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Alteration of behavior by desert bighorn sheep from human recreation and Desert Bighorn Sheep Survival in Canyonlands National Park: 2002 - 2010

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Alteration of Behavior by Desert Bighorn Sheep from Human Recreation and Desert Bighorn Sheep Survival in Canyonlands National Park: 2002 – 2010

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A thesis submitted to the faculty of
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ABSTRACT

Alteration of Behavior by Desert Bighorn Sheep from Human Recreation
and Desert Bighorn Sheep Survival in Canyonlands
National Park: 2002 – 2010

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Human encroachment into wilderness areas can influence the persistence of wildlife populations by decreasing and degrading habitat, displacement, and decreasing survival. For bighorn sheep (*Ovis canadensis*), some human activities are detrimental, causing both physiological stress and habitat abandonment. Between 1979 and 2000, human recreation has increased over 300% in areas occupied by desert bighorn sheep (*O. c. nelsonii*) in southeastern Utah. We investigated if an increase in human activity in areas used by bighorns affected their behavior. We observed 34 bighorn sheep using focal-animal sampling for >14 hrs to compare time spent grazing and scanning between areas of high and low human use. We identified group size, presence or absence of a lamb, distance to escape terrain, and human use (high versus low) as potential explanatory variables that influenced grazing and scanning times, and created an *a priori* list of models based on these variables. We used Akaike's Information Criterion adjusted for small sample sizes (AICc) to rank models, and used model selection to find a best approximating model (lowest AICc value) for both behaviors. Desert bighorn sheep spent less time grazing and more time scanning in high human use areas (22% grazing, 29% scanning) than in low human use areas (54% grazing, 8% scanning). Caution should be taken when considering which areas or trails should be opened during these important seasons to minimize and reduce additional stresses to bighorns caused by human activity.

Bighorn sheep populations experienced significant declines after European settlement in North America. Today, the primary practice of bighorn sheep conservation is through population restoration and augmentation from remnant source populations. We conducted a 9-year telemetry study for a source population of desert bighorn sheep in Canyonlands National Park, Utah. We captured and collared 58 bighorn sheep from 2002—2009. To estimate annual and seasonal survival, we used known-fate analysis in Program MARK 4.1. We used model selection to test hypotheses for bighorn survival, including sex, age, human use, year, and month, as possible explanatory variables. There were 20 mortalities during the study. Annual survival ranged from 83% – 88% with no significant variation among any of the years. Model selection results showed that the top six models included a temporal variable (*e.g.* season or month), and carried 92% of the AIC_c weight. Population persistence for bighorn sheep can be compromised by high levels of predation, habitat fragmentation, and disease transmitted from domestic sheep. We suggest that land managers continue to maintain the separation of domestic sheep from bighorns in CNP. We also recommend that survival studies continue to ensure that future translocation projects do not occur at the expense of the source population.

Keywords: desert bighorn sheep, foraging efficiency, human activity, *Ovis canadensis nelsoni*, restoration, source population, survival, translocation.

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Thank you to my wife and children. You inspire me to labor diligently and reach for more.

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Chapter 1: Alteration of Behavior by Desert Bighorn Sheep from Human Recreation

INTRODUCTION

Human encroachment into wildlands through mineral and oil exploration, development, and recreation can negatively impact wildlife populations. Possible consequences include habitat degradation, displacement of individuals, decreased reproduction, and decreased survival (Parks and Harcourt 2002, Taylor and Knight 2003). These activities sometimes have a cumulative effect for several wildlife species, significantly reducing the availability of effective habitat (Johnson et al. 2005). Recreational use of habitats during critical periods in the life-cycle decreases reproductive success for wildlife populations (Phillips and Alldredge 2000), while increased human population densities have been correlated with increased extinction rates among large mammals (Parks and Harcourt 2002).

For bighorn sheep (*Ovis canadensis*), some human activities are detrimental, causing both physiological stress and habitat abandonment (Dunaway 1971, Jorgensen 1974, DeForge 1981, MacArthur et al. 1982, King and Workman 1984, Etchberger et al. 1989). Human presence has been shown to influence bighorn physiology and behavior (Campbell and Remington 1981), causing an elevated heart rate (MacArthur et al. 1982), and changes in water-use patterns (Leslie and Douglas 1980). In several studies bighorns fled when approached by humans (King and Workman 1984, Papouchis et al. 2001). Bighorns react to adverse stimuli by reducing their range (DeForge 1981), including abandonment of suitable habitat (Etchberger et al. 1989) and use of water sources (Jorgensen 1974). Such displacements can have harmful impacts in desert environments where water can be a limiting factor for bighorn sheep (Leslie and Douglas 1980).

