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Space Use, Resource Selection, and Survival of Reintroduced Bighorn Sheep

Rusty Wade Robinson

A dissertation submitted to the faculty of
Brigham Young University
in partial fulfillment of the requirements for the degree of

Doctor of Philosophy

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ABSTRACT

Space Use, Resource Selection, and Survival of Reintroduced Bighorn Sheep

Rusty Wade Robinson
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Master of Science

Successful management of bighorn sheep depends on understanding the mechanisms responsible for population growth or decline, habitat selection, and utilization distribution after translocations. We studied a declining population of desert bighorn sheep in the North San Rafael Swell, Utah to determine birthdates of neonates, demographics, limiting factors, population size, probable cause of death, production, and survival. We documented 19 mortalities attributed to a variety of causes including cougar predation (n = 10, 53%), bluetongue virus (n = 2, 11%), reproductive complications (n = 2, 11%), hunter harvest (n = 1, 5%), and unknown (n = 4, 21%). Annual survival of females was 73% (95% CI = 0.55—0.86) in 2012 and 73% (95% CI = 0.55—0.86) in 2013. Adult male survival was 75% in 2012 (95% CI = 0.38—0.94) and 88% (95% CI = 0.50—0.98) in 2013. Disease testing revealed the presence of pneumonia-related pathogens. The population increased from an estimated 127 in 2012 to 139 in 2013 (λ = 1.09). Lamb:ewe ratios were 47:100 in 2012 and 31:100 in 2013. Mean birthing dates were 21 May in 2012 and 20 May in 2013. Spatial separation from domestic sheep and goats, and aggressive harvest of cougars, may have aided in the recovery of this population after disease events.

Second, we investigated the timing of parturition and nursery habitat of desert bighorn sheep in the North San Rafael Swell to determine the influence of vegetation, topography, and anthropogenic features on resource selection. We monitored 38 radio-tagged ewes to establish birthing dates. We documented birthdates of 45 lambs. We used collar-generated GPS locations to perform logistic regression within a model-selection framework to differentiate between nursery and random locations (n = 750 for each) based on a suite of covariates. The top model included elevation, slope, ruggedness, aspect, vegetation type, distance to trails, and distance to roads. We used these variables to create a GIS model of nursery habitat for the North San Rafael (desert bighorns) and the Green River Corridor (Rocky Mountain bighorns). Ewes showed preference for steep, north-facing slopes, rugged terrain, lower elevation, and avoidance of roads. Our model provides managers with a map of high probability nursery areas of desert and Rocky Mountain bighorns to aid in conservation planning and mitigate potential conflicts with industry and domestic livestock.

Finally, we monitored 127 reintroduced female bighorn sheep in three adjacent restored populations to investigate if the size and overlap of habitat use by augmented bighorns differed from resident bighorns. The size of seasonal ranges for residents was generally larger than augmented females. However, there was a shift in utilization distribution in all three populations after augmentation. Overlap indices between resident and augmented sheep varied by source herd. These data will help managers understand the dynamics of home range expansion and the overlap between provenance groups following augmentations.

Keywords: augmentation, bighorn sheep, habitat, home range, model-selection, mortality, nursery habitat, *Ovis canadensis*, reintroduction, resource selection function

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CHAPTER 1

The status and trend of desert bighorn sheep in the North San Rafael Swell

ABSTRACT

Dynamics of bighorn sheep populations are determined by multiple, and often stochastic, factors. Successful management depends on understanding the mechanisms responsible for population growth or decline. We studied a declining population of desert bighorn sheep from January 2012 to January 2014. Objectives were to obtain a disease profile of the population, determine bighorn survival through regular monitoring, determine cause of death and , limiting factors, quantify population size and demographics, and estimate production and survival of neonates, and identify lambing dates. Disease testing revealed the presence of pneumonia-related pathogens including *Mycoplasma ovipneumoniae*, a pathogen thought to be the primary agent associated with pneumonia. We documented 19 mortalities attributed to a variety of causes including cougar predation (n = 10, 53%), bluetongue virus (n = 2, 11%), reproductive complications (n = 2, 11%), hunter harvest (n = 1, 5%), and unknown causes (n = 4, 21%). Annual survival of adult females was 0.73 (95% CI = 0.55—0.86) in 2012 and 0.73 (95% CI = 0.55—0.86) in 2013. Annual survival of adult males was 0.75 in 2012 (95% CI = 0.38—0.94) and 0.88 (95% CI = 0.50—0.98) in 2013. The population increased from an estimated 127 in 2012 to 139 in 2013 (λ = 1.09). Lamb:ewe ratios were 47:100 in 2012 and 31:100 in 2013 with a mean birthing date of 21 May in 2012 and 20 May in 2013. Despite pneumonia-related pathogens, this population is currently on an increasing trend in population size. We recommend management for spatial separation from domestic sheep and goats and aggressive harvest of cougars to continue herd recovery and expansion.

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INTRODUCTION

Desert bighorn sheep *(Ovis canadensis nelsoni)*, although native to the North San Rafael Swell (NSR), were likely extirpated with the last confirmed sighting in 1964 (Dalton and Spillett 1971). The herd was re-established in the 1970s and 1980s with five translocations from Canyonlands National Park, Coal Wash, UT, and the San Juan unit totaling 57 bighorns (Utah Statewide Bighorn Management Plan 2013). An aerial survey in 2001 revealed that the herd had increased to an estimated 543 bighorns. However, subsequent surveys revealed an estimate of only 250 in 2008 and 143 in 2011. Based on these surveys, the population had declined at a mean rate of 11% per year from 2001 to 2011 ($\lambda = 0.89$). Lamb:ewe ratios were lowest in 2007 and 2008 (23:100 and 22:100, respectively). Generally, lamb:ewe ratios < 25:100 in successive years is cause for concern (Douglas and Leslie 1999). Many variables affect neonatal survival; however, low lamb survival is commonly associated with pneumonia epizootics in bighorn populations (Cassirer and Sinclair 2007, Besser et al. 2008). Although disease was suspected in the NSR population, the exact causes for declines were not known.

Dynamics of bighorn sheep populations are determined by multiple, and often stochastic, factors (Cassirer and Sinclair 2007). Successful management depends on understanding the mechanisms responsible for population growth or decline (Krebs 2002). Cougar (*Felis concolor*) predation (Wehausen 1996, Ross et al. 1997, Hayes et al. 2000, Kamler et al. 2002) and disease (Hobbs and Miller 1992, Singer et al. 2000) have been identified as the most common factors limiting native and reintroduced bighorn sheep populations. Cougar predation is especially impactful when bighorn density is low (Bowyer et al. 2014) and individual cougars become specialists at preying upon bighorn sheep (Ross et al. 1997, Ernest et al. 2002, Festa-Bianchet et al. 2006). Additionally, sympatric mule deer or livestock populations can facilitate high rates of

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cougar predation in small populations of bighorn sheep (Kamler et al. 2002, Rominger et al. 2004, Johnson et al. 2013). Bighorn populations that have experienced a disease related die-off, coupled with high rates of predation, have the potential for predation to be a growth-limiting factor.

Disease, especially bacterial pneumonia, has been responsible for numerous declines in bighorn populations throughout North America (Cassirer and Sinclair 2007). Pneumonia outbreaks typically affect all age/sex cohorts and are usually followed by several years of annual pneumonia outbreaks in lambs that dramatically reduce population growth (Spraker et al. 1984, Ryder et al. 1992, George et al. 2008). These events are attributed to the transfer of pathogens from domestic sheep (*Ovis aries*) or goats (*Capra aegagrus hircus*) to wild sheep through social contact (Singer et al. 2000, Monello et al. 2001, Cassirer and Sinclair 2007).

Routine monitoring of a mountain sheep population is critical for identifying and mitigating limiting factors (Douglas and Leslie 1999). Monitoring also provides baseline data to facilitate management decisions. The primary objectives of this study were to: 1) obtain a disease profile on the population, 2) determine bighorn survival through regular monitoring, 3) determine causes of death and population growth limiting factors, and 4) quantify population size and demographics, production and survival of neonates, and identify lambing dates.

STUDY AREA

The NSR unit is located in Emery County, Utah (Figure 1.1; 38°58′N, 110°37′W). The area is characterized by steep canyons in the Wingate Sandstone formation with broad mesa tops in Navajo and Entrada Sandstone formations. Desert bighorn sheep habitat in this area ranges in elevation from 1700-2100 m (~5600-7000 ft.). Vegetation consists of species typical of salt

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desert shrub environments. Common shrubs include blackbrush (*Coleogyne ramossisima*) and fourwing saltbush (*Atriplex canescens*). Pinyon pine (*Pinus edulis*) and juniper (*Juniperis sp.*) are the predominant tree species on mesa tops and on north facing canyon slopes. The NSR is dry with annual precipitation averaging less than 20 cm (7.9 in) per year. Daily high temperatures during the summer months average 31° C (87° F) and often exceed 35° C (95° F). Winters (November to February) were typified with daily low temperatures averaging -12° C (10° F). Native populations of pronghorn (*Antilocapra americana*) and mule deer (*Odocoileus hemionus*) inhabit the study area. Wild burros (*Equus asinus*) and domestic cattle also occupied portions of the NSR. Mammalian predators include mountain lions and coyotes (*Canis latrans*). The NSR study area is predominantly managed by the Bureau of Land Management (BLM). Recreation in the NSR includes on and off-road travel, rock climbing, biking, hiking, camping, and hunting. Peak recreation occurs in spring with influxes of activity near Easter and Memorial Day (W. Paskett, UDWR biologist, personal communication).

METHODS

In January 2012, we captured 30 ewes and eight rams by aerial net gunning (Krausman et al. 1985, Barrett et al. 1982, Webb et al. 2008). Efforts were made to sample a wide distribution of bighorns from across the NSR unit by distributing collars proportionally to aerial count numbers and locations established two months prior. Animals were equipped with GPS/VHF collars with mortality transmitters and pre-programmable drop off mechanisms. We also fitted sheep with numbered ear tags, identifiable through binoculars from a distance (~400 m). Captured bighorns were tested for pathogens associated with pneumonia using polymerase chain reaction (PCR), bacterial culture, and serology. In January 2013, ten additional bighorns (eight

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ewes and two rams) were captured and collared, bringing the total number of bighorns monitored to 48 (38 ewes and 10 rams).

We located and monitored bighorn sheep weekly using radio telemetry equipment, binoculars, and spotting scopes for the span of two years until collars dropped off in January 2014. During bighorn observations, we noted the age/sex cohort of individuals, group size, and composition (Whiting et al. 2010). Yearlings were identified and noted when identifiable. In addition to direct observations on the ground made by researchers, monthly telemetry flights were conducted by fixed wing aircraft to aid in locating animals. Upon detection of a radio collar mortality signal, bighorn carcasses were located and necropsied to identify the cause of death. When feasible, bighorn carcasses were transported whole to the Utah Veterinary Diagnostic Laboratory (Nephi, Utah) for necropsy. When physical extraction of the carcass was not feasible, field necropsies were performed, and tissues of interest (liver, lungs, and head) were sent to the Utah Veterinary Diagnostic Laboratory for analysis.

We determined mortalities caused by cougar predation from typical cougar kill-site characteristics. These include a dragline from kill site to cache site, mountain lion tracks at kill or cache site, mountain lion scat at cache site, canine puncture wounds in neck or face, canine punctures or claw slices in radio collar, rumen extracted and uneaten or buried, carcass partially or completely buried (i.e., rocks, sticks, grass, raked over carcass), broken neck (generally at cervical vertebrae 1, or more rarely 2), rostrum bones eaten back >10 cm, braincase cracked in female sheep (never males), humerus and/or femur cracked, mountain lion hair present at kill or cache site, mountain lion scrapes at or near cache site, hair plucked from carcass, and multiple cache sites (Rominger et al. 2004).

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Helicopter flights were performed in November of 2012, 2013, and 2015 to estimate population size and quantify herd demographics. Lambs, ewes, and rams were counted separately to quantify herd demographics; however, yearling ewes were not counted separately in aerial surveys as in ground surveys but included with adult ewes because of the difficulty of accurate identification from the air.

To estimate parturition dates we relocated collared and uncollared females to record birthdates from 25 April to 25 June during 2012 and 2013. We searched the NSR a mean (± *SD*) of every 2 days ± 1.6 days in 2012, and a mean of every 2 days ± 1.7 days in 2013. We observed the behavior of females before, during, and after parturition; as well as first sighting, motor skills, size, and behavior of neonates (Festa-Bianchet 1988, Whiting et al. 2008, Whiting et al. 2011). To determine birthdates for neonates of uncollared females, we compared their young with neonates of estimated ages of collared females when all females congregated in nursery bands after parturition (Côté and Festa-Bianchet 2001, Whiting et al. 2008, Whiting et al. 2012). When ewe and lamb pairings were questionable, we waited until the lamb nursed in order to identify its mother (Festa-Bianchet 1988). A mean (± *SD*) of 88 (± 3.6) adult females occupied the NSR during our study. We exercised care not to disturb females with young (Sikes et al. 2016).

We estimated birthdates of young, pooled them into sampling intervals and calculated corrected means (timing of births) and *SD* values (synchrony of births) for the NSR population in each year (Johnson et al. 2004, Whiting et al. 2011). This technique allowed robust calculations of unequal sampling intervals (bin sizes) in determining timing and synchrony of births (Johnson et al. 2004). We performed a known fate analysis (White and Burnham 1999) to determine

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annual survival rates by sex and year. Sightability was estimated by the proportion of known collared bighorns observed during aerial surveys.

RESULTS

Disease Testing

Disease testing showed that bacterial strains associated with pneumonic epizootics in bighorn sheep were present in the population (Appendix A; Table A.1). Thirty one percent of bighorns sampled tested positive in PCR for *Mycoplasma ovipneumoniae*, a pathogen suggested to be a primary agent associated with bronchopneumonia in bighorn sheep (Besser et al. 2008, 2012, 2013). Hemolytic, or leukotoxin producing, *Mannheimia haemolytica* was also detected in several samples (n = 5, 14%). Non-hemolytic *Biberseinia trehalosi* was also detected in the population (n = 22, 61%). *Pasturella multocida*, another infectious agent frequently isolated from affected animals during pneumonia outbreaks, was also isolated from this population.

Survival

Annual survival of adult females was 0.73 (95% CI = 0.55—0.86) in 2012 and 0.73 (95% CI = 0.55—0.86) in 2013. Adult male survival was 0.75 in 2012 (95% CI = 0.38—0.94) and 0.88 (95% CI = 0.50—0.98) in 2013. Nineteen mortalities of collared individuals were documented over the space of two years (Table 1.2, Figure 1.2, Figures B.1-B.19.). Ten mortalities (53%) were attributed to cougar predation (Figures B.1-B.4, B.9-B.10, B.13, B.17-B.19). Two mortalities (11%) were attributed to bluetongue virus (Figures B.7, B.11). Two mortalities (11%) were a result of reproductive complications. One bighorn ewe had a ruptured uterus (Figure B.12), and one had dystocia (obstructed birthing; Figure B.14). One mortality (5%) was a hunter

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harvested ram (Figure B.8). Four mortalities (21%) had unknown causes, with predation excluded as a putative cause (Figures B.6, B.15-B.16). One bighorn ewe had tumors on the head and face, possibly sinus tumors (Figure B.5) that likely contributed to mortality. Other mortalities of unmarked individuals opportunistically observed throughout the course of the study included road kill (n = 2), and cougar predation (n = 2). We also observed two capture related mortalities (4% of captured individuals; broken femur/neck injury, puncture wound).

Population Size and Sightability

We found sightability to be 80% (95% CI = 0.66—0.94) in 2012 (largely due to favorable weather conditions with fresh snow cover), and 68% (95% CI = 0.52—0.84) in 2013 (as a result of relatively poor conditions with patchy snow). In a flight conducted in 2011 before collars were deployed, we estimated a population size of 143 using a 60% sightability estimator (Utah Bighorn Management Plan 2013). In 2012 we estimated a population size of 168 total bighorns using 80% sightability (λ = 1.17). In 2013 we counted 94 bighorns with 68% sightability for a population estimate of 139 (λ = 1.09). A flight count was not performed in 2014, but in 2015, after collars had dropped off, we counted 124 individuals. Using a mean sightability estimate from 2012 and 2013 ($\bar{x}$ = 74%) we estimated a population size of 168 (λ = 1.10). Lamb:ewe ratios were 47:100 in 2012, 31:100 in 2013, and 42:100 in 2015. Ram:ewe ratios were 36:100 in 2012, 53:100 in 2013, and 67:100 in 2015 (Table 1.1).

