HABITAT USE BY FEMALE DESERT BIGHORN SHEEP, FRA CRISTOBAL MOUNTAINS, NEW MEXICO

by

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ABSTRACT

Desert bighorn sheep were translocated to the Fra Cristobal Mountains, New Mexico, in 1995. From 1997 to 2000, we used radiotelemetry to locate female desert bighorn sheep. We developed a geographic information system to describe habitat characteristics at sheep locations and random locations within a composite home range. We also described habitat use at parturition sites, random sites, pre-, and post-parturition sites. Habitat characteristics at bighorn sheep locations were similar between seasons. Bighorn sheep locations tended to be steeper, more rugged, closer to patches of 60% slope, and had lower visibility than random sites. Parturition sites and post-parturition sites were higher in elevation and more rugged than pre-parturition sites. Post-parturition sites were closer to patches of 100% slope than pre-parturition or parturition sites. Post-parturition sites had higher visibility and steeper slopes than pre-parturition sites. Parturition sites were steeper, higher in elevation, more rugged, and had lower visibility than random sites.

INTRODUCTION

Since the 1800s, the distribution and abundance of desert bighorn sheep (*Ovis canadensis* spp.) populations has declined significantly due to an array of anthropogenic activities (e.g., livestock overgrazing, unregulated hunting, and diseases from domestic sheep, Krausman 2000). At the end of the twentieth century, encroaching human development, urbanization, and the rapid increase in backcountry recreational activities are imposing additional threats to desert bighorn sheep habitat (U.S. Fish and Wildlife Service 2000, Papouchis et al. 2001, Krausman et al. 2002). Several bighorn sheep populations are listed as endangered at the Federal (e.g., Peninsular bighorn (*O. c. cremnobates*), Federal Register Volume 63, No. 52. 1998) or state level (e.g., desert bighorn [*O. c. mexicana*], New Mexico Department of Game and Fish [NMDGF] 1995).

Mortality of bighorn sheep neonates is typically high (DeForge and Scott 1982). Although parturition sites are used for only short periods (Hansen 1965, Etchberger and Krausman 1999), they play a critical role in neonate survival when lambs are vulnerable to predation. During parturition, female bighorn sheep seek isolation in discrete areas that appear to be precipitous and rugged (Geist 1971, DeForge and Scott 1982). Etchberger and Krausman (1999) found that females returned to the same general area each year to have their lambs.

Sheep in northern habitats (e.g., Dall's sheep [*Ovis dalli*], Rocky Mountain bighorn [*Ovis canadensis*]) often change habitat within the lambing period (Festa-Bianchet 1988, Rachlow and Bowyer 1998). Females used areas prior to parturition with greater forage to meet the high energetic costs of lactation and made trade-offs during peak parturition to provide greater predator avoidance at the expense of reduced forage availability (Rachlow and Bowyer 1998). Northern environments have a short lambing season when ungulates have access to high quality forage (Thompson and Turner 1982). Parturition is synchronized among females so the majority of lambs are born within 30 days (Bunnell 1982). In contrast, desert environments are characterized by variable temporal and spatial precipitation patterns, which causes plant productivity to be less predictable (Bunnell 1982). This is one explanation for the extended lambing season in desert bighorn sheep populations, which can last for 6 to 11 months (Bunnell 1982, Witham 1983).

Habitat use within the lambing period of desert bighorn sheep populations is not well understood. Etchberger and Krausman (1999) compared sites used during the lambing period, which they defined as the 8-week period surrounding parturition, to sites used other times of the year and found no differences in habitat use. We hypothesized that habitat use would differ during the period surrounding parturition in relation to the chronology of lambing. Our primary objective was to describe habitat characteristics at sites used throughout the lambing period. We predicted that females would use parturition sites that offered greater protection from predation because lambs are vulnerable during this time. Steep, rugged terrain is thought to provide protection from predators (Risenhoover and Bailey 1985, Berger 1991). Therefore we expected parturition and post-parturition sites to be steeper, more rugged, and closer to security cover than areas used before parturition. Our second objective was to describe characteristics of parturition sites relative to the surrounding area. We hypothesized that females would select parturition sites that offer greater protection from predation (i.e., steeper, more rugged, closer to security cover) than the surrounding area (i.e., random locations).