Encroachment by human populations into the deserts of southeastern Utah has increased greatly over the last several decades (Papouchis et al. 2001). Between 1979 and 2000, human recreation increased over 300% near Moab, Utah. Moab has become a hub for many outdoor enthusiasts, including mountain bikers, rock climbers, and off-road vehicle recreationists. Often the trails and roads used for recreation traverse high quality desert bighorn sheep (*O.c. nelsoni*) habitat. As these outdoor sports continue to grow in popularity, the contact between humans and bighorn will most likely increase. Smith et al. (1991) designated high human-use areas as those experiencing >500 visitors per year. In June 2002, one popular backcountry trail near Moab recorded >900 visitors. Several Jeep safari events are held annually, attracting >1500 vehicles, involving 30 different backcountry trails. Many of these trails extend into bighorn sheep habitat, facilitating an increase in human activity.

The Moab region is unique in that some areas are heavily used by recreationists while others remain wholly unvisited (Papouchis et al. 2001). There are bighorn sheep populations that inhabit both extremes in human use levels. Consequently, resource managers are increasingly concerned with the potential impacts these activities are having on the desert bighorn sheep that occupy the area.

The objectives of this study were to compare behaviors of female desert bighorn sheep in both high and low human use areas. Specifically, we compared the duration of scanning and grazing activities between these two groups. We predicted that bighorn sheep in high human use areas would spend less time grazing and more time scanning than sheep in low human use areas.

STUDY AREA

Canyonlands National Park (CNP) is home to one of the last native populations of bighorn sheep within Utah (Figure 1). The Island in the Sky District (ISD) of CNP is located at the north end of the park. Land ownership surrounding ISD consists of Bureau of Land Management (BLM), Utah Division of Natural Resources (DNR), and the Utah Land Trust. The study area is traversed by canyons in which desert bighorn sheep use talus slopes and adjacent meadows. Elevation within the area ranges from 1100—2100 m, with average annual precipitation of 125 – 200 mm. Vegetation is typically dominated by blackbrush (*Coleogyne ramosissima*) but also includes pinyon/juniper (*Pinus sp*/*Juniperus sp*) stands, Indian ricegrass (*Stipa hymenoides*) and galleta grass (*Hilaria jamesii*) (Bates and Workman 1983). The climate is classified as cool desert with July temperatures averaging 32.8 °C and January temperatures averaging 2.3 °C.

METHODS

Desert bighorn sheep were captured by the Utah Division of Wildlife Resources (UDWR) using net guns from helicopters in February 2002 and 2003 (Jessup et al. 1988). Bighorn were captured during this time period – after the rut and before lambing – to minimize stress for captured animals. Bighorn ewes were fitted with either global positioning system (GPS) or radio telemetry collars (TGW-3500 and MOD-501; Telonics®, Mesa, Arizona, USA). Bighorn were collared in both high and low human use areas within the study area. We followed Papouchis et al. (2001) to classify high and low human use sections of our study area. We treated the low human use area as a control site. We recorded sheep behaviors from May to August in 2002 and March to August 2003 during the season when the study area experienced the greatest levels of human use. We assumed that temperature, precipitation, forage quality and abundance, and predation pressures were similar across both study areas.

We systematically located radio-tagged bighorns at least once per sampling season through triangulation, using the radio signal from the GPS and VHF collars. We used binoculars, and spotting scopes to visually locate collared sheep. We also sampled un-collared female sheep opportunistically. To avoid detection by the sample group, and reduce bias, we recorded observations no closer than 300 m. We used 7.5” USGS topographic maps to record geographic locations for each observation. With each observation, we documented group size and demographics, level of human use (high/low), date, and time of day. To analyze distance to escape terrain, we input the coordinates for observational groups into ArcMap (ArcGIS 9.2®, Redlands, California). We used 30 m digital elevation models (DEM) of the study area obtained from the Utah GIS portal to estimate slope. We then used the raster calculator to classify all slopes 27° – 85° as escape terrain (Smith et al. 1991) and the measure tool to calculate the nearest distance from each sample point to escape terrain.

After visually locating a group of sheep, we randomly selected a bighorn ewe within the group to observe as a focal animal. We used 30 minute focal animal sampling to measure behavior (Altmann 1974) and recorded their activity to the nearest second, comparing the time spent grazing and scanning between high and low human use groups. If the focal animal moved out of sight during the sampling period we terminated the session. To standardize times among sample units we measured percent time (behavior time [s]/total sample time [s]).

We defined alert behavior when a sheep ceased its previous activity to scan its surrounding. In such instances, the sheep would stand erect, with its head upright, and scan in the direction of any perceived threat. We also identified alert behavior if the sheep moved quickly away from its original location after scanning. We classified the behavior as grazing when the focal animal was standing with its head bowed down toward the ground, or, if it was masticating plant biomass that it had recently collected, regardless of position of the head. We defined movement behaviors to include walking or running that was not associated with grazing or alert behavior, and resting as time spent lying down. Additional behaviors (i.e., suckling, grooming, urination, etc.) we grouped together as “other”.