Production and Lambing Dates

In 2012, we estimated birthdates for 29 young. Twenty-three neonates were assigned to collared ewes. Six were from uncollared ewes. Mean (± 2 *SD*s) birthdate for bighorn sheep in the

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NSR during that year was 21 May (± 19 days). In 2013, we estimated birthdates for 16 young (12 from collared ewes, 4 from uncollared ewes), and mean (± 2 *SD*s) birthdate for bighorn sheep in that area during that year was 20 May (± 21 days). The date range we used for our analyses of birth sites and nursery habitat from GPS collar data for 2012 was 2 May to 9 June. Whereas, for 2013 that range of dates for birth sites and nursery habitat was 29 April to 10 June. Backdating the approximate gestation period of desert bighorn sheep of 179 days (Turner and Hansen 1980) puts the peak rut approximately 22-24 November.

Of the collared ewes sampled in 2012, 96% (22 of 23) were observed with a lamb. One was observed noticeably pregnant but was never observed with a lamb, which was presumable lost shortly after parturition. In 2013, 100% were observed with lambs.

DISCUSSION

Mycoplasma spp. have long been associated with bronchopneumonia related die-offs in bighorn sheep (Woolf et al. 1970; Miller et al. 2012). *M. ovipneumoniae*, specifically, is strongly associated with bronchopneumonia in bighorn sheep and is a candidate primary etiologic agent for this respiratory disease (Besser et al. 2008, 2012, 2013). It has also been implicated as a predisposing factor for a secondary fatal infection (Besser et al. 2008, Dassanayake et al. 2010). Typically, the introduction of *M. ovipneumoniae* to a bighorn sheep population results in bacterial pneumonia (Besser et al. 2008, 2012, 2013) and a subsequent die-off event. Thirty one percent of bighorn sheep sampled in the NSR tested positive in PCR for *M. ovipneumoniae*, indicating not just exposure, but that these individuals were actively shedding the pathogen at the time of testing. Typically, exposed individuals that are shedding the pathogen facilitate the exposure of juveniles within the subpopulation or nursery group (Manlove et al. 2014), and

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disease-induced juvenile mortality imposes strong constraints on population growth (Manlove et al. 2016). However, despite the detection of *M. ovipneumoniae* in PCR, lamb survival was uncharacteristically high throughout the study. Furthermore, bighorns were observed coughing only twice in two years, and both of them were lambs.

While bronchopneumonia was not identified as a primary cause of death for any bighorn sheep in this study, it was identified as a secondary cause of death in three mortalities. In these cases, pneumonic symptoms were brought on by other infections identified as the primary cause of mortality (e.g., two bluetongue virus, one ruptured uterus). *M. ovipneumoniae* was isolated from one of these carcasses that were tested. Although, respiratory disease was not identified as a primary cause of death, the presence of *M. ovipneumoniae* in the population, along with the decline in population performance over time, indicates that the population most likely experienced a pneumonia related die-off with subsequent low lamb recruitment (Manlove et al. 2014, 2016).

Sporadic, or continuous, pneumonia episodes can persist in both adults and lambs in interconnected populations for many years, limiting population growth (Cassirer and Sinclair 2007). Therefore, even though pneumonia was not documented as a primary cause of death during this monitoring period, it is present in the population and may be partially responsible for observed declines in recent years (2001—2011). Initial pneumonia related die-offs in bighorn sheep are typically followed by chronic infection in recovered adults but diminished lamb survival, resulting in aging populations of immune adults with limited recruitment (Cassirer and Sinclair 2007, Besser et al. 2008, 2012 2013, Plowright et al. 2013). Observations made of the NSR bighorn herd (2012-2013) support the notion of a population recovering from pneumonia-mediated die-off. Disease-induced mortality rates in bighorn sheep vary substantially by

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population (Manlove et al. 2016). Additionally, variation in mortality rates can be attributable to multiple processes including contact rates and social substructuring (Manlove et al. 2014), pathogen virulence, host susceptibility to pathogen establishment, and factors associated with each individual's unique mucosal immunity and carriage status (Manlove et al. 2016). Notwithstanding, vital rates of the NSR population, including lamb survival, are on the upward trend, indicating that the herd has likely overcome the effects of pneumonia for the time being.

Predation is a cause for concern in the NSR bighorn population, as 53% of all adult mortalities were attributed to cougar kills (13% of the adult population annually). Because this herd experienced declines and diminished lamb survival following a pneumonia event, cougar predation would have represented additive mortality, further limiting population growth. Cougar predation may limit bighorn sheep in locations where predator populations are largely supported by sympatric prey populations (Schaefer et al. 2000, Hayes et al. 2000, Ernest et al. 2002), which, in this case, includes mule deer and domestic cattle. It has been hypothesized that declines in sympatric ungulate populations can increase predation on bighorn sheep as cougars switch to bighorns as an alternate prey source (Kamler et al. 2002, Rominger et al. 2004). Conversely, a relatively high density of mule deer and livestock occupying agricultural land surrounding the study area could be providing a stable food source for cougars, causing cougars to occupy the area and opportunistically prey upon bighorns (Johnson et al. 2013). Mule deer are present in the NSR and may be facilitating the persistence of cougars. However, because the health of bighorn sheep in this population is already compromised, predation losses by cougars may be highlighted to some degree (Cassirer and Sinclair 2007). As lamb recruitment is currently at high ratios, cougar predation is of lesser concern. However, if predation rates remain constant, future pneumonia events will again facilitate the likelihood of a predator pit scenario.

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Regardless of whether predation events in the NSR are proximate or ultimate causes of mortality, predator control programs have been shown to limit the overall amount of bighorn mortality in small, vulnerable populations (Miller et al. 2012). Consequently, the UDWR has taken an aggressive stance with regard to cougars within the NSR. The unit is classified as a harvest objective unit, allowing "over-the-counter" sales of cougar tags. Furthermore, the Utah Foundation for North American Wild Sheep has incentivized cougar harvest by instituting a bounty program on cougars harvested within the NSR. The UDWR has also worked closely with Wildlife Services and hunters to facilitate quick response time to cougar tracks or kills on bighorn sheep. During the course of the study (January 2012-January 2014), eight cougars were removed from the unit (6 females, 2 males). Seven of which (6 females, 1 male) were the result of a collaborative effort between UDWR, Wildlife Services, and hunters sharing information and working together to remove cougars.

The NSR reached a peak population estimate of over 500 individuals in 2001 and exhibited lamb:ewe ratios of 36-60 from 1995-2005. Declines in the population were first observed in 2003, but lamb:ewe ratios remained very high until 2007, suggesting that other causes may have been responsible for the initial declines. Low lamb:ewe ratios began in 2007, but the population never exhibited an acute die-off. Instead, it continued to gradually decline by ~11% annually. Initial research has shown that strains of *M. ovipneumoniae* transmitted from domestic goats may be less virulent than domestic sheep strains (T. Besser, unpublished data). The NSR population is thought to have been exposed to domestic goats prior to showing low lamb recruitment, which could potentially explain the gradual decline. It experienced limited lamb recruitment and population decline until 2012 when the lamb:ewe ratio increased from 29:100 to 47:100, and the population began to increase. Assuming there was no re-exposure to

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pneumonia related pathogens, the herd took 5-6 years to reverse the growth trend. Time to recovery is still unknown, but repeated exposure and persistence of pneumonia related pathogens prolongs recovery (Manlove et al. 2016). This highlights the importance of maintaining spatial separation from domestic sheep and goats to maintain overall herd health.

Because the NSR has been exposed to pneumonia related pathogens, specifically *M. ovipneumoniae*, traditional management options (such as augmenting the population) are limited. Instead, we recommend preventing re-infection as a primary management strategy. Bighorn sheep do not exhibit cross-strain immunity to *M. ovipneumoniae* (Cassirer et al. 2017), meaning the introduction of a new strain of *M. ovipneumoniae* can cause a new epizootic within the population. Maintaining spatial separation of bighorns and domestic sheep and goats are important to preventing repeated disease transmission. Soliciting cooperation by the public, improving monitoring efforts and early detection strategies, such as using GPS collars, may also be key to preventing pneumonia outbreaks.

The NSR population is somewhat fragmented into five distinct sub-herds with limited interaction (Buckhorn Wash, Wedge, Virgin Spring/Cane Wash, Secret Mesa/Coal Wash, and Reef). Because these sub-herds rarely interact, isolated depopulation or test and cull management actions may be effective in limiting the spread of pneumonia from one group to another should the herd be re-exposed in the future. However, rams move freely between groups across the population during the rut, which would facilitate exposure in the late fall/early winter. If a disease or commingling event is detected, managers should act immediately to control the spread of disease.

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TABLES

Table 1.1. Desert bighorn sheep (*Ovis canadensis nelsoni*) flight classification data, 2011-2015, North San Rafael Swell, Emery County, Utah.

Year	Lamb:Ewe	Ram:Ewe	Population Estimate	Lambda (λ)
2011	29:100	37:100	116	-
2012	47:100	36:100	127	1.09
2013	31:100	53:100	139	1.09
2014	-	-	-	-
2015	42:100	67:100	168	1.10

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Table 1.2. Probably cause of death of collared desert bighorn sheep (*Ovis canadensis nelsoni*) in the North San Rafael Swell, Emery County, Utah, 2012-2014.

Date Found	Animal ID	Sex	~Age	Cause of Death
1/28/2012	#6	Female	10	Cougar
8/1/2012	#27	Female	7	Cougar
9/13/2012	#16	Female	7	Cougar
9/13/2012	#29	Female	7	Cougar
9/14/2012	#25	Female	4	Unknown
9/18/2012	#15	Female	3	Unknown
9/28/2012	#7	Female	7	Bluetongue/Pneumonia
11/3/2012	#37	Male	8	Hunter Harvest
12/27/2012	#10	Female	9	Cougar
12/31/2012	#32	Male	7	Cougar
1/31/2013	#39	Male	7	Bluetongue/Pneumonia
3/20/2013	#28	Female	5	Ruptured Uterus/Pneumonia
3/29/2013	#13	Female	4	Cougar
5/15/2013	#22	Female	3	Dystocia
5/20/2013	#3	Female	4	Unknown
9/19/2013	#49	Female	6	Unknown
10/31/2013	#21	Female	4	Cougar
1/13/2014	#18	Female	7	Cougar
1/16/2014	#46	Female	5	Cougar

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FIGURES

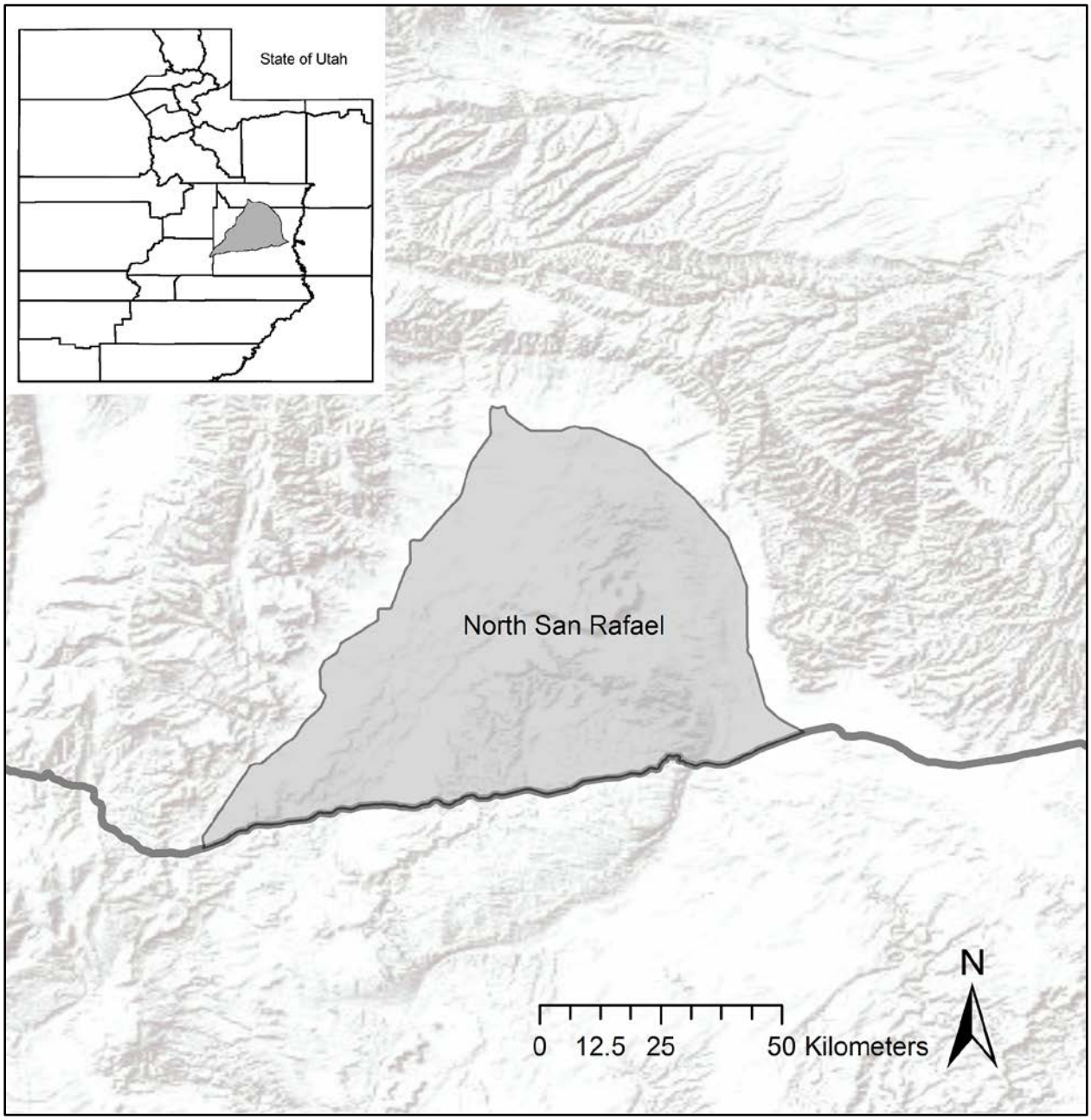

Figure 1.1. Location and map of desert bighorn sheep (*Ovis canadensis nelsoni*) study area during 2012-2013 in North San Rafael Swell, Emery County, Utah.