Numerous studies have examined broad scale habitat use by desert bighorn sheep, however studies are often short term (≤ 1 year), lack individually identifiable sheep (i.e., radiocollared), and are not stratified by season (McCarty and Bailey 1994). Many habitat use studies are further limited by having a coarse spatial resolution (e.g., 3 –4 km^2 area of analysis units, Cunningham [1989], Andrew et al. [1999]) relative to the complex and variable terrain used by desert bighorn sheep. Our third objective was to incorporate multiple years of bighorn sheep relocation data to describe seasonal habitat use in a spatially refined context.

The thesis is presented with 2 manuscripts as appendices. The first paper examines habitat use by female desert bighorn sheep during the lambing period and the second paper describes seasonal habitat use. The manuscripts are formatted following guidelines for the Journal of Wildlife Management.

PRESENT STUDY

The methods, results, and conclusions of this study are presented in the papers appended to this thesis. The following is a summary of the most important findings in this paper.

In October 1995, the NMDGF translocated 37 desert bighorn sheep from a captive population at the Red Rock Wildlife Area (RRWA) in southwestern New Mexico to the Fra Cristobal Mountains. All sheep (24 females, 13 males) were fitted with VHF telemetry collars (Model 500, Telonics, Mesa, Arizona, USA). Ground based monitoring began in July 1997 and continued through August 2000. We attempted to locate each radiocollared female on a near daily basis by telemetry and visual searches with optics. If we could not visually locate the animal, we did not record the observation. We plotted locations on United States Geological Survey (USGS) 1:24,000 scale topographical maps. Monitoring was restricted to daylight hours.

We identified parturition sites by sheep behavior and the presence of a new lamb. Typically, females left a group of sheep and sought isolation < 2 days before parturition. She remained at the parturition site for 2-3 days and then reunited with other sheep. Therefore, if we observed a lamb that was estimated to be > 3 days old, we did not count that location as the parturition site. For each radiocollared female, we randomly selected a location used in the pre-parturition and post-parturition periods (hereafter referred to as pre and post respectively) for comparison. We defined these periods as the 30 days before and after parturition, respectively. For each parturition site, including those from uncollared females, we selected a random site 500 m in a random direction for comparison. The average distance between yearly parturition sites of the same female was 450 m in Arizona (Etchberger and Krausman 1999); the location of our random sites was intended to be outside the lambing area, but in the near vicinity.

We used ArcView (Version 3.2, Environmental Systems Research Institute, Redlands, California, USA) with Spatial Analyst software to develop a geographic information system (GIS) that incorporated our site locations. We obtained digital elevation models with 10 m spatial resolution from the USGS. We described aspect, distance to steep patches, elevation, slope, substrate associations, terrain ruggedness, and visibility (i.e., proportion of surrounding area not obstructed by topography).

We described seasonal habitat use for females with $\geq$30 locations per in spring and autumn (n = 20). The average number of locations per individual was 121 (SD = 51.8) in spring, and 134 (SD = 54.4) in autumn. We generated an equal number of random locations within a composite home range (i.e., 100% minimum convex polygon, McClean et al. 1998) of the 20 female sheep. Habitat characteristics at bighorn sheep locations were similar between seasons. Bighorn sheep locations tended to be steeper, more rugged, closer to patches of 60% slope, and had lower visibility than random sites.

We located 38 parturition sites from 27 females (16 radiocollared), and identified 21 pre and post sites. For 8 females we located parturition sites in $\geq$ 2 years. The average distance between consecutive parturition sites for an individual female was 6.5 km (95% CI = 3.7 - 9.3). One female returned to the same parturition site as the previous year, however the following year she used a parturition site 5.5 km away. The maximum distance between consecutive parturition sites was 14.5 km. This population was recently translocated and females may not have had sufficient time to establish preferred lambing sites.