Statistical Analysis

We investigated the relationship between observed behaviors and a suite of potentially explanatory variables using model selection. Before our analysis, we checked for multicollinearity (variables correlated ≤ -0.60 or ≥0.60). We then created an *a priori* list of 10 models to potentially explain observed variation in scanning and grazing times (Table 1). We used Akaike's Information Criterion adjusted for small sample sizes (AICc) to rank these models, and used model selection to find a best approximating model (lowest AICc value) for both behaviors (Akaike 1973, Brunham and Anderson 2002). We identified group size, presence/absence of a lamb, distance to escape terrain, and human use (high vs low) as possible explanatory variables that influenced grazing/scanning times. We included human use in six of the ten models to better understand the influence it may have on desert bighorn sheep behaviors. Given model uncertainty (if the greatest change in ΔAICc among competing models was ≤ 6), we obtained model-averaged estimates of coefficient values to evaluate the direction and strength of associations between explanatory variables and both behaviors. We used the MASS (Venables and Ripley 2002) library in version 2.7 of program R (R Development Core Team 2007) to perform the analyses.

RESULTS

In January 2002, the UDWR captured and collared 14 sheep. Collars were set out in both high human use areas (*n*=10) and low human use areas (*n*=4). From February 2002 – January 2003 there were 4 collared sheep that suffered mortality; 2 in high use and 2 in low use areas. The UDWR deployed 4 additional collars (high human use = 2, low human use = 2) in February 2003 to supplement the loss in sample size.

During focal scanning sessions, we observed 34 bighorn sheep for 13.1 hours total. Group sizes ranged from 1 – 10 individuals. We did not observe any groups of sheep flee from their initial location; therefore, we reclassified alert behavior as scanning times. The average amount of time spent scanning by desert bighorn sheep in high recreational use areas was 29% whereas sheep in low use areas spent an average of 8% time scanning behavior (t = 2.89, SE = 0.05, P = 0.007). Sheep in high use areas spent an average of 22% grazing compared to 54% for sheep in low use areas (t = -2.7, SE = 0.06, P = 0.014). Desert bighorn sheep in high use areas congregated at an average group size of 2.7, while group size for sheep in low use areas was 5.4 (t = 3.61, SE = 0.49, P = 0.001).

Human use constituted the best-fit model for approximating grazing times for desert bighorn sheep (Table 3). Group size and human use made up the second best model and group size alone comprised the next best. These three models carried 60% of the Akaike weight. The range of ΔAICc values for all competing models was 0.7 – 5.6, resulting in a need for model averaging. Model average estimates for coefficients showed that level of human use (coeff. = -0.25, 95% CI = -0.50 – 0.00) was negatively associated with grazing times. Group size (coeff. = 0.04, 95% CI = -0.01 – 0.08) was positively associated with grazing times, while distance to escape terrain (coeff. = 0.00, 95% CI = -0.0016 – 0.0008) and the presence of a lamb (coeff. = -0.12, 95% CI = -0.37 – 0.13) had little influence.

Human use was the best-fit model for approximating scanning times for desert bighorn sheep (Table 2). Human use was a contributing factor in the top four models which included varying combinations of group size and distance to escape terrain. The combined Akaike weight for these models was 61%. The range of ΔAICc values for all competing models was 0.19 – 5.20, resulting in the need for model averaging. Model averaged estimates for the coefficients showed that scanning time was negatively associated with group size (coeff. = -0.3, 95% CI =

-0.07 – 0.00). Conversely, the level of human use (coeff. = 0.22, 95% CI = 0.01 – 0.42) was positively associated with sheep scanning time. Distance to escape terrain (coeff. = 0.00, 95% CI = -0.0017 – 0.0002) and the presence of a lamb (coeff. = 0.09, 95% CI = -0.12 – 0.30) had little influence on scanning time.

DISCUSSION

Desert bighorn sheep spent significantly less time grazing and more time scanning in high human use areas than in low human use areas. Level of human use (high versus low) was the only variable that significantly affected (having 95% CI that did not overlap zero) grazing times for bighorns. In high human use areas grazing times decreased by 0.25 units, or approx. 7.5 minutes /30 minute sampling period compared to bighorn in low human use areas. Both human use and group size were significant factors in estimating scanning times. The level of human use was estimated to increase scanning times by 0.22 units, or 6.6 minutes/30 minute focal animal sample. Conversely, scanning times decreased by 54 seconds/30 minute focal animal sample with each individual that was added to the group.

Some species alter their behavior in the presence of humans, spending more time scanning and less time foraging (Duchesne et al. 2000). Such behaviors occur at the cost of foraging efficiency, in turn impacting the energy budget of the individual. For many animals, active visual and olfactory scanning increases predator detection and decreases risk of predation (Lima 1987, Krebs et al. 1997). When more time is required for vigilance, a reduced energy budget results in fewer resources being available to compensate for excitation or alarm responses. Vigilance level is positively correlated with increasing predation risk (Berger 1991), and smaller groups of bighorn sheep correspondingly have a greater predation risk (Mooring et al. 2004). The increase in scanning times for bighorns in high human use areas suggests a perceived increase in predation risk.