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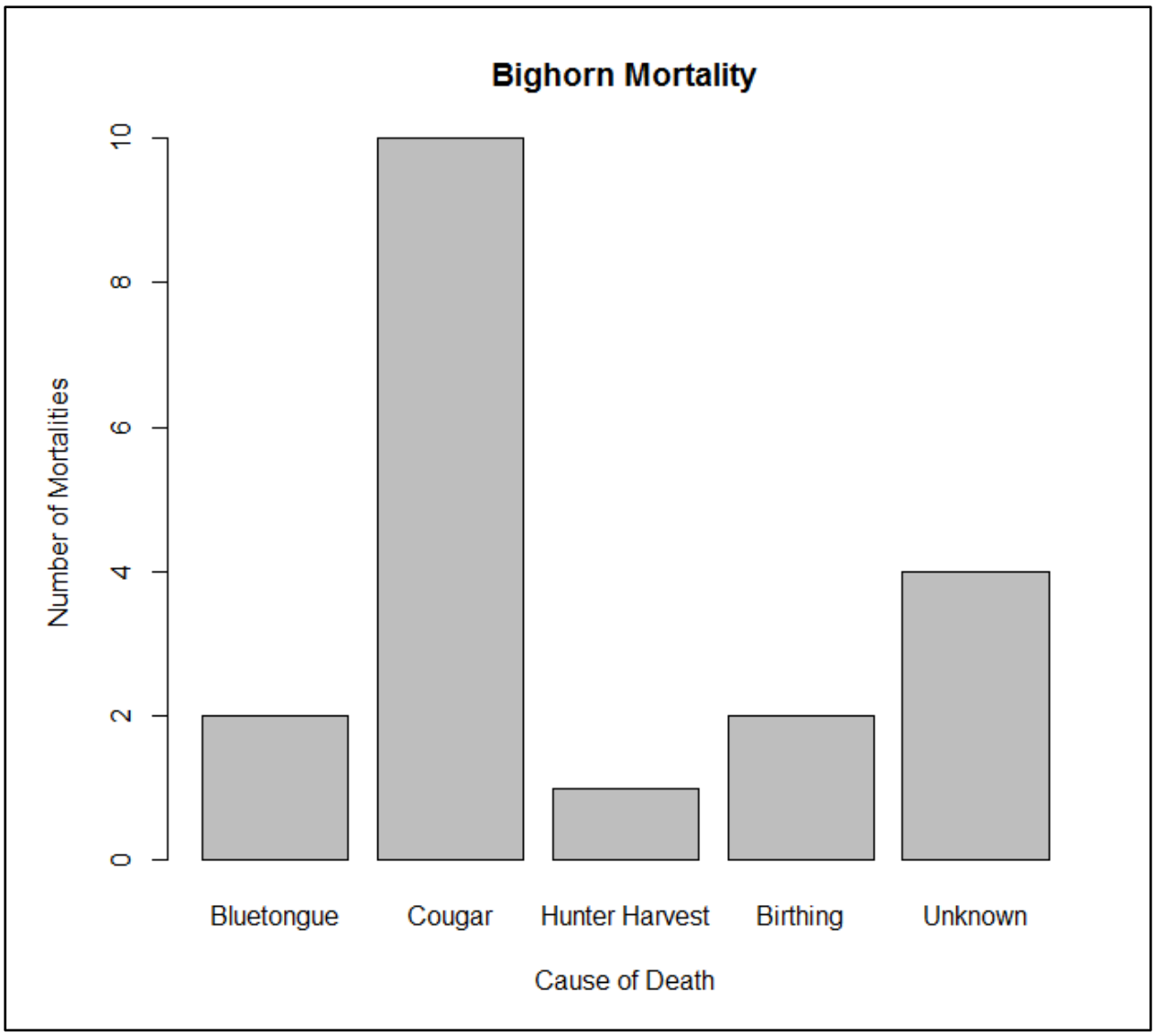

Figure 1.2. Cause specific mortality (n = 19) for collared desert bighorn sheep (*Ovis canadensis nelsoni*) during 2012-2013, North San Rafael Swell, Emery County, Utah.

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Appendix A: Individual Disease Profiles

Table A.1. Disease testing results of 36 bighorn sheep, NSR, Emery County, Utah, 2012.

Sample	Movi	Pasteurella	Bacterial Isolates	Number	Strain	*M. ovipneumoniae*
1	x	x	*Bibersteinia trehalosi*	Few		Not detected
2	x	x	*Bibersteinia trehalosi*	Few		Not detected
3	x	x	*Pasteurella multocida*	Moderate		Detected
4	x	x	*Mannheimia haemolytica*	Moderate	Beta-hemolytic	Indeterminate
			Bibersteinia trehalosi	Few		
5	x	x	*Bibersteinia trehalosi*	Few		Detected
6	x	x	No pasteurella isolates			Detected
7	x	x	*Bibersteinia trehalosi*	Moderate		Not detected
8	x	x	*Bibersteinia trehalosi*	Few		Not detected
9	x	x	*Bibersteinia trehalosi*	Few		Not detected
10	x	x	*No pasteurella isolates*			Detected
11	x	x	*Bibersteinia trehalosi*	Moderate		Not detected
			Pasteurella multocida	Moderate		
12	x	x	*No pasteurella isolates*			Not detected
13	x	x	*Bibersteinia trehalosi*	One colony		Detected
14	x	x	*Bibersteinia trehalosi*	Many		Not detected
15	x	x	*No pasteurella isolates*			Not detected
16	x	x	*Moraxella spp*	Very many	Mucoid	Detected
			Bibersteinia trehalosi	Moderate		
			Mannheimia haemolytica		Non-hemolytic	
17	x	x	*Mannheimia haemolytica*		Non-hemolytic	Not detected
18	x	x	*No pasteurella isolates*			Not detected
			Moraxella spp	Many	Mucoid	
19	x	x	*Bibersteinia trehalosi*	Few		
			Mannheimia haemolytica	Very many	Hemolytic	Not detected
20	x	broken	*No sample taken*			Not detected
21	x	x	*Bibersteinia trehalosi*	Moderate		Detected
22	x	x	*Bibersteinia trehalosi*	Many		Not detected
23	x	x	*No pasteurella isolates*			Not detected
24	x	x	*Bibersteinia trehalosi*	Many		Not detected
25	x	x	*Bibersteinia trehalosi*	Few		
			Mannheimia haemolytica	Few	Hemolytic	Indeterminate
26	x	x	*Bibersteinia trehalosi*	Few		Not detected
			Mannheimia haemolytica	Moderate	Hemolytic	
			Pasteurella multocida	Many		
27	x	x	*Bibersteinia trehalosi*	few		Detected
28	x	x	*No pasteurella isolates*			Not detected
29	x	x	*Bibersteinia trehalosi*	Few		Not detected
30	x	x	*No pasteurella isolates*			Not detected
31	x	x	*No pasteurella isolates*			Not detected
32	x	x	*No pasteurella isolates*			Detected
33	x	x	*Bibersteinia trehalosi*	Few		Detected
			Mannheimia haemolytica			
34	x	x	*Bibersteinia trehalosi*	Few		Not detected
			Mannheimia haemolytica	Few	Hemolytic	
35	x	x	*No pasteurella isolates*			Not detected
36	x	x	*Bibersteinia trehalosi*	Few		Detected

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Figure B.1. Ewe #6: Located January 28, 2012. Probable cause of death was cougar predation. The ewe was mostly consumed, carcass covered in debris. Hunters with hounds were at site within approximately 4 hours. Cougar had returned and uncovered carcass between my departure and hunters' arrival. Hunters were unsuccessful due to rugged terrain.

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Figure B.2. Ewe #27. Located August 1, 2012. Probable cause of death was cougar predation. Ewe and lamb were found in bottom of wash. Both were consumed. Cougar tracks and drag marks were found. Ewe was under juniper with debris and bury marks.

Figure B.3. Ewe #16. Located on September 13, 2012. Probable cause of death was cougar predation. Ewe was found on a bench totally consumed under a juniper.

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Figure B.4. Ewe #29. Located on September 13, 2012. Probable cause of death was cougar predation. Ewe was found totally consumed approximately 800m south of ewe #16 (figure B.3) on the same bench. Cougar tracks and drag marks were found.

Figure B.5. Ewe #25. Located on September 14, 2012. Probable cause of death is unknown, but this ewe had two tumors on her forehead, possibly sinus tumors, which probably contributed to mortality. The ewe was found in the bottom of a steep and narrow canyon. The head had been scavenged by foxes and birds. The body cavity had a small opening near the back. The rest of the body was intact and not scavenged. However, organs were decomposed preventing any samples from being taken.

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Figure B.6. Ewe #15. Located on September 18, 2012. Probable cause of death is unknown. This ewe was found dead in a bedding area near the bottom of a steep canyon. The carcass was intact but with heavy insect activity. The body cavity was open, and organs were too decomposed for testing.

Figure B.7. Ewe #7. Located on September 28, 2012. Probable cause of death was bluetongue virus. This ewe was found extremely fresh, mucous coming out of nose and mouth. The whole carcass was carried out and driven to Nephi for necropsy. Early results identified bacterial bronchopneumonia attributed to *Pasteurella multocida* as the Probable cause of death. Further testing revealed the presence of bluetongue virus, so the probable cause of death was attributed to bluetongue with complications from a secondary bacterial pleuro-pneumonia.

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Figure B.8. Ram #37. Harvested on November 3, 2012. Cause of death was hunter harvest.

Figure B.9. Ewe #10. Located on December 27, 2012. Probable cause of death was cougar predation. Ewe was found dead in bottom of shallow wash. It was totally consumed. An uncollared ewe was also found consumed in the same location (~50m away). It was also a lion kill and appeared to be from the week prior. There were cougar tracks and drag marks in the snow surrounding both sheep. Heavy fox scavenging was also evident.

(No Photos)
Figure B.10. Ram #32. Located on December 31, 2012. Probable cause of death was cougar predation. Ram was close to the western edge of the reef in a shallow wash under a juniper. It was totally consumed with the exception of the head, which was partially consumed. There were lots of fresh cougar tracks surrounding kill site. Tracks were followed north for several miles until two additional sets of lion tracks met up with them and all three sets dropped off the western edge of the reef.

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Figure B.11. Ram #39. Located on January 30, 2013. Probable cause of death was bluetongue virus. Bluetongue virus was isolated from the lung tissue, so the animal was positive for bluetongue. In addition, *Mycoplasma ovipneumonia* was isolated from the culture and identified by PCR. Primary cause of death was attributed to bluetongue, but the infection triggered pneumonia (secondary cause of death).

Figure B.12. Ewe #28. Located on March 20, 2013. Probable cause of death was ruptured uterus, more specifically, complications from a rupture of the uterus which caused the contents of the uterus to spill into the peritoneal cavity. This led to a bacterial infection (peritonitis) and bronchopneumonia. The pneumonia is secondary to the bacterial infection. This is an individual animal issue and not a population issue. Uterine ruptures typically occur during labor but may also occur during late pregnancy.

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Figure B.13. Ewe #13. Located on March 29, 2013. Probable cause of death was cougar predation. Ewe was found entirely consumed with mountain lion tracks and drag marks in the vicinity. A mountain lion was photographed on a nearby trail camera during the same time period.

Figure B.14. Ewe #22. Located on May 15, 2013. Probable cause of death was Dystocia. The lamb was very large and likely got stuck during the birthing process. Autolysis was too advanced for further testing.

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Figure B.15. Ewe #3. Located on May 20, 2013. Probable cause of death was unknown. This ewe could not be located for several weeks but was eventually found dead in a depression within a deep canyon. There were signs of scavenging activity, and the sheep was entirely consumed, but it did not appear that predation was the cause of death.

Figure B.16. Ewe #49. Located on September 19, 2013. Probable cause of death was unknown. A mortality signal was detected on September 18. She was found dead the following morning. The carcass was too decomposed to identify a cause of death or take test samples. Predation was not involved. Based on tracks, she had isolated herself from a group of other bighorns and laid in several different beds within a small area. No bloody stool was found. No outward signs of injury. It rained on September 15 leaving tracks in wet ground. Death likely occurred shortly after that.

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Figure B.17. Ewe #21. Located on October 31, 2013. Probable cause of death was cougar predation. This ewe could not be located for several weeks but was found on a flat bench under a juniper south of I-70. Ewe was totally consumed and scavenged, but there was evidence of two different cache sites where debris was piled up and the rumen had been extracted.

Figure B.18. Ewe #18. Located on January 13, 2014. Ewe was found in the bottom of a steep canyon entirely consumed with mountain lion tracks, scat, and beds in the vicinity.

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Figure B.19. Ewe #46. Located on January 16, 2014. Probable cause of death was cougar predation. Ewe was found at the top of a deep canyon, totally consumed with mountain lion tracks in the vicinity.

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CHAPTER 2

Identifying nursery habitat and timing of parturition for bighorn sheep: implications for conservation and management

ABSTRACT

Delineating timing of parturition and habitat for nursery groups of bighorn sheep has important implications for the conservation and management of populations. Conservation planning and habitat management will increasingly rely on identifying preferred habitats with varying levels of human use. We investigated timing of birth and nursery habitat selection of desert bighorn sheep in the North San Rafael Swell, Utah to determine the relative influence of vegetation, topography, and anthropogenic features. We monitored radio-collared ewes year-round 2012—2013 to establish birthing seasons. We documented birthdates of 29 lambs in 2012 and 16 in 2013. We used GPS collar locations to perform logistic regression analysis within a model-selection framework to differentiate between nursery and random locations based on a suite of covariates. We quantified covariate values at 750 nursery and 750 random locations. The top model for site selection included elevation, slope, terrain ruggedness, aspect, existing vegetation type, distance to trails, and distance to roads, and we used it to project a GIS model of nursery habitat onto the North San Rafael (desert bighorns) and the Green River Corridor (Rocky Mountain bighorns). Ewes showed preference for steep slopes, rugged terrain, north facing slopes, low elevation, and avoidance of roads. Our model provides managers with a map of high probability nursery areas in a region of Utah where resource extraction and recreation are on the rise. This model is also robust enough to apply to both desert and Rocky Mountain bighorns. Identifying area-specific timing of parturition, and identifying high probability nursery areas, could help managers mitigate potential conflict with recreation, mining, and domestic livestock in other areas.

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INTRODUCTION

Free-ranging female ungulates select birth sites and habitat for nursery groups based on a variety of trade-offs (Bowyer 1991, Rachlow and Bowyer 1991, 1994). These trade-offs include predation risk, exposure to heat, and forage quality and availability for the mother to fulfill nutritional requirements during late gestation and early lactation (Altmann 1958, Festa-Bianchet 1988b, Berger 1991, Rachlow and Bowyer 1998). For example, female bighorn sheep (*Ovis canadensis*) often return to the same general area each year to give birth (Etchberger and Krausman 1999). Young are usually born in relatively flat areas (mean slope = 38 ± 13 degrees) of high elevation in rugged, steep terrain that are close to perennial water, on south and west facing slopes, and away from anthropogenic disturbance (Geist 1971, Shackleton et al. 1999, Bangs et al. 2005, Smith et al. 2015). After giving birth, female bighorns form nursery groups with other females and young in nursery areas of high elevation, steep slopes, and increased ruggedness (Bangs et al. 2005, Karsch et al. 2016). Groups then move cohesively among patches of nursery habitat for the subsequent months (Bangs et al. 2005, Whiting et al. 2011, Whiting et al. 2012, Wiedmann and Bleich 2014). Delineating birthing habitat and habitat for nursery groups of bighorn sheep has important implications for the conservation, management, reproductive biology, and perpetuation of populations of these ungulates (Etchberger and Krausman 1999, Bangs et al. 2005, Wiedmann and Bleich 2014, Smith et al. 2015).

Timing of parturition in bighorn sheep is influenced by many factors, and differences in seasonality of births have been well-documented (Buechner 1960, Geist 1971, Whiting et al. 2012). Latitude, elevation, growing season length, climate, nutrition, and photoperiod are factors influencing reproductive seasonality in bighorn sheep (Bunnell 1982, Thompson and Turner 1982, Whiting et al. 2012). Generally, bighorn sheep occupying northern latitudes and higher

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elevations give birth late in spring, because of a constricted birthing period and shortened growing season (Bunnell 1982, Thompson and Turner 1982). Conversely, bighorn sheep occupying southern latitudes give birth during most months, likely because growing seasons are much less predictable (Lenarz 1979, Thompson and Turner 1982, Rubin et al. 2000). Understanding the timing of births for bighorn sheep can assist in managing and conserving populations, especially for reintroduced animals (Whiting et al. 2008, Whiting et al. 2010, Whiting et al. 2011).

Anthropogenic activities can influence habitat used by female ungulates during birthing and when animals congregate in nursery groups (Altmann 1958, Stankowich 2008, Dzialak et al. 2011), and can also reduce forage intake and suppress population growth (Ciuti et al. 2012). Saiga antelope (*Saiga tatarica*) avoided areas of human use while selecting birthing sites (Singh et al. 2010). Parturient bison (*Bison bison*) selected birthing habitat that was away from recreational trails, roads, and buildings (Kaze et al. 2016). Female elk (*Cervus elaphus*) avoided areas of high-human use during the day, but selected areas of high human use at night (Dzialak et al. 2011). Additionally, in an area that was intentionally disturbed by humans during parturition, counts of young/female elk were 22.5% lower than in areas with undisturbed herds (Phillips and Alldredge 2000). Populations of bighorn sheep can be negatively influenced by anthropogenic disturbances, especially during the birthing season (Papouchis et al. 2001, Wiedmann and Bleich 2014, Smith et al. 2015). These disturbances can cause females to abandon previously used nursery habitat, thus using less-suitable habitat (Longshore et al. 2013), which may increase predation risk for lambs (Papouchis et al. 2001) and lower recruitment of young, resulting in a declining population (Papouchis et al. 2001, Wiedmann and Bleich 2014). Indeed, researchers

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have recommended that known habitat for nursery groups of bighorn sheep be closed to hiking during portions of the year to benefit ewes and lambs (Papouchis et al. 2001).

