major bighorn sheep dieoff from pneumonia in southern Alberta. Biennial Symposium of the North American Wild Sheep and Goat Council 4:356-363.

Onderka D. K., S. A. Rawluk, and W.D. Wishart. 1988. Susceptibility of Rocky Mountain bighorn sheep and domestic sheep to pneumonia induced by bighorn and domestic livestock strains of Pasteurella haemolytica. Canadian Journal of Veterinary Research 52:439-444.

Owen-Smith, N. 2003. Foraging behavior, habitat suitability, and translocation success, with special reference to large mammalian herbivores pp 93-109 in Animal behavior and wildlife conservation. M. Festa-Bianchet and M. Apollonio, editors. Island Press, Washington, D.C., USA. 380 pp.

Orr, H. K. 1959. Precipitation and streamflow in the Black Hills. USDA Station Paper 44. Rocky Mountain Forest and Range Experiment Station, Fort Collins, Colorado. 25pp.

Parr, B. L., J. Kanta, J. Sandrini, D. J. Thompson, and J. A. Jenks. 2014. Bobcat predation on bighorn lamb in the western Black Hills of South Dakota. The Prairie Naturalist 46:41-43.

Parr, B. L. 2015. Population parameters of a bighorn sheep herd inhabiting the Elk Mountain region of South Dakota and Wyoming. M.S. Thesis, South Dakota State University, Brookings. 148pp.

Plowright, R. K., K. Manlove, E. F. Cassirer, P. C. Cross, T. E. Besser, and P. J. Hudson. 2013. Use of exposure history to identify patterns of immunity to pneumonia in bighorn sheep (*Ovis canadensis*). Plos ONE 8: e61919.

Puls, R. 1994. Mineral levels in animal health. Diagnostic data. Sherpa International. British Columbia, Canada.

Richardson, A. H., and L. E. Peterson. 1974. History and management of South Dakota deer. South Dakota Department of Game, Fish and Parks Public Bulletin No. 5. Pierre, South Dakota. 113pp.

Robel, R. J., J. N. Briggs, A. D. Dayton, and L. C. Hulbert. 1970. Relationships between visual obstruction measurements and weight of grassland vegetation. Journal of Range Management 23:295-297.

Rodgers, A. R., A. P. Carr, L. Smith, and J. G. Kie. 2005. HRT: Home-range tools for ArcGIS. Ontario Ministry of Natural Resources, Centre for Northern Forest Ecosystem Research, Thunder Bay, Ontario, Canada, Roy, J. L., and L. R. Irby. 1994. Augmentation of a bighorn sheep herd in southwest Montana. Wildlife Society Bulletin 22:470–478.

Rominger, E. M., A. R. Dale, and J. A. Bailey. 1988. Shrubs in the summer diet of Rocky Mountain bighorn sheep. The Journal of Wildlife Management 52:47-50.

Rominger, E. M., H. A. Whitlaw, D. L. Weybright, W. C. Dunn, and W. Ballard. 2004. The influence of mountain lion predation on bighorn sheep translocations. Journal of Wildlife Management 68:993-999.

Rosenfeld, I. and O.A. Beath. 1964. Selenium geobotany, biochemistry, toxicity and nutrition. Academic Press, New York, USA.

Sawyer, H., M. J. Kauffman, R. M. Nielson, and J. S. Horne. 2009. Identifying and prioritizing ungulate migration routes for landscape-level conservation. Ecology Applications 19:2016-2025.

Schroeder, C., T. R. Bowyer, V. Bleich, and T. Stephenson. 2010. Sexual segregation in Sierra Nevada bighorn sheep, *Ovis canadensis sierrae*: ramifications for conservation. Arctic, Antarctic, and Alpine Research. 42:4760-489.

Schuler, K.L., G.M. Schroeder, J.A. Jenks, and J.G. Kie. 2014. Ad hoc smoothing parameter performance in kernel estimates of GPS-derived home ranges. Wildlife Biology 20:259-266.

Seegmiller, R. F., and R. D. Ohmart. 1981. Ecological relationships of feral burros and desert bighorn sheep. Wildlife Monograph 78:1-58.

Seton, E. T. 1929. Lives of game animals. Doubleday, Doran and Co., Inc., New York Volume 4:441-501.

Simmons, L. 1982. Photo series for quantifying forest residues in the Black Hills: Ponderosa pine type-spruce type. U.S. Forest Service, Rocky Mountain Region, Fort Collins, Colorado, USA.

Singer, F. J., C. M. Papouchis, and K. K. Symonds. 2000. Translocations as a tool for restoring populations of bighorn sheep. Restoration Ecology 8:6-13.