MANAGEMENT IMPLICATIONS

Though bighorn sheep graze more and scan less in low human use areas, it does not appear to have affected survival rates within the population (K.K. Sproat et al., Brigham Young University, unpublished report). There may be a biological threshold that has not yet been crossed, allowing for bighorns to sustain themselves as a population in areas of increased human activity. Human activity in CNP, and in the surrounding areas, is very seasonal, with the highest levels occurring during summer months. The most crucial periods of a bighorn's life cycle include lambing and rutting, which occur in early spring and late fall, respectively. These findings suggest that managers should carefully consider the temporal and spatial levels of human activity permitted in bighorn habitat, particularly for populations in decline.

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Table 1. Models describing scanning times and behavior times as a function of group size (GS), distance to escape terrain (DET), presence of a lamb (L), and human use (HU) in southeastern Utah during the summers of 2002 and 2003.

Model	Hypothesis description[a]	Model Structure
1	Behavior time influenced by group size	Scanning or Grazing ~ GS
2	Behavior time influenced by presence of a lamb	Scanning or Grazing ~ L
3	Behavior time influenced by distance to escape terrain	Scanning or Grazing ~ DET
4	Behavior time influenced by Human Use	Scanning or Grazing ~ HU
5	Behavior time influenced by group size and distance to escape terrain	Scanning or Grazing ~ GS + DET
6	Behavior time influenced by group size and human use	Scanning or Grazing ~ GS + HU
7	Behavior time influenced by distance to escape terrain and human use	Scanning or Grazing ~ DET + HU
8	Behavior time influenced by presence of a lamb and human use	Scanning or Grazing ~ L + HU
9	Behavior time influenced by group size, distance to escape terrain, and human use	Scanning or Grazing ~ GS + DET + HU
10	Behavior time influenced by group size, distance to escape terrain, presence of a lamb, and human use	Scanning or Grazing ~ GS + DET + L + HU

[a]Behavior time = scanning or grazing times

Table 2. The *a priori* models we used to investigate the factors influencing desert bighorn sheep scanning behavior in Utah during the summers of 2002 and 2003.

Model[a]	Factors[b]	K[c]	AICc[d]	Δ AICc[e]	w_i[f]	log-like[g]
4	Human Use	2	14.90	0.00	0.18	−10.73
9	Group Size + Distance to Escape Terrain + Human Use	4	15.09	0.19	0.16	−9.84
7	Distance to Escape Terrain + Human Use	3	15.16	0.26	0.16	−10.57
6	Group Size + Human Use	3	15.85	0.95	0.11	−9.89
1	Group Size	2	15.96	1.06	0.11	−11.21
5	Group Size + Distance to Escape Terrain	3	16.12	1.22	0.10	−11.07
10	Group Size +Distance to Escape Terrain + Lamb + Human Use	5	16.44	1.54	0.08	−8.34
8	Lamb + Human Use	3	16.79	1.89	0.07	−10.64
2	Lamb	2	19.66	4.76	0.02	−13.53
3	Distance to Escape Terrain	2	20.10	5.20	0.01	−13.09

[a]Model number

[b]Factors (variables) included in model

[c]Number of model parameters

[d]Akaike's Information Criterion

[e]AIC relative to most parsimonious model

[f]Akaike weight

[g]Log-likelihood

Table 3. The *a priori* models we used to investigate the factors influencing desert bighorn sheep grazing times in Utah during the summers of 2002 and 2003.

Model[a]	Factors[b]	K[c]	AICc[d]	Δ AIC[e]	w_i[f]	log-like[g]
4	Human Use	2	27.82	0.00	0.26	−4.27
6	Group Size + Human Use	3	28.52	0.70	0.18	−3.55
1	Group Size	2	28.78	0.96	0.16	−4.80
7	Distance to Escape Terrain + Human Use	3	29.88	2.06	0.09	−3.20
8	Lamb + Human Use	3	30.02	2.20	0.09	−402
10	Group Size +Distance to Escape Terrain + Lamb + Human Use	5	30.69	2.87	0.06	−1.22
5	Group Size + Distance to Escape Terrain	3	30.90	3.08	0.06	−3.68
9	Group Size + Distance to Escape Terrain + Human Use	4	30.97	3.15	0.05	−1.90
3	Distance to Escape Terrain	2	32.55	4.73	0.02	−6.87
2	Lamb	2	33.42	5.60	0.02	−6.66