Conservation planning and habitat management will increasingly rely on identifying preferred habitats of wildlife in areas of varying levels of human use (Margules and Pressey 2000, Dzialak et al. 2011, Harju et al. 2011). Biologists can substantially reduce impacts to female ungulates during birthing from humans by identifying where and when animals give birth (Dzialak et al. 2011, Kaze et al. 2016), thereby mitigating potential disturbance. Additional research is needed for bighorn sheep populations to understand and predict habitat use during birthing and nursery periods (Bangs et al. 2005). GPS data can effectively document such patterns at fine scales (Longshore et al. 2013), especially for parturient female bighorns (Smith et al. 2015). That information can be extremely useful for land-use planning (Papouchis et al. 2001).

Southeastern Utah is the largest, contiguous area in the state consisting of important habitat for bighorn sheep populations. This area, however, has experienced > 300% growth in outdoor recreation since 1979 (Sproat 2012), which often peaks in May (Papouchis et al. 2001). Oil and gas exploration is also an important industry in this area. These activities can impact wildlife populations (Sawyer et al. 2006, 2009, Wiedmann and Bleich 2014). Possible consequences include habitat degradation, displacement of individuals, decreased reproduction, and decreased survival (Parks and Harcourt 2002, Taylor and Knight 2003). The objectives of this study were to characterize timing of births and nursery habitat for desert bighorn sheep (*O. c. nelsoni*) and Rocky Mountain bighorn sheep (*O. c. canadensis*) in two of the largest populations of those subspecies in Utah, construct a resource selection function model that encompasses birthing areas and habitat for nursery groups, and gather data concerning timing of births that

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will provide biologists with locations of areas and a time of year at which human activities can be limited to reduce potential impacts to bighorn sheep and their young. Our model can potentially be extrapolated to other areas in the Colorado Plateau ecoregion occupied by Rocky Mountain and desert bighorn sheep in order to aid in land-use planning, as well as conserve and manage these animals and their habitat.

STUDY AREAS

The population of desert bighorn sheep we studied occupy the North San Rafael Swell (NSR). The NSR is located in Emery County, Utah (Figure 2.1; 38°58′N, 110°37′W). Bighorns were native and abundant in the NSR, but were likely extirpated from that area; the last confirmed sighting occurred in 1964 (Dalton and Spillett 1971). That population was re-established in the 1970s and 1980s with five translocations of 57 bighorns from Canyonlands National Park and the San Juan population in Utah (UDWR 2013). This translocation effort was successful, and in 2001 the Utah Division of Wildlife Resources (UDWR) estimated 543 animals in this population. However, bighorn sheep started to decline in the 2000s, and one month prior to our study, biologists estimated 143 individuals in that area.

The NSR is characterized by steep canyons in the Wingate Formation with broad mesa tops in Navajo and Entrada Sandstone formations. Desert bighorn sheep habitat in that area ranged in elevation from 1,700 to 2,100 m. Vegetation consisted of species typical of salt desert shrub environments. Common shrubs included blackbrush (*Coleogyne ramossisima*) and fourwing saltbush (*Atriplex canescens*). Pinyon pine (*Pinus edulis*) and juniper (*Juniperis* spp.) were predominate on mesa tops and on north facing canyon slopes. The NSR is dry with annual precipitation averaging < 20 cm per year. Daily high temperatures during summer (June-

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September) averaged 31°C and often exceed 35°C. Winters (November to February) were typified with daily low temperatures averaging -12°C. Native populations of pronghorn (*Antilocapra americana*) and mule deer (*Odocoileus hemionus*) inhabited the study area, although mule deer persisted at low densities. Wild burros (*Equus asinus*) and domestic cattle also occupied portions of the NSR. Mammalian predators included primarily mountain lions (*Puma concolor*) and coyotes (*Canis latrans*). The NSR study area was predominantly managed by the Bureau of Land Management (BLM). Recreation in the NSR includes on and off-road travel, rock climbing, biking, hiking, camping, and hunting. Peak recreation occurs in spring with influxes of activity near Easter and Memorial Day (W. Paskett, personal communication).

We also studied a population of Rocky Mountain bighorn sheep in the Green River corridor (GRC) located in Emery and Carbon counties, Utah (Figure 2.1). That area divides the Nine Mile/Range Creek population of Rocky Mountain bighorn sheep west of the river from the Book Cliffs/Rattlesnake population east of the river. Bighorns were native to the GRC, but were extirpated by 1960 (Dalton and Spillett 1971). Currently, that metapopulation is a result of 9 transplants beginning in 1970 with bighorns from Utah, Montana, Wyoming, Colorado, Alberta, and British Columbia. Rocky Mountain bighorn in GRC form the largest metapopulation of this subspecies in Utah (Figure 2.1), and that area contains one of the largest contiguous sections of Rocky Mountain bighorn sheep habitat in Utah. An estimated 1,000 individuals occupied this area at the beginning of our study.

Elevation used by bighorn sheep in the GRC varied from 1,250 m to 3,000 m. Riparian areas in that area were dominated by willow (*Salix* spp.), cottonwood (*Populus fremontii*), and box elder (*Acer negundo*) trees. Generally, the GRC is considered a desert environment dominated by salt shrubs, bunch grasses, pinyon (*Pinus edulis*), and juniper (*Juniperus*

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osteosperma). Populations of pronghorn, mule deer, bison (*Bison bison*), and elk (*Cervus elaphus*) occupied that area; and mammalian predators were the same as those that occurred in NSR, except the GRC has a thriving black bear *(Ursus americanus)* population. The GRC is of mixed land ownership, most of which is managed by the BLM. Recreation in the GRC includes on and off-road travel, rock climbing, biking, hiking, camping, fishing and hunting. The GRC is also governed by the 1979 River Management Plan (Barry 1979), which allows for private and commercial float permits and establishes a carrying capacity of 35,000 user days per year. The recreation season is divided into high and low use periods. High use occurred from May 15 through August 15. Total user days on the river have increased by 148% since 2002.

METHODS

In January 2012, 30 adult female bighorn sheep were captured by aerial net gunning (Krausman et al. 1985) in the NSR, and 17 adult females were captured in the GRC. Efforts were made to sample a wide distribution of bighorns across the units by distributing collars proportionally to aerial count numbers and locations of bighorns established two months prior. Animals were equipped with Lotek 6000SD GPS/VHF collars with mortality transmitters and pre-programmable drop off mechanisms. Collars were programmed to acquire a GPS fix every 8 hours. In January 2013, eight additional ewes in the NSR and five in the GRC were captured and collared to replace mortalities, bringing the total number of collared females to 38 ewes in the NSR and 22 in the GRC. Due to collar malfunctions and mortalities, data from 36 GPS collars (NSR = 19 and GRC = 17) were used for GIS analyses; however, all ewes with active collars at the time of lambing were observed for collection of data for parturition timing. Collars were retrieved after mortalities or at the end of the study period in January 2014, and GPS locations

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were uploaded from the onboard data storage of the collars. We performed a database query in ArcGIS 10.3 (Redlands, CA) to eliminate locations with < 3D accuracy for both study areas.

We monitored collared bighorn sheep weekly using radio telemetry for two years until the collars dropped in January 2014. We relocated collared and uncollared females to record birthdates from 25 April to 25 June during 2012 and 2013. We searched the NSR a mean (± *SD*) of every 2 days ± 1.6 days in 2012, and a mean of every 2 days ± 1.7 days in 2013. To estimate parturition dates, we observed the behavior of marked females before, during, and after parturition; as well as first sighting, motor skills, size, and behavior of neonates (Festa-Bianchet 1988a, Whiting et al. 2008, 2011). To determine birthdates for neonates of uncollared females, we compared their young with neonates of estimated ages of collared females when all females congregated in nursery bands after parturition (Côté and Festa-Bianchet 2001, Whiting et al. 2008, 2012). When ewe and lamb pairings were questionable, we waited until the lamb nursed in order to identify its mother (Festa-Bianchet 1988a). A mean (± *SD*) of 88 (± 3.6) adult females occupied the NSR during our study. We exercised care not to disturb females with young (Sikes et al. 2016).

We estimated birthdates of young, pooled them into sampling intervals and calculated corrected means (timing of births) and *SD* values (synchrony of births) for the NSR population in each year (Johnson et al. 2004, Whiting et al. 2011). This technique allowed robust calculations of unequal sampling intervals (bin sizes) in determining timing and synchrony of births (Johnson et al. 2004). We then calculated a date range using ± 2 *SD*s from the mean that encompassed birth sites and habitat for nursery groups for our spatial analyses using data from GPS collars in the NSR population.

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We were not able to estimate birthdates of young in GRC during our study. The general estimate of the peak birthing period, however, for that population was from 25 May to 5 June (Whiting et al. 2011). We therefore used the date range of May 1 to June 5 for our analyses of birth sites and nursery habitat in that population. A mean (± *SD*) of 462 (± 69.3) adult females occupied the GRC during our study.

Resource Selection Functions

Using the appropriate spatial scale when defining availability to animals is critical when making inferences about habitat selection at the population level, making it important to define an area biologically relevant to the species of interest (Johnson 1980, Boyce 2006). We used the reproducible home range (rhr) package in Program R 3.1 to define a 95% minimum convex polygon for each study area. Those polygons were created using bighorn birthing and nursery season locations during the date range calculated for both study populations.

We evaluated bighorn birthing and nursery habitat selection using a resource selection function within a use-availability study design (Manly et al. 2002) where the response variable location was "1" (one location/day per individual with time of day randomly selected) or a "0" for random site. Random points were extracted with the random points tool in ArcMap 10.3 (ESRI, Redlands, California) and R (R Core Team 2014). We used mixed-effects, logistic regression with a random intercept for individual bighorn (radio collar ID) and analyzed covariates at use vs available (random) locations. We evaluated birthing and nursery habitat using locations from the NSR study area. After removing locations with less than 3D accuracy and those that occurred outside the 95% minimum convex polygon, locations totaled 750. We generated an equal number of random locations and assigned them equal weight. Because

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random locations were cast within the boundary of the study area and not associated with individual home ranges, our modeling of resource selection generally corresponded to Johnson's second order of selection (Johnson 1980). To ensure that 750 random locations adequately characterized our study area, we calculated the true mean (i.e. mean of all pixels within the study area) for continuous variables and compared our sample means with 95% CIs to these values Long et al. 2014. In every case, the confidence intervals of our sample overlapped the true mean values suggesting that 750 random locations was adequate to characterize our study area.

We selected the following landscape level features potentially influencing bighorn sheep habitat selection: slope, ruggedness (Bleich et al. 1997, Sappington et al. 2007, Longshore et al. 2013), elevation, aspect, Landfire existing vegetation type (LANDFIRE; http://www.landfire.gov; Rollins 2009), distance to trails, and distance to roads. Topographic features were extracted using a USGS 30m digital elevation model. Slope was calculated using the slope tool in the Spatial Analyst Tools extension. Ruggedness was calculated using the VRM tool in the Terrain Tools extension (Sappington et al. 2007). Aspect was calculated using the aspect tool in the spatial analyst extension and was divided into the four cardinal directions (north, east, south, west). The LANDFIRE existing vegetation type layer consisted of five types (barren, sparse, herb, shrub, and tree). Distance to roads and trails was calculated using the generate near table tool in the analysis tools extension. Distance to water sources was not included in the analysis. Because of the extensive nature of ephemeral, water sources formed in sandstone "potholes" after precipitation events or from seasonal seeps, it was not feasible to map water source locations accurately or comprehensively.

We developed models using an information theoretic approach (Burnham and Anderson 2002) within a mixed-effects logistic regression (Hosmer and Lemeshow 2000) and used a

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random intercept to account for individual heterogeneity. We used R package lme4 for mixed-effect modeling analysis (Bates et al. 2014). We used combinations of covariates (all permutations) to build models. All continuous covariates (slope, ruggedness, elevation, distance to trails, and distance to roads) were standardized before model development [Baxter et al. 2017; $(x_i - \bar{x})/s$]. We used AIC_c values to identify the most supported models as well as which variables were informative.

To assess predictive ability of our top model, we performed *k*-folds cross validation with $k = 5$ (Long et al., 2009, Villepique et al. 2015) on the NSR study area. We randomly sorted observations into five partitions, with an equal number of locations in each partition. During each iteration of this procedure, we used four partitions (80% of the data) as the training set to estimate model coefficients and the remaining partition (20% of the data) to test model predictions. We repeated this procedure until all observations were used as both the test set and part of the training set. Coefficients from the predictive model were then applied to calculate relative probability of use within both the NSR and GRC study areas. We generated two predictive maps, one for the NSR and one for the GRC, by applying this procedure to each raster pixel in each study area. We then used four equal-area bins to categorize the relative probabilities of use for each pixel from low to high (Sawyer et al. 2006, 2007, 2009, Long et al. 2009).

RESULTS

In 2012, we estimated birthdates for 29 young. Mean (± 2 *SD*s) birthdate for bighorn sheep in the NSR during that year was 21 May (± 19 days). In 2013, we estimated birthdates for 16 young, and mean (± 2 *SD*s) birthdate for bighorn sheep in that area during that year was 20 May (± 21 days). The date range we used for our analyses of birth sites and nursery habitat from

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GPS collar data for 2012 was 2 May to 9 June. Whereas, for 2013 that range of dates for birth sites and nursery habitat was 29 April to 10 June.

Our habitat analyses resulted in two top models that accounted for 99% of the AICc weight (Table 2.1). Because the top model accounted for 86% of AICc weight and included all covariates from the second top model, we chose not to model average and only report parameter estimates from the top model (Table 2.2). That model included measures of elevation, slope, ruggedness, aspect, existing vegetation type, distance to trails, and distance to roads (all covariates). Estimates for variables with evidence of selection ($p < 0.05$) were positive for barren vegetation, slope, ruggedness, north facing slopes, and distance to roads (indicating a preference for areas farther from roads). Estimates for variables with significant negative correlation were elevation (indicating a preference for lower elevations), south facing slopes, herb, shrub, and tree vegetation types, and distance to trails (indicating a preference for areas closer to trails). In the NSR, 77.5% of ewe locations fell within the top two probability categories (high, medium-high), 16.6% fell within the medium-low category, and 5.9% fell within the low category (Figure 2.2). In the GRC, 79.5% of nursery season ewe locations fell within the top two categories of probability (high; 51%, medium high; 28.5%), 16.1% fell into the medium-low category, and 4.4% fell within the low category (Figure 2.3).

DISCUSSION

Expectedly, slope and ruggedness were significant variables in our models. Many other studies have indicated that these habitat components are important to minimize risk of predation for bighorn sheep with young (Geist 1971, Krausman and Leopold 1986, Bleich et al. 1997, Rachlow and Bowyer 1998, Bangs et al. 2005, Olson et al. 2008). Smith et al. (2015) also

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documented these components selected for at parturition sites, as well as south and west facing slopes. However, our model showed a preference for north facing slopes and an avoidance of south facing slopes. We speculate this may be due, in part, to a difference in latitude and temperature relative to differing study areas. Smith et al. (2015) were also modeling parturition sites specifically, while we analyzed parturition sites and nursery habitat. Lactating ewes have high water demands, and travel of young lambs is restricted, necessitating the use of areas in close proximity to water (Zeigenfuss et al. 2000). This could explain the preference for north facing slopes and lower elevation where water collects and is retained.

While our model showed an avoidance of roads, largely corroborating past work (Wilson et al. 1980, Krausman et al. 1989, Ebert and Douglas 1993, Papouchis et al. 2001), it also indicated a preference for areas near trails. We assume that this result is because most trails in the NSR traverse up the bottoms and around the rims of many side canyons used by nursery groups. Trail traffic is relatively low in the NSR. For example, a motion-sensor camera placed on a canyon rim trail within high use nursery habitat recorded 316 spring visitor days by hikers and bikers, but previous research has shown an avoidance of areas with more intensive recreation ($\overline{x}$ = 15,925, *SD* = 6,038) and even an associated drop in herd performance (Wiedmann and Bleich 2014).