Parturition sites and post-parturition sites were higher in elevation and more rugged than pre-parturition sites. Post-parturition sites were closer to patches of 100% slope than pre-parturition or parturition sites. Post-parturition sites had higher visibility and steeper slopes than pre-parturition sites. Parturition sites were steeper, higher in elevation, more rugged, and had lower visibility than random sites. Additional research is recommended in other desert bighorn sheep populations to better understand and predict habitat use during the lambing period.

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Appendix A

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RH: Lambing habitat • *Bangs et al.*

HABITAT USE DURING THE LAMBING PERIOD OF DESERT BIGHORN SHEEP

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Abstract: Female desert bighorn sheep (*Ovis canadensis* spp.) seek isolation in discrete areas for parturition. Although parturition sites are used for only short periods, they play an important role in neonate survival. Mortality of bighorn sheep neonates is often high and a lack of suitable parturition sites could limit

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populations. Our objective was to describe habitat use by female bighorn sheep during the lambing period. We compared habitat characteristics at pre-parturition sites (n = 21), parturition sites (n = 38), random sites (n = 38), and post-parturition sites (n = 21). At each site we described aspect, distance to steep patches, elevation, ruggedness, slope, substrate, visibility, and vegetation association. Parturition sites and post-parturition sites were higher in elevation and more rugged than pre-parturition sites. Post-parturition sites were closer to patches of 100% slope than pre-parturition or parturition sites. Post-parturition sites had higher visibility and steeper slopes than pre-parturition sites. Parturition sites were steeper, higher in elevation, more rugged, and had lower visibility than random sites. Parturition site fidelity was observed on 1 occasion. This population was recently translocated and females may not have had sufficient time to establish preferred lambing sites. Additional research is recommended in other desert bighorn sheep populations to better understand and predict habitat use during the lambing period.

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***Key words**:* bighorn sheep, lambing habitat, New Mexico, *Ovis canadensis*, parturition.

Since the 1800s, the distribution and abundance of desert bighorn sheep (*Ovis canadensis* spp.) populations has declined significantly due to an array of anthropogenic activities (e.g., livestock overgrazing, unregulated hunting, and diseases from domestic sheep, Krausman 2000). At the end of the twentieth century, encroaching human development, urbanization, and the rapid increase in backcountry recreational activities are imposing additional threats to desert bighorn sheep habitat (U.S. Fish and Wildlife Service 1999, Papouchis et al. 2001, Krausman et al. 2002). Several bighorn sheep populations are listed as endangered at the federal (e.g., peninsular bighorn [*O. c. cremnobates*], Federal Register Volume 63, No. 52. 1998) or state level (e.g., desert bighorn [*O. c. mexicana*], New Mexico Department of Game and Fish [NMDGF] 1995).

Mortality of bighorn sheep neonates is typically high (DeForge and Scott 1982). Parturition sites are used for short periods (Hansen 1965, Etchberger and Krausman 1999), but they play a critical role in neonate survival when lambs are vulnerable to predation. During parturition, female bighorn sheep seek isolation in discrete areas that appear to be precipitous and rugged (Geist 1971, DeForge and Scott 1982). Etchberger and Krausman (1999) found that females returned to the same general area each year to have their lambs.

Sheep in northern habitats (e.g., Dall's sheep [*Ovis dalli*], Rocky Mountain bighorn [*Ovis canadensis*]) change habitat use within the lambing period (Festa-Bianchet 1988, Rachlow and Bowyer 1998). Females used areas prior to parturition with greater forage to meet the high energetic costs of lactation and made trade-offs during peak parturition to provide greater predator avoidance at the expense of reduced forage availability (Rachlow and Bowyer 1998). Northern environments have a short lambing season when ungulates have access to high quality forage (Thompson and Turner 1982). Parturition is synchronized among females so the majority of lambs are born within 30 days (Bunnell 1982). In contrast, desert environments are characterized by variable temporal and spatial precipitation patterns, which causes plant productivity to be less predictable (Bunnell 1982). This is one explanation for the extended lambing season in desert bighorn sheep populations, which can last for 6 to 11 months (Bunnell 1982, Witham 1983).