[a]Model number

[b]Factors (variables) included in model

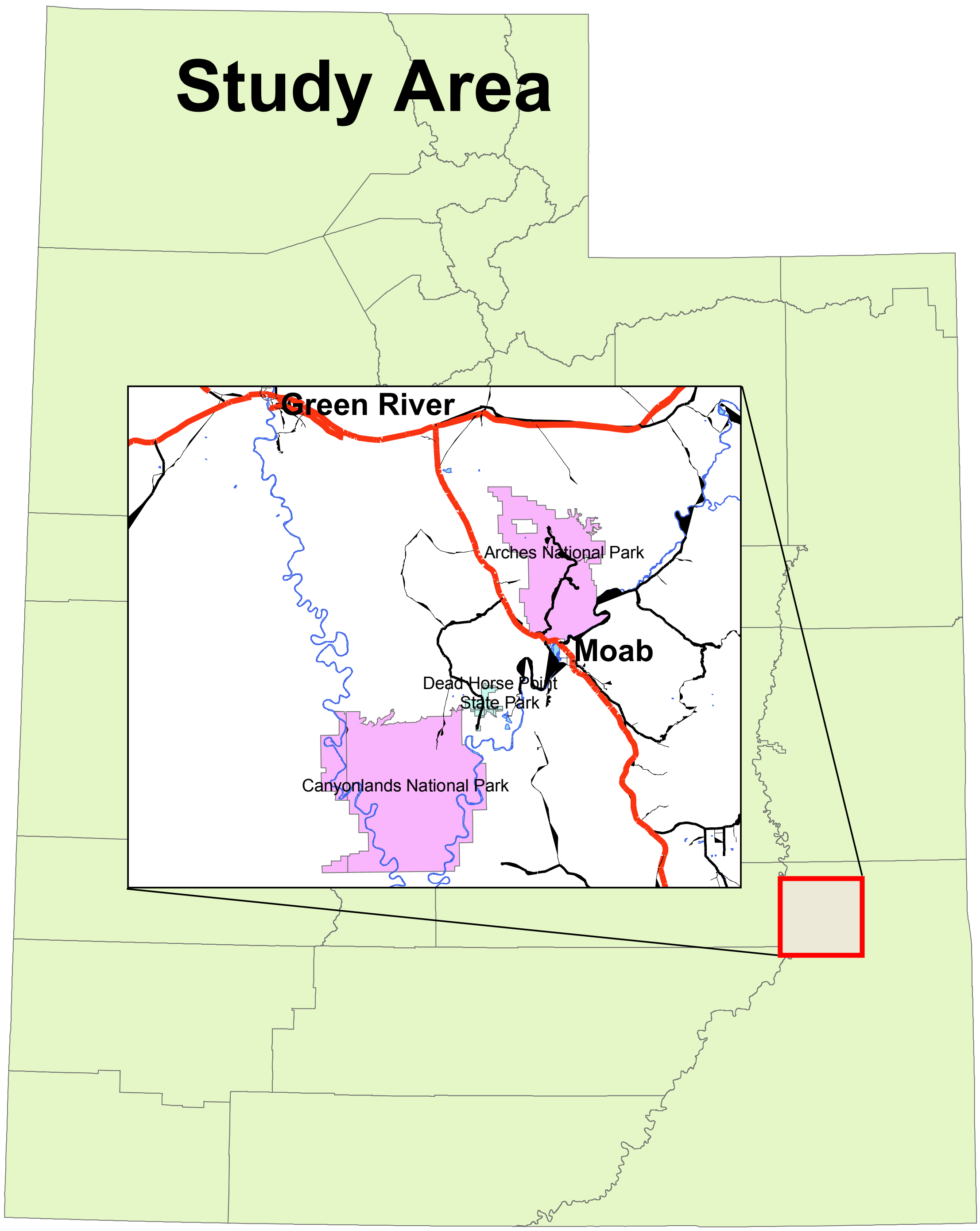
[c]Number of model parameters

[d]Akaike's Information Criterion

[e]AIC relative to most parsimonious model

[f]Akaike weight

[g]Log-likelihood



Study Area
Green River
Arches National Park
Moab
Dead Horse Point
State Park
Canyonlands National Park

Chapter 2: Desert Bighorn Sheep Survival in Canyonlands National Park: 2002 – 2010

INTRODUCTION

An understanding of survival for wildlife populations is an important aspect of wildlife management. Estimates of survival for harvested species provide important knowledge of population trends, helping managers make informed management decisions. Without accurate survival information, less effective decisions and policies will be implemented. For bighorn sheep (*Ovis canadensis*) in southeastern Utah, information on estimating adult survival is limited.

Native to western North America, bighorn sheep populations experienced significant declines after European settlement (Buechner 1960, Krausman 2000). Though historical abundance estimates vary between 500,000 and 2 million (Seton 1929, Buechner 1960), numbers decreased to <15,000 for all subspecies (Towell and Geist 1999). Overhunting, direct competition with livestock, habitat fragmentation, displacement, and disease introduced by domestic livestock had all played a role in this decline (Buechner 1960, Berger 1990). Consequently, bighorn sheep conservation has become a priority for several state and provincial agencies.

Today, the primary practice of bighorn sheep conservation is through population restoration and augmentation. Translocation of individuals from existing populations into historic habitat is the primary tool used to restore sheep populations (Leslie 1980, Shannon et al. 2008). Indigenous herds are the preferred source for translocations, and several have been used for decades to supply these restoration initiatives (Krausman 2000). Under such circumstances, it is crucial to understand population fluctuations to ensure the persistence of the source population.

Canyonlands National Park (CNP), and its bordering canyons, is home to one of the only remaining natural populations of desert bighorn sheep (*O.c. nelsoni*) in Utah (Figure 1). This once desolate and isolated area now hosts greatly increased seasonal human activity. Consequently, resource managers are increasingly concerned with the potential impacts these activities are having on the desert bighorn sheep that occupy the area. We conducted a 9-year telemetry study of desert bighorn sheep in Canyonlands National Park, Utah. Our objectives were to 1) estimate seasonal and annual survival, 2) compare survival estimates between high and low human use areas, and 3) compare estimates of survival for both age and sex.