Using GPS data is an extremely effective way to document parturition sites in bighorn sheep, and these data should be used over other sources (i.e., VHF collars) when delineating critical birthing habitat for this species (Smith et al. 2015), especially when considering anthropogenic influences on habitat use (Longshore et al. 2013). Indeed, management decisions for bighorn sheep are often made on parturition habitat (Longshore et al. 2013). With the advance of GPS data, better habitat models can be produced (Moorcroft 2012) when compared

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with other methods such as visual observation (Smith et al. 2015). Indeed, visual observations can be biased for open habitat (Smith et al. 2015).

The parturition timing data in our study were collected in one of the largest metapopulations of desert bighorn sheep in Utah. This area is also part of the most contiguous habitat section for this subspecies in Utah (UDWR 2013). Consequently, we hypothesize that these parturition timing data can be loosely extrapolated to other areas in Utah and elsewhere. The Colorado River corridor is the nearest proximate occupied area adjacent to both study areas, and although timing of births in the Colorado River corridor is slightly earlier in some populations, our GIS model is robust and can be applied to those areas. We are aware of some populations in Utah that differ more drastically in birth timing, such as the Zion and Pine Valley herds. Therefore, we recommend that managers document site-specific birth timing and adjust dates to fit local populations in order to apply this model effectively and facilitate management decisions.

This model was also successful at predicting nursery habitat for both subspecies in Utah (desert and Rocky Mountain bighorns). Reintroductions and augmentations continue to be valuable management tools for bighorn conservation in Utah with over 1,000 Rocky Mountain bighorn sheep and over 850 desert bighorn sheep being released in areas of historical habitat since 1966. Thirty-two units/subunits are identified as potential sites considered for augmentation or reintroduction in the state (UDWR 2013). A robust model that can identify potential release sites based on access to lambing and nursery habitat for both subspecies can be useful when considering potential transplant sites. Furthermore, our GIS models can have application in identifying potential threats to transplant success by identifying overlap in birthing and nursery habitat with recreation and areas with domestic sheep and goats.

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Proximity of bighorn sheep to domestic sheep allotments on public land (Cahn et al. 2011, Carpenter et al. 2014, O'Brien et al. 2014), as well as proximity of those wild ungulates to areas occupied by domestic sheep and goats on private land (Turner et al. 2004, Shannon et al. 2014), are controversial issues in the western USA. As domestic sheep and goats can transmit disease to bighorn sheep, these issues are critical for the conservation and management of bighorn sheep populations (McClintock and White 2007, Wehausen et al. 2011, Besser et al. 2012). With female bighorn sheep showing general fidelity to birth sites and habitat for nursery groups (Etchberger and Krausman 1999), our data can be used to guide land-management decisions when assessing allotments on public land and working with land owners on private land, especially when reintroducing bighorn sheep (Shannon et al. 2014). Additionally, recent work indicates that domestic cattle can affect habitat use by bighorns (Garrison et al. 2016), our data for timing of births and nursery habitat can also provide information for informed decision making when discussing land-use management and planning on public land in Utah.

We recognize that one limitation of our study is that we collected data on a relatively isolated population of desert bighorn sheep in southeastern Utah. However, that population is one of the largest in Utah (UDWR 2013), and our study areas received comparably little impact from recreation and oil and gas development, which will allow us to potentially extrapolate our results to other areas with much greater disturbance. Doing such is a powerful way to identify and conserve habitat in areas with higher anthropogenic impact, because conservation and management may be misapplied when resource selection models are produced from and used for animals influenced heavily by human activity (Harju et al. 2011). Additionally, using before-after/control impacts studies to document potential impacts of wildlife by humans is increasingly difficult, because of the pervasive influence of humans (Harju et al. 2011). Our results will

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become more salient as urban interface continues to encroach on bighorn sheep habitat. This is an important issue when trying to manage, conserve, and reintroduce bighorn sheep, especially in many areas where the urban interface encroaches on habitat of bighorn sheep (Etchberger et al. 1989, Turner et al. 2004, Clifford et al. 2009).

Identification of birthing and nursery habitat are becoming increasingly more important for bighorn conservation and management. It is important to identify how disturbance influences animals at different stages of their reproductive cycle (Stankowich 2008). Other researchers have recommended that hiking be confined to established trails during the birthing season, or that known lambing habitat should be closed to all hiking (Papouchis et al. 2001). Birthing and nursing habitat can be easily defined, because bighorn sheep use these areas consistently (Etchberger and Krausman 1999). Additionally, with GPS data being more readily accessible in wildlife studies; therefore, our methods could be replicated in other areas. Although, our data apply to areas in Utah, managers could use the same type of information to make management decisions for bighorn sheep.

In southeastern Utah, outdoor recreation and energy development has increased dramatically in the last 40 years and is predicted to continually increase (Papouchis et al. 2001). Forms of recreation that can potentially impact bighorn sheep are mountain biking, hiking, rafting and camping near rivers (Goodson et al. 1999, Papouchis et al. 2001), with hiking being most pronounced because of the unpredictable locations of that activity and people surprisingly approaching bighorn sheep, especially in spring when females are giving birth (Macarthur et al. 1979, Papouchis et al. 2001). In addition, this area is important for oil and gas development, mining, etc. Energy development is increasing drastically in the western USA (Knick et al. 2003, Knick et al. 2010, Dzialak et al. 2011). Some bighorn sheep avoid major roads during birthing

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(Zeigenfuss et al. 2000, Papouchis et al. 2001, Smith et al. 2015); whereas, others may adapt to human disturbance near roads, because of the predictable nature of vehicle travel on roads (Papouchis et al. 2001). Bighorn sheep can also become habituated to hikers if they remain in predictable locations on well-used trails (Hicks and Elder 1979).

The conservation of bighorn sheep populations remains an important issue across much of western North America (Buechner 1960, Krausman 2000, Gutierrez-Espeleta et al. 2001). Documenting the effects of human disturbance on wildlife is critical for effective management and conservation of animals, especially in an increasingly human-dominated world (Dzialak et al. 2011, Ciuti et al. 2012). Human-dominated landscapes, however, are complex and it can be challenging to disentangle all sources of human disturbance on wildlife (Ciuti et al. 2012). Human disturbance has caused the abandonment of habitat by desert bighorn sheep (Etchberger et al. 1989) and Rocky Mountain bighorn sheep (Wiedmann and Bleich 2014), decreased population performance (Wiedmann and Bleich 2014), and interrupted metapopulation dynamics for these animals (Epps et al. 2005). Two conservation and management questions often asked about wildlife are: 1) how does environmental change alter the spatial distribution of animals, and 2) are there demographic consequences of such environmental change (Moorcroft 2012). Answers to those questions are needed to conserve wildlife, especially in the face of human-caused changes (Moorcroft 2012). Indeed, human disturbance was one of the factors for the listing of one subspecies of bighorn sheep in California under the Endangered Species Act (US Fish and Wildlife Service 2000). As anthropogenic activity expands, conservation planning and management of habitat will increasingly rely on identifying preferred habitats by wildlife in areas of varying levels of human use (Goodson et al. 1999, Margules and Pressey 2000, Harju et al. 2011). Biologists can substantially reduce impacts from human activities to female bighorn

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sheep by identifying where and when animals give birth and rear young (Dzialak et al. 2011, Kaze et al. 2016).

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TABLES

Table 2.1. Model results (≥ 0.01 model weight) for habitat selection by desert bighorn sheep (*Ovis canadensis nelsoni*) ewes during nursery season in the North San Rafael Swell, Utah, 2012-2013, USA, showing number of parameters (K), corrected Akaike's Information Criterion (AICc), ΔAICc, model weight (ωi), and log likelihood (LL).

Model	*K*	AIC*c*	Δ AIC*c*	ω*i*	LL
Elevation + Slope + Ruggedness + Aspect + Existing Vegetation Type + Distance to Trails + Distance to Roads	14	1585.60	0.00	0.86	-778.66
Elevation + Slope + Ruggedness + Existing Vegetation Type + Distance to Trails + Distance to Roads	11	1589.45	3.85	0.13	-783.64

Table 2.2. Scaled β coefficients for nursery habitat resource selection from top model in Table 2.1, Emery County, Utah, USA, 2012-2013.

Parameter	β	SE	*Z*-value	*P*-value
(Intercept)	0.68	0.23	3.00	<0.01
Elevation	-0.48	0.07	-6.57	<0.001
Slope	0.59	0.09	6.87	<0.001
Ruggedness	0.51	0.09	5.78	<0.001
Aspect_East	0.02	0.18	0.09	0.93
Aspect_South	-0.55	0.21	-2.61	<0.01
Aspect_West	-0.20	0.18	-1.14	0.25
Existing Vegetation Type_Herb	-1.30	0.32	-4.11	<0.001
Existing Vegetation Type_Shrub	-1.09	0.20	-5.55	<0.001
Existing Vegetation Type_Sparse	-0.05	0.20	-0.23	0.82
Existing Vegetation Type_Tree	-1.11	0.34	-3.28	<0.01
Distance to Trails	-0.25	0.08	-3.24	<0.01
Distance to Roads	0.42	0.07	6.37	<0.001

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FIGURES

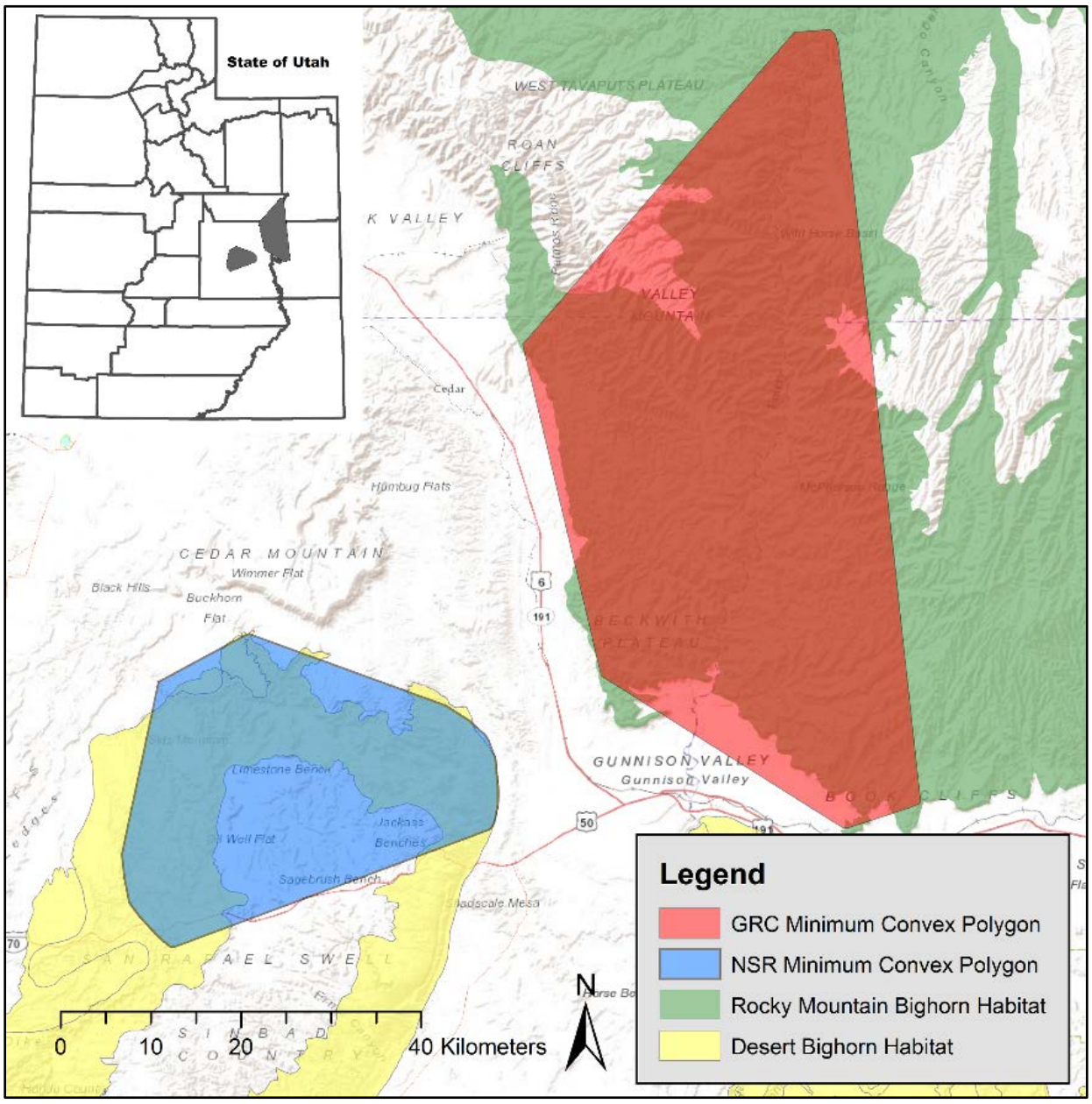

Figure 2.1. North San Rafael Swell and Green River Corridor study areas, southeastern Utah, 2012-2013.

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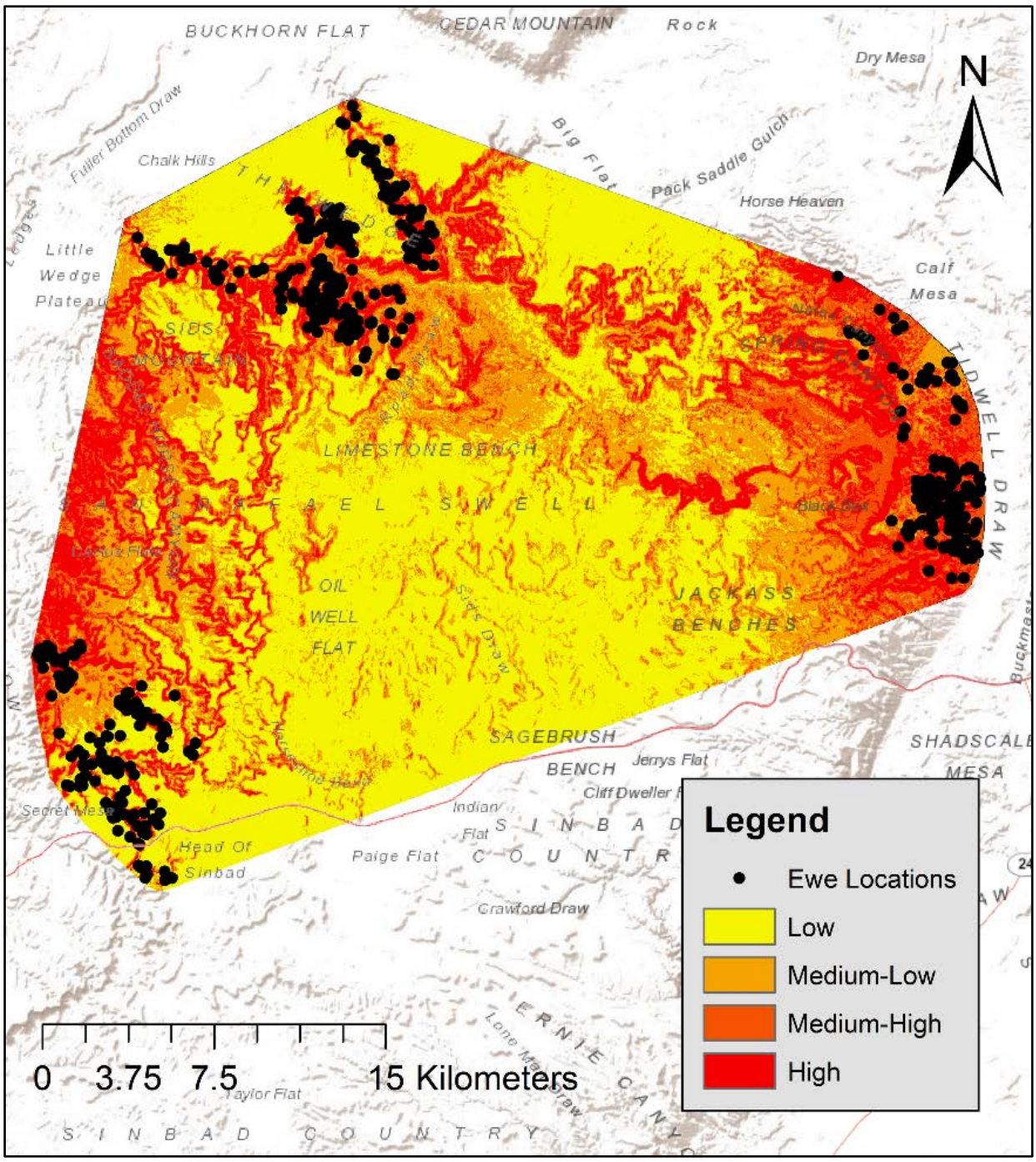

Figure 2.2. Predicted probabilities and associated categories of desert bighorn sheep (*Ovis canadensis nelsoni*) nursery habitat use in the North San Rafael Swell in spring 2012-2013, Emery County, Utah, USA.