Singer, F. J., E. Williams, M. W. Miller, L. C. Zeigenfuss. 2000. Population growth, fecundity, and survivorship in recovering populations of bighorn sheep. Restoration Ecology 8:75-84.

Smith, D. R. 1954. The bighorn sheep in Idaho: its status, life history, and management. Idaho Department of Fish and Game Wildlife Bulletin Number 1, Boise, Idaho, 154 pp.

Smith, J. B., J. A. Jenks, T. W. Grovenburg, and R. W. Klaver. 2014. Disease and predation: sorting out causes of a bighorn sheep (*Ovis canadensis*) decline. Plos ONE 9: e88271.

Smith, J. B., T. W. Grovenburg, K. L. Monteith, and J. A. Jenks. 2015. Survival of female bighorn sheep (*Ovis canadensis*) in the Black Hills, South Dakota. The American Midland Naturalist 174:290-301.

South Dakota Department of Game, Fish and Parks. 2013. Action Plan for Management of bighorn sheep in South Dakota. Available: http://gfp.sd.gov/wildlife/management/plans. Accessed 27 February 2017.

Stelfox, J. G. 1976. Range ecology of Rocky Mountain bighorn sheep. Canadian Wildlife Service Report Series Number 39.

Stumpf, K. A. 1993. The estimation of forest vegetation cover descriptions using a vertical densitometer. Joint Inventory and Biometrics Working Groups Session, Indianapolis, Indiana, USA.

Thilenius, J. F. 1972. Classification of deer habitat in the ponderosa pine forest of the Black Hills, South Dakota. USDA Forest Service Research Paper RM-91. Fort Collins, Colorado. 28pp.

Uresk, D. W., and T. A. Benzon. 2007. Monitoring with a modified Robel pole on meadows in the central Black Hills of South Dakota. Western North American Naturalist. 67:46-50.

Uresk, D. W., D. E. Mergen, and T. A. Benzon. 2009. Monitoring meadows with a modified Robel pole in the northern Black Hills, South Dakota. The Prairie Naturalist 41:121-125.

Valdez, R., and P. R. Krausman. 1999. Mountain Sheep of North America. University of Arizona Press, Tucson, AZ. 353 pp.

Van Vuren, D. 1998. Mammalian dispersal and reserve design. Pages 369-393 in T. Caro, editor. Behavioral ecology and conservation biology. Oxford University Press, New York, USA.

Wagner, G. D., and J. M. Peek. 2006. Bighorn sheep diet selection and forage quality in central Idaho. Northwest Science 80:246.

Walter, W. D., J. W. Fischer, S. Baruch-Mordo, and K. C. VerCeauteren. 2011. What is the proper method to delineate home range of an animal using today's advanced GPS telemetry systems: the initial step. USDA National Wildlife Research Center. Staff Publications, Paper 1375. 19pp.

Walter, W. D., J. W. Fischer, T. J. Frink, S. E. Hygnstrom, J. A. Jenks, and K. C. VerCeauteren. 2013. Topographic home range of large mammals: is planimetric home range still a viable method? The Prairie Naturalist 45:21-27.

Wehausen J. D., S. T. Kelley, and R.R. Ramey II. 2011. Domestic sheep, bighorn sheep, and respiratory disease: A review of the experimental evidence. California Fish and Game 97:7-24.

Whittaker, D. G., S. D. Ostermann, and W. M. Boyce. 2004. Genetic variability of reintroduced California bighorn sheep in Oregon. Journal of Wildlife Management 68:850-859.

Wikeem, B. M., and M. D. Pitt. 1992. Diet of California bighorn sheep, *Ovis canadensis californiana*, in British Columbia: assessing optimal foraging habitat. Canadian Field-Naturalist 106:327-335.

Wilckens, D. 2014. Ecology of mountain lions *(Puma concolor*) in the North Dakota Badlands: population dynamics and prey use. Thesis, South Dakota State University, Brookings, South Dakota. 92 p.

Wilckens, D. T., J. B. Smith, S. A. Tucker, D. J Thompson, and J. A. Jenks. 2016. Mountain lion (*Puma concolor*) feeding behavior in the recently recolonized Little Missouri Badlands, North Dakota. Journal of Mammalogy 97:373-385.

Witte, S. S., and M. V. Gallagher. 2012. The North American Journals of Prince Maximilian of Wied. University of Oklahoma Press, Norman, Oklahoma, USA. Volume 3, September 1833-August 1834.

Worton, B.J. 1989. Kernel methods for estimating the utilization distribution in homerange studies. Ecology 70:164-168.

Zimmerman, T. J. 2008. Evaluation of an augmentation of Rocky Mountain bighorn sheep at Badlands National Park, South Dakota. Ph.D. Dissertation, South Dakota State University, Brookings. 139pp.