STUDY AREA

The study area included the Island in the Sky District (ISD) of CNP and the Utah Division of Wildlife Resources (UDWR) Potash hunting unit which consists of Bureau of Land Management, Utah Division of Natural Resources, and the State Institutional Trust Lands (Figure 1; 38°27'35.40"N 109°49'14.5"W). It is dissected by canyons in which desert bighorn sheep use talus slopes and adjacent meadows. The study area elevation ranges from 1,100—2,100 m, with average annual precipitation of 125 – 200 mm. Vegetation is typically dominated by blackbrush (*Coleogyne ramosissima*) but also includes pinyon/juniper (*Pinus sp*/*Juniperus sp*) stands, Indian ricegrass (*Stipa hymenoides*) and galleta grass (*Hilaria jamesii*) (Bates and Workman 1983). The climate is classified as cool desert with July temperatures averaging 32.8 °C and January temperatures averaging 2.3 °C. The study area is unique in that some regions are heavily used by recreationists while others remain wholly unvisited (Papouchis et al. 2001). Bighorns inhabit both extremes in human use levels thus providing an opportunity to learn how activity levels influence survival.

METHODS

Human use statistics provided by the NPS were used to stratify the study area into areas of high and low human use according to Papouchis et al. (2001). We considered the low human use sections of the study area to be our control sites. Desert bighorn sheep were captured within each use category by the UDWR using net guns from helicopters. We captured and collared 57 desert bighorn sheep (Table 4; 18 bighorns in February 2002, 3 bighorns in February 2003, 15 bighorns in January 2006 and 21 in January 2009), including 39 females and 19 males. We collared 39 bighorns in high human use areas and 19 in low human areas. Capture operations were conducted during late winter months (January and February) in 2002, 2003, 2006, and 2009. Male and female bighorns were fitted with either Global Positioning System (GPS) or radio telemetry collars (TGW-3500 [GEN III and GEN IV models] and MOD-501; Telonics®, Mesa, Arizona, USA). Collars were programmed to record 5 geospatial locations per day and included a 6-hour mortality switch. Upon capture we used horn growth annuli and the emergence of incisors to estimate age for males and females respectively.

We monitored bighorn sheep using an RA-14K VHF antenna (Telonics®, Mesa, Arizona, USA) and an R-1000 digital radio receiver (Communication Specialists Incorporated®, Orange, CA). We visually located collared sheep on the ground or by aerial survey 3 – 6 times per year from 2002 – 2010. When a mortality signal was detected we attempted to recover the carcass as quickly as possible to assess the probable cause of mortality (Robinson et al. 2009), including predation, human causes (i.e. vehicle collision, hunting, etc.), and natural causes (i.e. accidental falls, old age, illness, etc.). Mountain lions (*Puma concolor*) are present within the study area, and predation from lions can have devastating effects on bighorn sheep populations (Wehausen 1996, Rominger et al. 2004). We followed guidance by Rominger et al. (2004) to determine if mortalities were caused by mountain lion predation (*e.g.*, cached bighorn carcass, a dragline from kill site to cache site, mountain lion tracks, mountain lion scat, canine punctures or claw marks in radio collar, or a broken neck). We did not perform any necropsies to determine if mortality was caused by disease. GPS collars made it possible to estimate the month of mortality.

Statistical Analysis

We used the known fate analysis feature in Program MARK 4.1 (White and Burnham 1999) to estimate annual and seasonal survival rates. We used model selection to test hypotheses for bighorn survival. We coded encounter histories in monthly intervals from March to February to more accurately represent desert bighorn sheep life histories. We coded each encounter as live, dead, or censored. If a mortality was discovered > 1 month from the last live encounter we estimated time of death as the mid-point between the two encounters. We formatted each year as a group for the following reasons: 1) to more easily estimate annual survival and 2) to be able to graduate individuals from one age class to the next. We included sex, age, and human use (high versus low) as individual covariates (Jorgenson et al. 1997). We considered the first full month post-capture as an acclimatization period and excluded bighorns that died during this period from survival modeling.

We analyzed survival data in 2 steps. First, we created an *a priori* list of 18 candidate models including variables for sex, age, human use, year, month, annual precipitation, average summer high temperature, 2 year delay in spring precipitation (Douglas 2001), and spring (March – May) precipitation (Table 5). To build models that included weather-related variables we used meteorological data collected at the Canyonlands Field airport, 28 km north of Moab, Utah. We used Akaike's Information Criterion adjusted for small sample size (AIC_c) and AIC_c weights (w_i) to find the best approximating model (Akaike 1973, Burnham and Anderson 2002).

Second, given model uncertainty, we used model averaged estimates to evaluate annual and seasonal survival.