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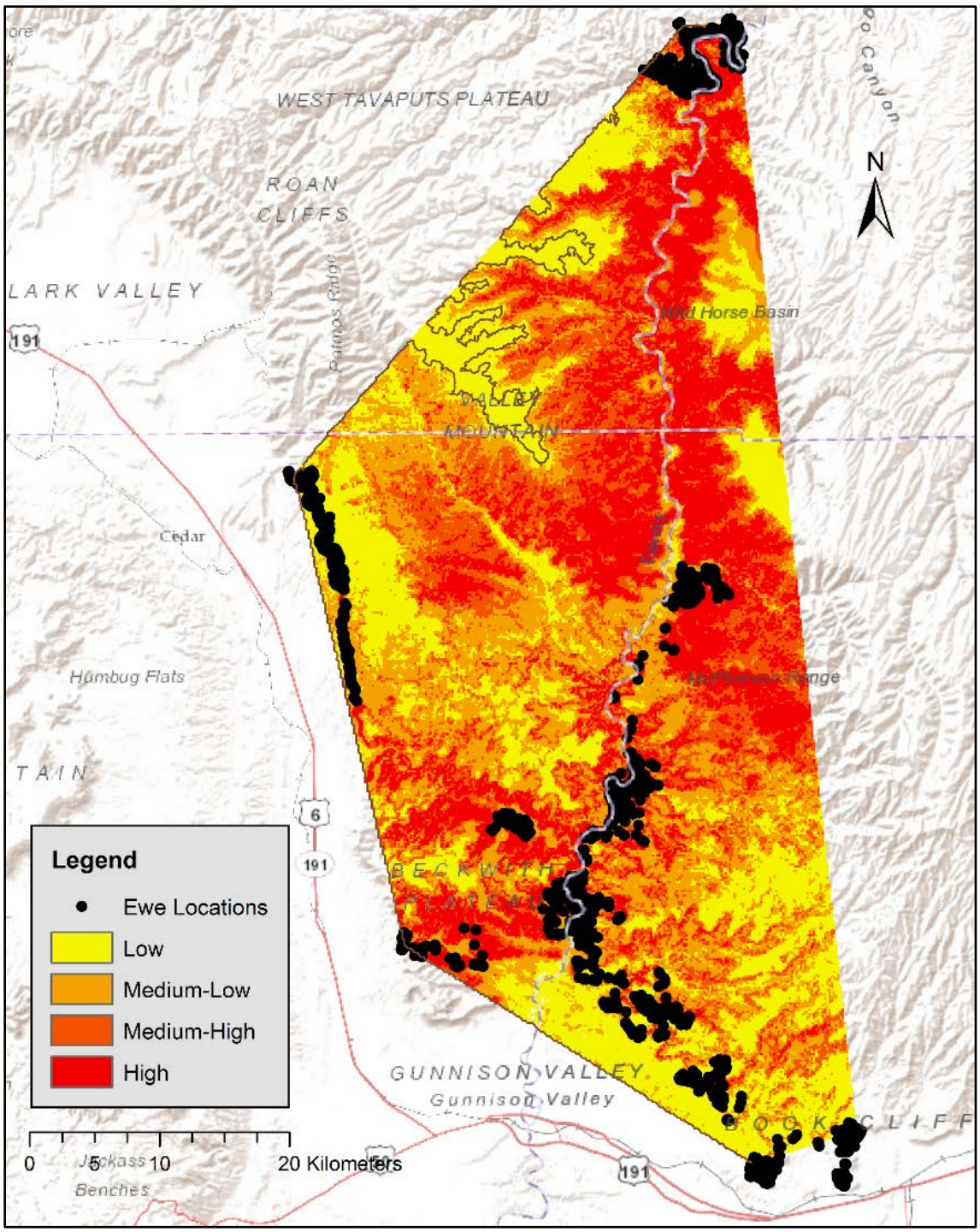

Figure 2.3. Predicted probabilities and associated categories of desert bighorn sheep (*Ovis canadensis nelsoni*) nursery habitat use in the Green River Corridor in spring 2012-2013, Carbon, Emery, Uintah, Grand Counties, Utah, USA.

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CHAPTER 3

Long-term evaluation of bighorn sheep augmentations: implications for habitat use and range expansion

ABSTRACT

Monitoring the dispersal and habitat use of released ungulates is important to understand success of translocations and reintroductions. Ungulates released into areas already occupied by resident animals may adjust dispersal and home range use based on the presence of resident animals; however, little is known about this dynamic. We monitored the space use of 127 reintroduced female bighorn sheep (*Ovis canadensis*) in three adjacent populations in northern Utah from 2000 to 2009 to investigate if the size and overlap of habitat use by augmented (2007 to 2009) bighorns differed from resident bighorns (2000 to 2007). On Mount Timpanogos, size of seasonal range-use areas (50% core areas and 95% utilization distributions) for resident bighorn sheep were at least 1.2 times larger (range = 1.2—3.8 times larger) than augmented females. Overlap of seasonal space use (50% core areas and 95% utilization distributions) was at least 2.9 times lower (range = 2.9—36 times) than residents for an augmented group from a high elevation area in Colorado compared with an augmented group from Montana and Utah residents. Additionally, augmented bighorns from Colorado shifted space use to areas 333 m (*SE* ± 425 m) higher in elevation. In Rock Canyon, sizes of seasonal range-use areas for resident females were at least 1.2 times smaller (range = 1.2—3.6) than augmented females, and overlap in space use was minimal. Augmented females in Rock Canyon shifted 95% utilization distributions 0.4 km to the north but expanded range by 3.9 km^2. Finally, on Mount Nebo, although from the same source herd, augmented bighorn annual range-use estimates were 1.2 larger than for resident bighorns. Overlap in annual space use by augmented females was minimal, augmented females used higher elevations ($\bar{x}$ = 260 m, *SE* ± 304 m), shifted 95%

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utilization distributions 4.2 km north, and expanded range by 6.5 km^2. Our results provide important insight regarding how augmented bighorn sheep mix with resident animals and use habitat after releases. This information is needed to improve our understanding of reintroduced bighorn sheep populations.

INTRODUCTION

Monitoring the dispersal and habitat use of released ungulates is important to understand rates of dispersal, release-site fidelity, feasibility of future releases, and success of translocations and reintroduction (Singer et al. 2000c, La Morgia et al. 2011, Yott et al. 2011). Exploratory movements by reintroduced animals allow them to become acquainted with their environment (Ryckman et al. 2010, Scillitani et al. 2013), may connect isolated populations (Gross et al. 2000, La Morgia et al. 2011), or reconnect populations in a metapopulation structure (Bleich et al. 1996). Dispersal of released ungulates can be influenced by gender, age, and group dynamics (Ryckman et al. 2010, Yott et al. 2011). These exploratory movements, however, can increase mortality by predation and be energetically costly (Nicholson et al. 1997, Stamps et al. 2005, Scillitani et al. 2013). Quantifying habitat use of recently released ungulates is critical for conservation and management of these animals and their habitat (Scillitani et al. 2013, Yan et al. 2013). For example, translocated bighorn sheep (*Ovis canadensis*) released into suitable habitat that established seasonal migrations increased the probability of translocation success (Singer et al. 2000a, Singer et al. 2000b, Zeigenfuss et al. 2000). Understanding dispersal and habitat use of reintroduced animals that are naïve to their surroundings is critical for successful reintroductions (Griffith et al. 1989, Seddon et al. 2007), especially in cases when survival or reproductive rates

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are low, as animals become accustomed to the habitat of their release site (Stussy et al. 1994, Armstrong and Seddon 2008, Whiting et al. 2011, Wiedmann and Sargeant 2014).

Ungulates released to new areas may adjust dispersal and home range use based on the presence of resident animals. For example, gregarious ungulates that are translocated can use different areas because of interference competition with resident animals (Dolev et al. 2002), or they can slowly assimilate space use with resident animals (Dolev et al. 2002, Scillitani et al. 2013). Some individuals released later may establish home ranges similar to those of previously released animals (Dolev et al. 2002). This adaptation of home range use of resident animals by released individuals may happen quickly or can take up to three years (Dolev et al. 2002, Scillitani et al. 2012, Scillitani et al. 2013). Individuals that assimilate with resident animals can increase success of reintroductions by settling in areas used by resident animals; therefore, increasing population size and probability of population persistence (Scillitani et al. 2013).

In the past, bighorn sheep reintroductions have been conducted to establish new populations or to ostensibly expand the distributions of existing herds (Risenhoover et al. 1988, Krausman 2000, Singer et al. 2000b). Sedentary populations that receive additional translocated individuals potentially will increase migration and movements of both resident and augmented animals (Singer et al. 2000b). This expansion was hypothesized to occur, because these ungulates have open societies and migration patterns, and the use of seasonal ranges are learned and passed through generations (Geist 1971). Therefore, transplanting bighorn sheep into areas with established herds may result in the transfer the habitat use knowledge from residents to augmented individuals (Geist 1971, Festa-Bianchet 1986). Transplanted individuals should not disperse widely and should follow resident movements (Geist 1971). However, some studies have found that transplanted bighorns used different home ranges within the first two and one

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half years after release (Roy and Irby 1994), but the degree to which that difference in habitat use occurred was not documented. This type of behavior could increase the area used by a herd and consequently the carrying capacity of the habitat, which could be beneficial for sedentary, resident populations that underutilize available habitat (Roy and Irby 1994). In fact, Singer et al. (2000a) recommended that sedentary populations receive additional translocations to increase migration and movements, but to our knowledge this strategy has not been tested. We posit that much can be learned from augmented animals and how they interact with resident animals, which can improve reintroduction and translocation success.

Reintroductions of bighorn sheep are likely to proceed at an increasing rate, especially with habitat loss and fragmentation further threatening bighorn populations (Hein et al. 1997, Seddon et al. 2007). Transplanted populations of bighorn sheep, however, may be small, isolated, and non-migratory, which may lead to higher susceptibility of failure (Risenhoover et al. 1988). Understanding factors that affect habitat use in a new environment is critical for improving conservation programs that use reintroductions (Scillitani et al. 2013). Although, few long-term studies have been conducted for translocated animals (Darmon et al. 2007) and little is known regarding how reintroduced bighorns will potentially adapt habitat-use patterns of resident animals. We monitored 127 reintroduced female bighorn sheep in three sympatric populations in northern Utah, USA from 2000 to 2009 to investigate if augmented female bighorns expanded seasonal ranges compared with resident female bighorns. Specifically, we predicted that augmented sheep would occupy similar areas (50% core areas and 95% seasonal utilizations distributions) and select abiotic habitat characteristics (slope, aspect, elevation, and vegetation type) similar to those used by resident female bighorns. Our results provide important data regarding how augmented bighorn sheep mix with, and use habitat of, resident animals.

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Such information is needed to improve our understanding of reintroducing these ungulates into historical habitat.

STUDY AREA

We studied female Rocky Mountain bighorn sheep (*O. c. canadensis*) that were reintroduced to Mount Timpanogos, Rock Canyon, and Mount Nebo in northern Utah, USA (Figure 3.1). Those populations occupy the Uinta National Forest of the Wasatch Mountains. Elevation in those areas ranges from 1,388 to 3,636 m (Whiting et al. 2008). Mean summer temperature was 19º C, and average winter temperature was 3º C (Whiting et al. 2011). Mean annual rainfall is 51 cm and the average yearly snowfall 145 cm (Shannon et al. 2014). Similar topography and flora occur in all three study areas. Generalized vegetative zones descending in elevation is alpine, conifer, aspen (*Populus tremuloides*), maple (*Acer* spp.), juniper (*Juniperus* spp.), big sagebrush (*Artemisia tridentata* ssp.), forbs, and grasses (Whiting et al. 2008). Prominent forage species in those areas used by bighorn sheep include bluebunch wheatgrass (*Elymus spicatus*), spike fescue (*Lecopoa kingii*), Sandberg's bluegrass (*Poa secunda*), shortstem buckwheat (*Eriogonum brevicaule*), and littlecup penstemon (*Penstemon sepalulus*) (Whiting et al. 2010b).

METHODS

From 2000 to 2007, 157 bighorn sheep were released onto Mount Timpanogos (n = 82), Rock Canyon (n = 32), and Mount Nebo (n = 43), (Table 3.1). Ninety-six females were equipped with VHF radio collars at the time of release (Table 3.1), and 12 additional females were collared periodically throughout the study (Shannon et al. 2014) for a total of 68 collared resident females

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and 52 augmented females. In addition, 19 females received identifiable ear tags but no collar. In releases of resident female bighorn sheep (Mount Timpanogos 2000 to 2002, Rock Canyon 2001, and Mount Nebo 2004), all adult females in Rock canyon and Mount Nebo had colored ear tags. On Mount Timpanogos, all females had blue ear tags from the 2001 release from Alberta, Canada, and females released from Sula, Montana in 2002 had blue ear tags. Wildlife biologists from the Utah Division of Wildlife Resources (UDWR) used care when handling, translocating, and attaching radio-transmitting collars and ear tags to bighorns (Sikes 2016).

We located bighorn sheep with radio collars using radio telemetry equipment, binoculars, and spotting scopes year-round from 2000 to 2009 for Mount Timpanogos, 2000 to 2008 for Rock Canyon, and 2004 to 2009 for Mount Nebo (Whiting et al. 2011, Whiting et al. 2012, Shannon et al. 2014). We observed groups of bighorns an average of 24 times each month. When we observed groups of bighorns, we noted sex of individuals, group size, and composition (Whiting et al. 2010b). We considered undisturbed animals to be a part of the same group if they were ≤ 50 m from one another, or if they appeared to be aware of the presence of other sheep and moved as a cohesive unit (Bleich et al. 1997, Whiting et al. 2010b). We only used sightings that contained ≥ 1 female bighorn sheep for analysis. In all areas, those sightings could include young, yearlings, and males, as long as ≥ 1 adult female was present in the group.

To differentiate resident from augmented individuals, bighorns released in all study areas in 2007 were marked with two colored ear tags (Table 3.1) (Scillitani et al. 2012). Therefore, after releases in 2007, all augmented females had either a radio-transmitting collar or ear tags, which facilitated group structure classification. Consequently, all unmarked ewes observed after augmentation, and before April 2009, could be distinguished as either adult residents, lambs, or yearlings. Lambs or yearlings observed alone, and therefore indistinguishable from any group,

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were censored from the database (one observation from Rock Canyon; <1%). From April 1–December 31, 2009 two-year-old ewes (offspring of augmented ewes) could not be accurately distinguished from resident uncollared ewes. In these cases, the locations were censored from the analysis. In total, four locations (1%) were censored from Mount Nebo and 28 (1.7%) were censored from Mount Timpanogos.

After initial reintroduction of bighorn sheep on Mount Timpanogos in 2000, two subsequent releases occurred in 2001 and 2002 totaling 14 females. We considered all bighorn sheep released from 2000 to 2002 on Mount Timpanogos as resident animals and those released in 2007 as augmented bighorns (Table 3.1; Shannon et al. 2014) for the following reasons: 1) survival rates for those 14 females released from 2000 to 2002 were low (Shannon et al. 2014); 2) similar clumping of ungulates released in subsequent years has been done in other studies (Scillitani et al. 2013). We also considered animals released in Rock Canyon (2001) and on Mount Nebo (2004) as resident animals and those released in 2007 as augmented bighorns (Table 3.1; Shannon et al. 2014). Consequently, in all study areas there was at least three years separating releases of residents and augmented sheep. Other studies indicate that it can take up to 3 years for augmented ungulates to assimilate with residents animals (Scillitani et al. 2012). Finally, with our combining animals across 3 years as resident on Mount Timpanogos, all augmented sheep were released in the same year which helped control for environmental factors that could have potentially influenced movements and space use (e.g., snow depth).