Habitat use within the lambing period of desert bighorn sheep populations is not well understood. Etchberger and Krausman (1999) compared sites used during the lambing period, which they defined as the 8-week period surrounding parturition, to sites used other times of the year and found no differences in habitat use. We hypothesized that habitat use would differ during the period surrounding parturition in relation to the chronology of lambing. Our primary objective was to describe habitat characteristics at sites used throughout the lambing period. We predicted that females would use parturition sites that offered greater protection from predation because lambs are vulnerable during this time. Steep, rugged terrain provides protection from predators (Risenhoover and Bailey 1985, Berger 1991), therefore we expected parturition and post-parturition sites to be steeper, more rugged, and closer to security cover than areas used before parturition. Our second objective was to describe characteristics of parturition sites relative to the surrounding area. We hypothesized that females would select parturition sites that offer greater protection from predation (e.g., steeper, more rugged, and closer to security cover) than the surrounding area (i.e., random locations).

STUDY AREA

The privately owned Fra Cristobal Mountains (33.25 – 33.5° N, 107.05 – 107.15° W) were located in Sierra County, approximately 32 km northeast of Truth or Consequences, New Mexico. The range was an east-tilted horst ~ 24 km long by 5 km wide with an elevation range of 1,400 to 2,109 m (Nelson 1986). Five apron water catchments capable of holding ~ 19,000 L and a few ephemeral springs are located on the range. Precipitation at Elephant Butte Dam (16 km southwest of the range, elevation 1,395 m) averages 23.6 cm annually (P. D. Bangs, P. R. Krausman, K. E. Kunkel, Z. D. Parsons, Habitat use by female desert bighorn sheep, Fra Cristobal Mountains, New Mexico, unpublished data). Desert scrub and desert grassland were the predominant vegetation associations. Montane scrub was found at higher elevations, typically between 1,850 and 1,950 m. A limited amount of coniferous woodlands was at the highest elevations. The mountain range has ~ 65 km^2 of desert bighorn habitat (Dunn 1994) and supported ~ 50 desert bighorn sheep during the study. No known domestic sheep herds occurred within 50 km of the range. Predators within the study area were cougars (*Puma concolor*), golden eagles (*Aquilo chrysaetos*), bobcats (*Lynx rufus*), and coyotes (*Canis latrans*). Cougars were the primary source of mortality for adult sheep (Turner Endangered Species Fund, unpublished data).

METHODS

In October 1995, the NMDGF translocated 37 desert bighorn sheep (24 F, 13 M) from a captive population at the Red Rock Wildlife Area in southwestern New Mexico to the Fra Cristobal Mountains. All sheep were fitted with VHF radiocollars (Model 500, Telonics, Mesa, Arizona, USA). In November 1999, NMDGF used a helicopter and net gun (Krausman et al. 1985) to capture and radiocollar 16 females; 9 were previously radiocollared.

Parturition in this population occurred from January through May in 1999 - 2001. During parturition, we attempted to locate each radiocollared female on a daily basis by telemetry and visual searches with optics during daylight hours. If we could not visually locate the animal, we did not record the observation. We plotted locations of bighorn sheep on United States Geological Survey (USGS) 1:24,000 scale topographical maps.

We identified parturition sites by sheep behavior and the presence of a new lamb. Typically, a female left a group of sheep and sought isolation < 2 days before parturition. She remained at the parturition site for 2-3 days and then reunited with other sheep. Therefore, if we observed a lamb that was estimated to be > 3 days old, we did not count that location as the parturition site. We estimated age by comparison with known age lambs and characteristics described by Hansen (1965), Hansen and Deming (1980), and Bleich (1982). If we observed an uncollared female with a lamb $\leq$ 3 days old, we included these parturition sites in our analysis.