RESULTS

We excluded 1 bighorn in 2002 from our analysis due to death during the acclimatization period. There were 19 mortalities (Table 4; 15 females and 4 males). Extreme winter weather conditions precluded the timely recovery of 10 carcasses and determination of probable cause of death. Of the 9 sheep carcasses recovered, 4 died from cougar predation, 1 was hit by a car, and 4 died of natural causes (e.g., age-related deaths).

Survival

Results of model selection showed that the top 2 models carried 51% of the AIC_c weight (Table 6). The top ranked model included survival as a function of season and average summer high temperature. Season was the only variable in the second ranked model, and had a ΔAIC_c value of 0.40. Overall, models that included season as a variable carried 60% of the AIC_c weight. The top six models all included a temporal variable (*e.g.* season or month), and carried 92% of the AIC_c weight.

We predicted that desert bighorn sheep survival would be lower in high human use areas than in low human use areas. The model with the lowest AIC_c value that contained human use ranked 5 and carried 9% of the AIC_c weight. Within this model, human use did not affect survival (coeff. = -0.2, 95% CI = -1.2—0.73).

Annual survival ranged from 83% – 88% with no inter-annual variation among any of the years (Figure 2). We found limited support for models that included individual covariates sex and age. Model-averaged β estimates for both sex (coeff. = 0.50, 95% CI = -0.6—1.6) and age (coeff. = -0.14, 95% CI = -0.34—0.07) overlapped zero.

DISCUSSION

Survival for desert bighorn sheep in CNP was relatively high (83%—88%; Table 7), as evidenced by population estimates (n = 400, status = stable/increasing). Our statistical analyses indicate that temporal variables (season and month) had the greatest effect on survival. Population persistence for bighorn sheep can be compromised by high levels of predation (Munoz 1982, Hayes et al. 2000, Kamler et al. 2002, Rominger et al. 2004), habitat fragmentation (Buechner 1960), and disease transmitted from domestic sheep (Goodson 1982, Foreyt 1990, Monello et al. 2001). Steady, high survival rates suggest that none of these factors are currently limiting for the CNP population. Of the known mortalities, only 44% (n=4) were caused by predation, which is low compared to studies where predation proved to be a limiting factor (69% for Hayes et al. 2000, 66% for Kamler et al. 2002, and 75% for Rominger et al. 2004). Domestic sheep grazing has been eliminated from the study area since the 1970's when grazing permits were retired. This appears to have successfully excluded contact with bighorns. Consequently, disease has not played a significant role in bighorn survival.

Survival for bighorn sheep may be also affected by age and sex (Jorgenson et al. 1997, Loison et al. 1999). Jorgensen et al. (1997) found that survival significantly decreased for sheep >8 yr old and ewes had significantly higher survival rates compared to rams. Results did not support a difference in survival for age or sex. Our low number of mortalities (n = 20) limited our ability to statistically analyze the effects that age or sex may have had on survival.

Though translocations are the primary tool used for restoring bighorn populations (Krausman 2000), repeated removals can be detrimental. Since the 1980's, the bighorn population in CNP has been used as a source for 20 translocation and augmentation projects within the region, with 265 individuals being relocated (Utah Division of Wildlife Resources

2008). Our results show that these activities have not negatively affected the population status, though it may have slowed the population growth rate.

MANAGEMENT IMPLICATIONS

Excessive subtractions of individuals from a source population for translocations may have similar effects as over-hunting or high levels of predation, limiting population growth rates or reducing genetic diversity. Therefore, we suggest that studies monitoring survival continue in CNP to ensure that the population remains healthy and viable.

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Table 4. Number of collars deployed, number of collared desert bighorn sheep, and number of mortalities by year (March – February) in Canyonlands National Park, Utah, USA, March 2002 – February 2011.

Year	No. collars deployed	No. collared individuals	No. mortalities
2002	18	20	1
2003	3	20	1
2004	0	15	3
2005	0	8	0
2006	15	21	3
2007	0	17	2
2008	0	14	1
2009	21	23	4
2010	0	18	4

Table 5. The *a priori* list of candidate models explaining bighorn sheep survival in Canyonlands National Park.

Model	Hypothesis Description	Model Structure
1	Survival constant	(.)
2	Survival by month	Month
3	Survival by year	Yr
4	Survival by season	Season
5	Survival by age	Age
6	Survival by sex	Sex
7	Survival by human use	Human Use (High vs Low)
8	Survival by annual precipitation	Annual Precip
9	Survival by 2 year delayed annual precipitation	2YrPrecip
10	Survival by average summer high temperature	SumTemp
11	Survival by spring precipitation	Spring Precip
12	Survival by age and sex	Age + Sex
13	Survival by season and average summer high temperature	Season + SumTemp
14	Surviavl by season and human use	Season + Human Use
15	Survival by month and average summer high temperature	Month + SumTemp
16	Survival by month and human use	Month + Human Use
17	Survival by average summer high temperature and annual precipitation	SumTemp + Annual Precip
18	Survival by year and month in a multiplicative manner	Yr X Month

Table 6. Ranking of *a priori* hypothesized models evaluating survival by season, month, year, human use, demograpics (age and sex), annual precipitation, average summer high temperature, spring precipitation, and 2 year delay in annual precipitation.