To produce utilization distributions and subsequent analyses, we defined bighorn groups as follows: resident was ≥ 1 adult female bighorn sheep from original releases, augmented was ≥ 1 adult female bighorn sheep from 2007 augmentations mixed with yearlings, lambs, and males. After release of augmented bighorns, when groups of resident and augmented bighorn sheep

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were mixed, we assigned a location for each group (resident or augmented) for each sighting. During our study, two augmented individuals released in Rock Canyon crossed a major highway that was considered a barrier to major movements of bighorn sheep and occupied areas on Mount Timpanogos (Whiting et al. 2011). We censored locations from these individuals because their inclusion caused utilization distribution estimates for Rock Canyon augmented bighorns to be overestimated.

We calculated seasonal and annual 50% core use areas and 95% kernel utilization distribution (Rubin et al. 2002, Oehler Sr et al. 2003, Whiting et al. 2010a) by study area and groups (resident or augmented) using the direct plug-in methodology to select bandwidth (Sheather and Jones 1991, Wand and Jones 1994), and only produced core areas and utilization distribution for areas or seasons with ≥ 18 locations, which has been done before for bighorn sheep (Rubin et al. 2002). We determined seasons by plotting precipitation against temperature, which has been done previously for these areas (Whiting et al. 2008). The following four seasons were evident for this area: spring (March–May), summer (June–September), autumn (October), and winter (November–February); (Whiting et al. 2008). Because October is a transitional month (Whiting et al. 2008), and sample sizes were <18 for all study areas, we did not produce seasonal UDs for autumn. However, autumn locations were included in annual UDs. We also compared seasonal and annual core areas utilization distributions for resident bighorns before (2000-2006) and after augmentations (2007-2009) to assess whether or not utilization distributions were altered by the presence of augmented individuals.

After UDs were produced by study area, season, and provenance group (resident or augmented), we quantified overlapping space use between groups using the utilization distribution overlap index (UDOI) (Fieberg and Kochanny 2005). UDOI values typically range

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from 0 to 1, with 0 indicating no overlap and 1 indicating 100% overlap. UDOI can be greater than 1 when UDs are nonuniformly distributed and have a high degree of overlap. We used the KernSmooth package (Wand and Jones 1994) for kernel smoothing and density estimation and the adehabitat package (Calenge 2006) for home range analysis and mapping. To quantify shifts in distribution of the overall population as a result of augmentations, we used the calculate geometry feature in ArcGIS to create a centroid for 95% kernel UD polygons of bighorn locations before (2000-2007) and after augmentations (2007-2009) and measured the linear distance between them. We also measured overall UD area before and after augmentation, not by provenance group, but for the population as a whole, to assess any changes in overall UD.

Lastly, we examined abiotic features potentially influencing bighorn sheep habitat selection such as slope and ruggedness (Bleich et al. 1997, Sappington et al. 2007, Longshore et al. 2013), elevation, aspect, and LANDFIRE existing vegetation type (Rollins 2009), and compared habitat use between resident and augmented bighorns (Roy and Irby 1994). All areas were historical bighorn sheep habitat and identified as suitable release sites by the Utah Division of Wildlife Resources. Topographic features were extracted using a USGS 30 m digital elevation model. Slope was calculated using the slope tool in the Spatial Analyst Tools extension for ArcGIS. Ruggedness was calculated using the VRM tool in the Terrain Tools extension (Sappington et al. 2007). Aspect was calculated using the aspect tool in the Spatial Analyst Extension of ArcGIS and was divided into the four cardinal directions (north, east, south, west). The LANDFIRE existing vegetation type layer (Rollins 2009) consisted of six types (barren, developed, herb, shrub, sparse, and tree). We used a 95% confidence interval of the difference of means to test for differences in bighorn habitat use of numerical abiotic factors (slope, elevation, ruggedness) between groups within respective study areas (Baxter et al. 2008, Dahlgren et al.

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2016). We used a chi-square test to compare use of categorical variables (aspect, existing vegetation type) between groups within respective study areas.

RESULTS

We used 1,613 sightings to produce seasonal and annual core areas and utilization distributions for female bighorn sheep in the Mount Timpanogos, 708 in the Rock Canyon, and 403 in the Mount Nebo (Table 3.2). On Mount Timpanogos, size of seasonal range-use areas (50% core areas and 95% seasonal utilization distributions) for resident bighorn sheep were at least 1.2 times larger (range = 1.2—3.8 times larger) than estimates for augmented females (Table 3.2). Augmented female bighorn sheep from Colorado had a smaller annual utilization distribution compared with those of resident and Montana bighorns, with the smallest areas used in spring by the Colorado females (Table 3.2). In Rock Canyon, size of seasonal range-use areas for resident females was at least 1.2 times smaller (range = 1.2— 3.6) than estimates for augmented females. The smallest seasonal range for resident females in Rock Canyon was during birthing (spring; Table 3.2). On Mount Nebo, annual range-use estimates were 1.2 larger for resident bighorns compared with estimates for augmented females (Table 3.2).

Utilization distributions for resident bighorn sheep before and after augmentation exhibited a high degree of overlap for Mount Timpanogos (UDOI = 1.09) and Rock Canyon (UDOI = 1.00) signifying little change in seasonal range use of resident animals after augmentations. UDOI values were lower (0.44) on Mount Nebo for resident females before and after augmentation. Overlap of seasonal space use (50% core areas and 95% seasonal utilization distributions) on Mount Timpanogos was comparable for resident animals and augmented females from Montana (Table 3.3). Overlap of space use for was at least 2.9 times lower (range =

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2.9 to 36 times lower) for augmented females from Colorado compared with an augmented group from Montana and resident females, with the lowest overlap occurring in winter and summer (Table 3.3). Overlap in space use was minimal by augmented female bighorn sheep in Rock Canyon and Mount Nebo, with the least overlap occurring in spring in Rock Canyon (Table 3.4).

On Mount Timpanogos, augmented bighorns from Colorado shifted 95% utilization distributions to areas on average 333 m (*SE* ± 425 m) higher in elevation (Figure 3.2; Table 3.5). Overall, augmentations on Mount Timpanogos expanded UD by 5.17 km^2 with a 1.2 km shift in utilization. In Rock Canyon, augmented females shifted 95% utilization distributions a linear distance of only 0.4 km to the north, however, UD was expanded in both the north and south directions to an area 3.9 km^2 larger than before augmentation (Figure 3.3). Finally on Mount Nebo, augmented females used areas of higher elevations ($\bar{x}$ = 260 m, *SE* ± 304 m, Table 3.5), shifted 95% utilization distributions 4.2 km north of distributions of resident animals, and expanded range by 6.5 km^2 (Figure 3.4).

DISCUSSION

Habitat structure and movement among bighorn sheep populations increases the probability of bighorns encountering other populations, which transfers that information of habitat use to other individuals (Geist 1971, Risenhoover et al. 1988). Augmented bighorn sheep in our study areas would potentially benefit from this excessive movement with the possibility of finding new habitat or encountering other individuals (Risenhoover et al. 1988). On Mount Timpanogos, space use for females was similar for resident and augmented Montana females; more so than for females released from Colorado. Those individuals from Colorado came from a

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source herd that used year-round habitat at high elevations. One purpose of releasing those bighorns was to expand range use of resident animals to areas of higher elevation. Our results indicate that such a release did expand range use to areas of higher elevation. We hypothesize that augmented Montana and resident females will continue to intermix and increase range use in this area (Roy and Irby 1994).

In Rock Canyon, augmented female bighorns increased UD size and shifted 50% core areas and 95% utilization distributions compared with those of resident females. That shift in size and direction was greatest in spring. Resident females in Rock Canyon used small rocky areas to give birth and small winter ranges. Augmented animals expanded those seasonal ranges, especially during spring when females are giving birth. Additionally, resident bighorn sheep in Rock Canyon came from an open-pit coal-mining site in Alberta, Canada (Demarchi et al. 2000). Bighorns in that area use limited seasonal ranges. We hypothesize that animals that are captured in areas with limited seasonal range use will establish similar patterns of range use when transplanted to new ranges. Supporting this notion, the Alberta source herd utilized a UD much smaller than those used by augmented individuals from Montana.

On Mount Nebo, both resident and augmented bighorn sheep were transplanted from the same source herd. Overlap in annual space use by augmented females was minimal. Augmented females used areas of higher elevations, shifted 95% utilization distributions 4.2 km north of distributions of resident animals, and expanded range by 6.5 km^2. Although from the same source herd, augmentations of individuals separated by 3 years used habitats much differently. All three populations of bighorns exhibited expanded UD size after augmentations even though all three populations reached their highest population sizes prior to augmentations (Shannon et al. 2014). Likewise, all three populations showed a shift in spatial utilization after augmentation.

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This is especially important to managers who wish to expand UD of existing populations. Our data indicate that this could be accomplished with augmentations.

Variation in resource utilization was minimal when comparing residents to augmented females, although some differences in elevation were observed, presumably a function of elevational differences between source areas from which transplanted sheep originated. While all chi-square utilization comparisons of existing vegetation type and aspect were statistically different, we suggest that these results are not biologically different. All groups exhibited a preference for a southwest orientation, and trees and shrubs were the top two vegetation type categories utilized by all groups.

Bighorn sheep are generally considered poor colonizers (Geist 1971). Native female bighorn sheep may recognize individuals from their own group and may not readily join other groups even if their range use overlaps (Festa-Bianchet 1986). For example, when new bighorn sheep joined an existing band of bighorns, the animals would sniff each other as dogs do for identification (Woolf et al. 1970). Therefore, consideration for groups of individual animals in an area need to be considered when conserving or managing habitat. Management strategies designed to conserve a resource that is important, on average, to the population may overlook resources that are critical to individuals that comprise a smaller demographic segment that functions disproportionately in population persistence (Dzialak et al. 2011).

Populations of bighorn sheep (*Ovis canadensis*) have declined substantially since the late 1800s, and these ungulates face a precarious future (Buechner 1960, Geist 1971, Krausman 2000). Transplants of bighorn sheep are often used to re-establish populations in historic habitat and to supplement declining herds (Risenhoover et al. 1988, Roy and Irby 1994, Singer et al. 2000b). Despite those efforts, success rate of translocated populations of bighorns is low (Roy

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and Irby 1994, Krausman 2000, Singer et al. 2000b). Connectivity and continuous habitat between reintroduced herds and other herds are crucial for successful bighorn sheep transplants (Singer et al. 2000a).

Several studies aptly describe the large-scale habitat parameters (e.g. size of winter range, distance to perennial water, etc.) of release sites necessary to improve reintroduction success (Woolf et al. 1970, Singer et al. 2000b, Zeigenfuss et al. 2000). No published data, however, compare the use of habitat by reintroduced individuals with the use of habitat of their source population. We documented shifts in size and direction of seasonal range-use areas (50% core areas and 95% seasonal utilization distributions) for resident bighorn sheep and augmented bighorn sheep in three populations in northern Utah. Our results provide important data on how augmented bighorn sheep mix with resident animals and use habitat after releases. Such information is needed to improve our understanding of reintroducing ungulates.

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TABLES

Table 3.1. Locations, years of capture, source areas, and demographic information for populations of bighorn sheep (*Ovis canadensis*) released in northern Utah, USA.

Release site and date	Source area	Males	Females	Young	Total	% Females collared
Mount Timpanogos						
Jan-2000[a]	Rattlesnake Canyon, Utah	6	16	3	25	81
Jan-2001[a]	Hinton, Alberta, Canada	2	8	0	10	100
Feb-2002[a]	Sula, Montana	2	6	1	9	67
Jan-2007	Sula, Montana	0	20	0	20	70
Mar-2007	Alamosa, Colorado	1	17	0	18	100
Rock Canyon						
Jan-2001[a]	Hinton, Alberta, Canada	4	15	3	22	67
Jan-2007	Sula, Montana	0	5	0	5	60
Jan-2007	Augusta, Montana	0	5	0	5	60
Mount Nebo						
Dec-2004[a]	Augusta, Montana	2	13	3	18	69
Jan-2007	Augusta, Montana	3	22	0	25	59

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Table 3.2. Study areas and number of observations used to calculate size (km^2) of 50% and 95% seasonal and annual utilization distributions for 127 female bighorn sheep (*Ovis canadensis*) in three populations in northern Utah from 2000 to 2009.

		50%				95%			
Study Areas	*n*	Winter	Spring	Summer	Annual	Winter	Spring	Summer	Annual
Mount Timpanogos									
Resident	922	1.83	2.48	2.63	2.70	13.74	14.14	17.17	19.50
Aug. Montana	364	0.98	1.09	1.81	2.13	7.14	7.34	11.02	14.19
Aug. Colorado	327	0.97	0.65	1.92	1.59	6.16	5.18	11.8	13.07
Rock Canyon									
Resident	579	0.49	0.31	0.86	0.73	2.87	2.25	4.20	4.20
Augmented	129	0.86	1.10	1.08	1.28	4.20	4.68	5.58	6.63
Mount Nebo									
Resident	146	1.43	1.56	2.11	2.79	6.41	8.08	8.85	12.27
Augmented	256	0.69	0.48	1.61	2.14	4.18	2.06	7.58	10.21

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Table 3.3. Overlap of 50% and 95% utilization distributions for reintroduced bighorn sheep (*Ovis canadensis*) on Mount Timpanogos, Utah, USA, 2000-2009.

Timpanogos	Augmented Montana								Augmented Colorado							
	Winter		Spring		Summer		Annual		Winter		Spring		Summer		Annual	
	50%	95%	50%	95%	50%	95%	50%	95%	50%	95%	50%	95%	50%	95%	50%	95%
Resident	0.36	1.23	0.3	1.11	0.41	1.08	0.45	1.23	0.01	0.19	0.02	0.38	0	0.22	0.01	0.32

Table 3.4. Overlap of 50% core areas and 95% utilization distributions between augmented bighorn sheep (*Ovis canadensis*) in Rock Canyon and Mount Nebo, Utah, USA compared with resident bighorns. All augmented bighorn sheep came from Montana.

Rock Canyon and Mount Nebo	Augmented Montana							
	Winter		Spring		Summer		Annual	
	50%	95%	50%	95%	50%	95%	50%	95%
Resident Rock Canyon	0.39	0.83	0.13	0.43	0.43	0.8	0.34	0.79
Resident Mount Nebo	0.37	0.55	0.23	0.38	0.37	0.56	0.32	0.63

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Table 3.5. Topographical factor habitat use comparisons for numerical variables by study area and provenance group, 2000–2009, Utah County, Utah, USA. SE, standard error; LCL, lower confidence limit for the 95% confidence intervals of the difference in means; UCL, upper confidence limit for the 95% confidence intervals of the difference in means.