Model[a]	Model Structure	K[b]	AICc[c]	Δ AICc[d]	w_i[e]
13	s(season + avg summer high temp)	5	212.41	0	0.28
4	s(season)	4	212.81	0.40	0.23
15	s(month + avg summer high temp)	13	213.66	1.25	0.15
2	s(month)	12	214.05	1.64	0.12
14	s(season + human use)	5	214.58	2.17	0.09
16	s(month + human use)	13	215.83	3.42	0.05
10	s(avg summer high temp)	2	217.97	5.56	0.02
1	s(.)	1	218.30	5.88	0.01
5	s(age)	2	218.59	6.18	0.01
6	s(sex)	2	219.42	7.01	0.01
11	s(spring precip)	2	219.69	7.28	0.01
7	s(human use)	2	220.11	7.70	0.01
9	s(2 yr delay annual precip)	2	220.29	7.88	0.01
8	s(annual precip)	2	220.30	7.89	0.01
12	s(age + sex)	3	220.33	7.92	0.01
17	s(avg summer high temp + annual precip)	3	220.82	8.41	0.00
3	s(year)	9	226.78	14.37	0.00
18	s(g*t)	108	374.33	161.92	0.00

[a]Model number

[b]Number of model parameters

[c]Akaike's Information Criterion

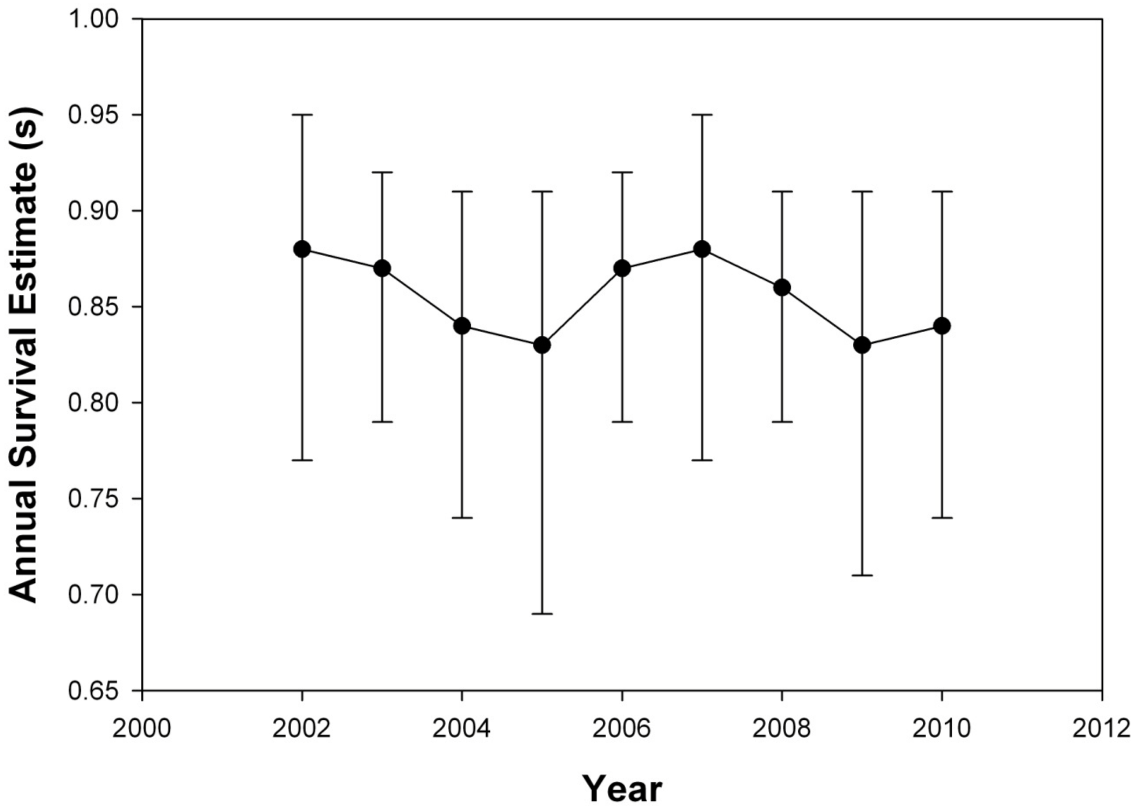
[d]AIC relative to most parsimonious model

[e]Akaike weight

Table 7. Survival rates for desert bighorn sheep (*Ovis canadensis nelsoni*) adults in North America.

Study	Survival	Area
Kamler et al. (2002)	0.70—0.88[a]	Throughout AZ
Hayes et al. (2000)	0.72—0.91	Peninsular Ranges, CA
Rominger et al. (2004)	0.95[a]	Wheeler Peak, NM
This study	0.83—0.88	Canyonlands National Park, UT

[a]Survival rates for desert bighorn sheep under low predation pressure.


Annual Survival Estimate (s)
1.00
0.95
0.90
0.85
0.80
0.75
0.70
0.65
2000
2002
2004
2006
2008
2010
2012
Year