Abiotic Factor	Provenance Group	*n*	x̄	SE	LCL	UCL
Slope	MT Resident	922	69.7	29.9	-4.028	2.63
	MT Colorado	327	69	29.9		
	MT Resident	922	69.7	29.9	-0.97	5.43
	MT Montana	364	71.9	29.9		
	RC Resident	579	81.8	29.9	-14.9	-4.83
	RC Augmented	129	72	30		
	NB Resident	146	67.4	2.73	-2.87	7.85
	NB Augmented	257	69.9	21.17		
Elevation	MT Resident	922	1989	425.4	286.5	381
	MT Colorado	327	2322	425.8		
	MT Resident	922	1989	425.4	22.4	113.3
	MT Montana	364	2057	425.8		
	RC Resident	579	1907	425.5	-107.1	35.9
	RC Augmented	129	1871	426.6		
	NB Resident	146	2504	38.8	184.7	335.5
	NB Augmented	257	2764	303.7		
Ruggedness	MT Resident	922	0.016	0.02	-0.0034	0.0011
	MT Colorado	327	0.015	0.02		
	MT Resident	922	0.016	0.02	-0.0024	0.0019
	MT Montana	364	0.016	0.02		
	RC Resident	579	0.016	0.02	-0.0059	0.0009
	RC Augmented	129	0.014	0.02		
	NB Resident	146	0.015	0.0018	-0.0052	0.002
	NB Augmented	257	0.013	0.014		

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FIGURES

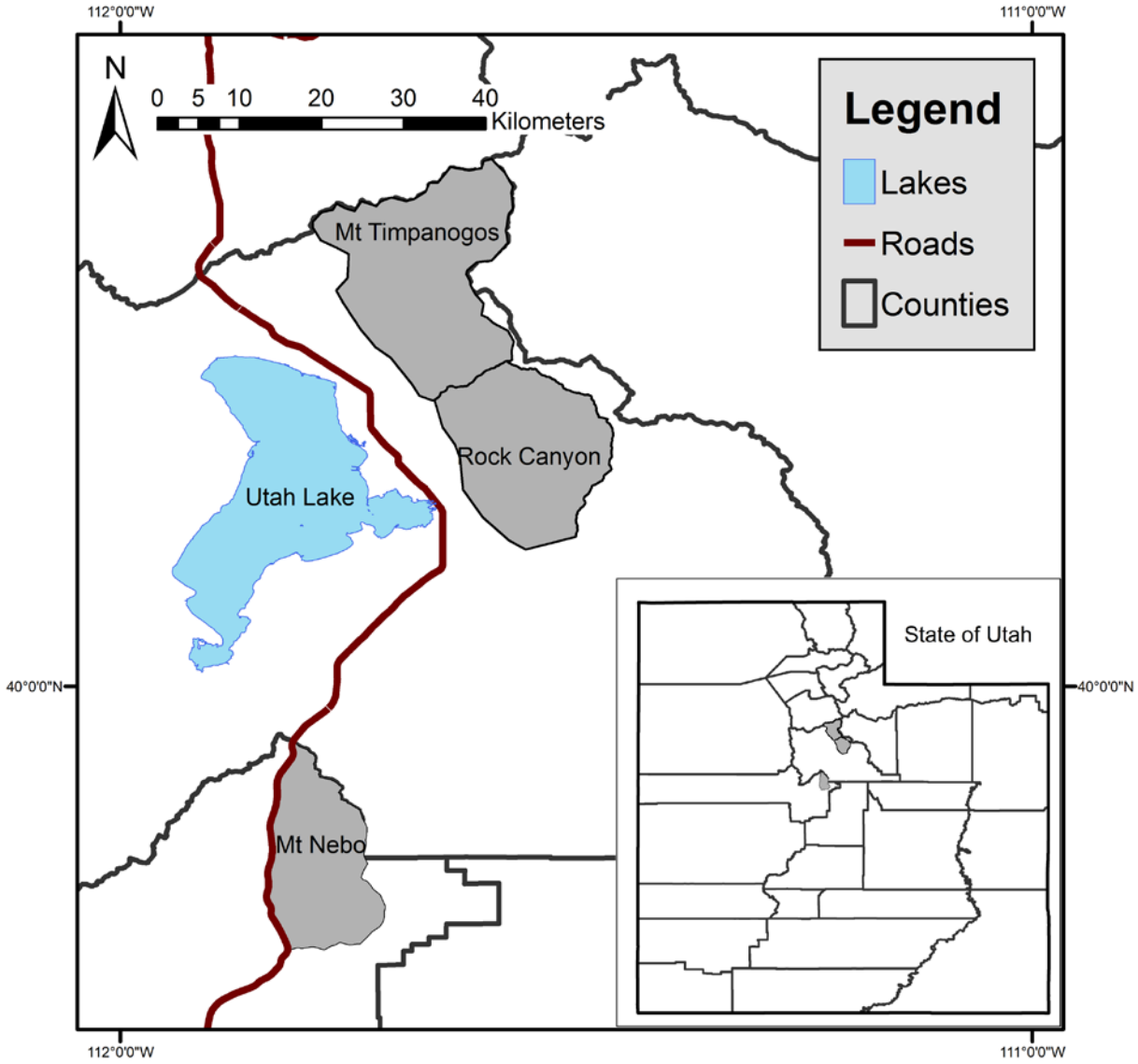

Figure 3.1. Areas in which we tracked reintroduced bighorn sheep (*Ovis canadensis*) to document movements and habitat use on Mount Timpanogos, Rock Canyon, Mount Nebo, Utah County, Utah, from 2000 to 2009.

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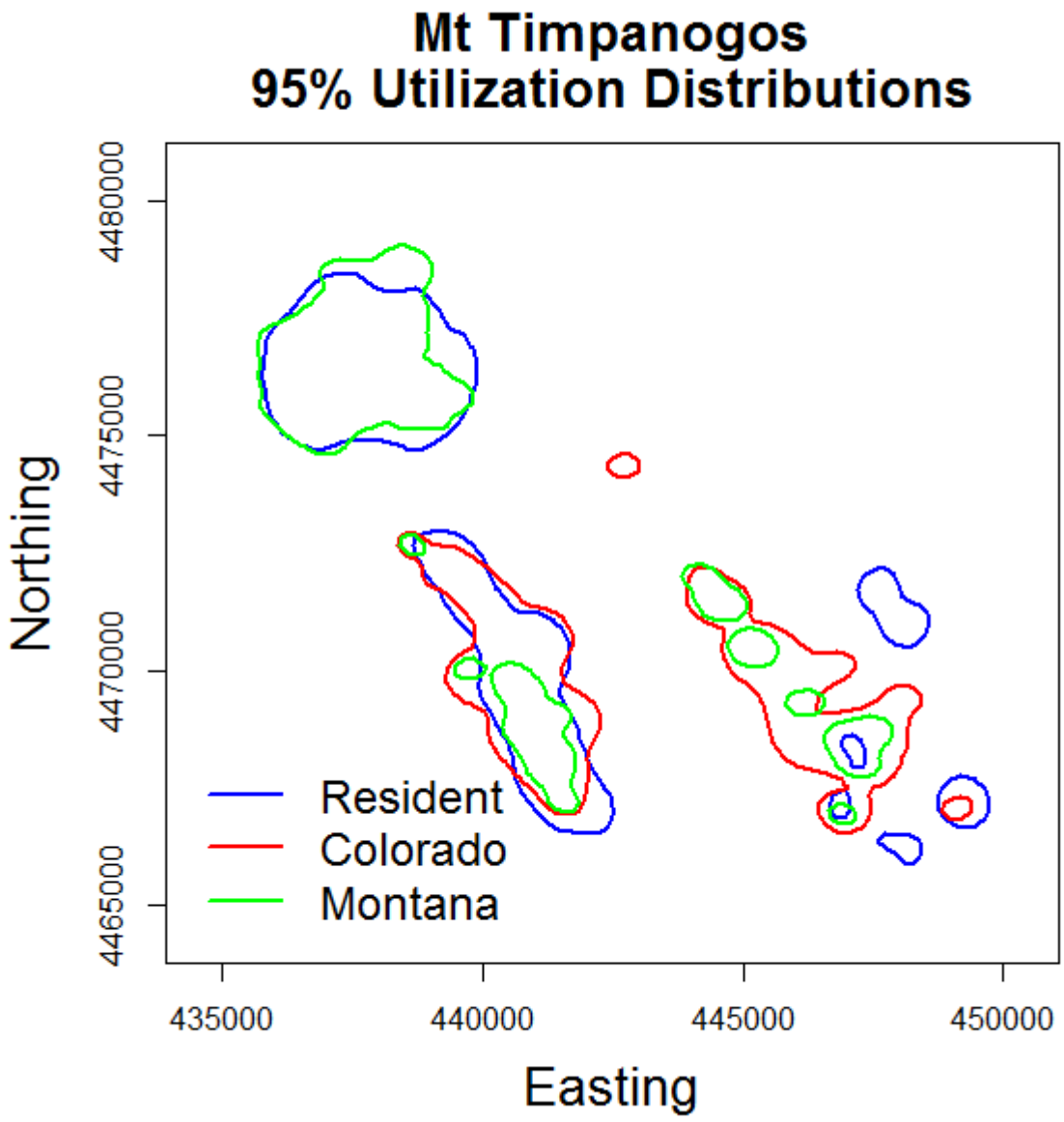

Figure 3.2. Mount Timpanogos 95% utilization distributions for resident, Montana augmented, and Colorado augmented provenance groups, Utah County, UT, 2000-2009.

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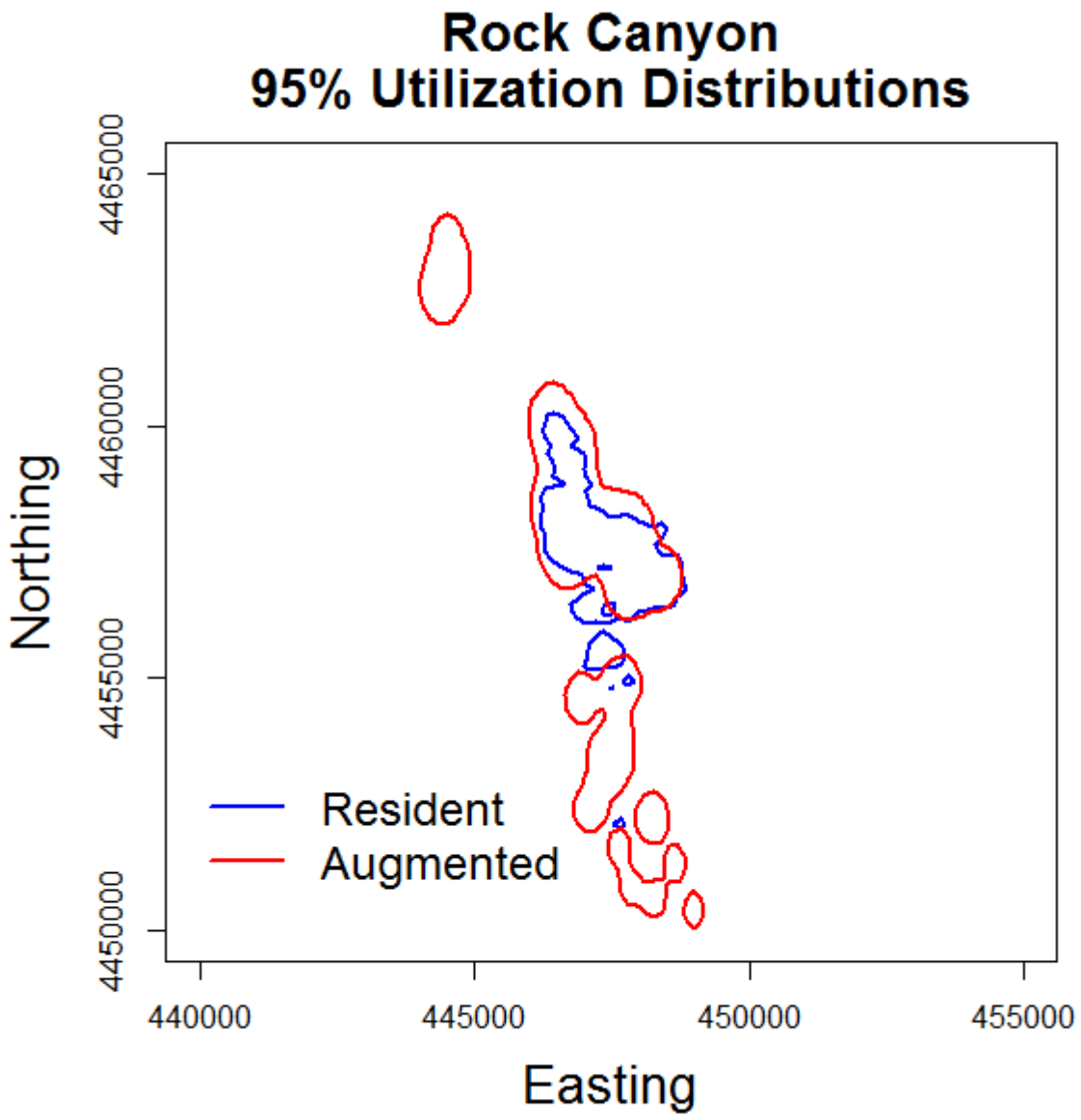

Figure 3.3. Rock Canyon 95% utilization distributions for resident and augmented provenance groups, Utah County, UT, 2001-2009.

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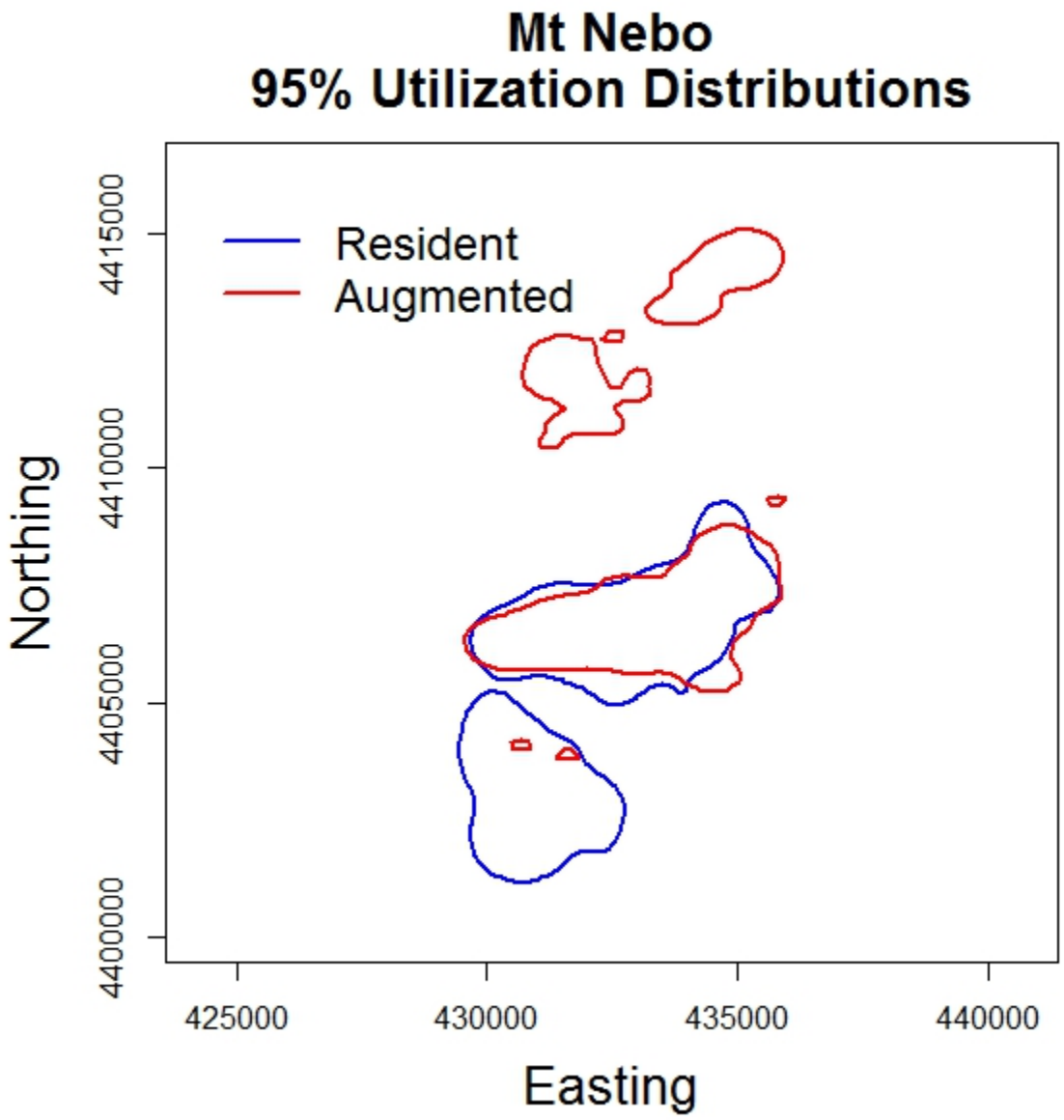

Figure 3.4. Mount Nebo 95% utilization distributions for resident and augmented provenance groups, Utah County, UT, 2004-2009.

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