For each radiocollared female, we randomly selected a date in both the pre-parturition and post-parturition periods (hereafter referred to as pre and post respectively). We defined these periods as the 30 days before and after parturition, respectively. For each female we selected the location that occurred on or nearest the randomly selected date in each period. If a lamb died during the post period, before the predetermined randomly selected date, we replaced this location with a randomly selected location that occurred prior to the mortality. This was necessary because females that lost their lamb no longer selected habitat based on the welfare of their offspring. If the lamb died within 5 days of parturition, we did not include a post site in the analysis. Pre and post locations for uncollared females were not available.

For each parturition site, including those from uncollared females, we selected a site separated from the parturition site by 500 m in a random direction for comparison. The average distance between yearly parturition sites of the same female was 450 m in Arizona (Etchberger and Krausman 1999). The location of our random sites was designed to be outside the lambing area, but in the near vicinity. If > 1 female shared a parturition site, we used the location (and associated random site) only once in the analysis.

We used ArcView (Version 3.2, Environmental Systems Research Institute, Redlands, California, USA) with Spatial Analyst software to develop a geographic information system (GIS) that incorporated our site locations. We obtained digital elevation models with 10 m spatial resolution from the USGS. If we located parturition sites in 2 years for a female, we calculated the distance between consecutive parturition sites by using the map measure feature of ArcView (Hutchinson and Daniel 2000:123). If we located parturition sites in all 3 years, we calculated the average distance between consecutive parturition sites.

We developed a GIS coverage depicting vegetation and substrate associations based on available maps (M. E. Miller. 1999. Vegetation of the Fra Cristobal Range, Southern New Mexico, Turner Biodiversity Division, Truth or Consequences, New Mexico, USA). M. E. Miller (1999) used color infrared aerial photographs (scale 1:24,000) and ground surveys to classify vegetation based on the classification scheme of Dick-Peddie (1992). Substrate classification is based on Neher (1984) and Nelson (1986).

We also described, aspect, distance to steep patches, elevation, slope, terrain ruggedness, and visibility (proportion of surrounding area not obstructed by topography). We described visibility and ruggedness at 2 spatial scales because the scale at which females select habitat may vary as a function of predation risk. Lambs are especially vulnerable to predation during their first few days of life (Rachlow and Bowyer 1998). We suspected that habitat use might occur at a more localized scale during this period. Vulnerability to predation decreases as lambs mature, and vigilance increases when females join a group of sheep. Therefore, we suspected that selection might occur at a slightly broader scale in the pre and post periods.

Distance to steep slope represented proximity to security cover. Escape terrain for desert bighorn sheep has been defined numerous ways, typically with a minimum slope steepness of 60 – 100% and often with subjective descriptions of topographic ruggedness (e.g., rock outcroppings or cliffs, McCarty and Bailey 1994). To prevent unreliable comparisons, we avoided subjective descriptions. Minimum size requirements of 1.6 – 2 ha have been proposed for escape terrain patches (Tilton 1977, Armentrout and Brigham 1988), however McCarty and Bailey (1994) suggest these sizes may be arbitrary. Because of the uncertainty in defining escape patches, we delineated security cover in 2 ways ($\geq$ 60% and $\geq$ 100% slope), both incorporating a minimum patch size of 1 ha. This approach does not incorporate ruggedness, which may be an important component of escape terrain (McCarty and Bailey 1994); therefore we refer to these areas as steep patches.

We performed a viewshed analysis (Sorenson and Lanter 1993) in ArcView to calculate visibility. We selected an offset height of 1.5 meters to approximate the eye level of a bighorn sheep. We calculated the number of cells visible in a given radius around each location, and multiplied the cell count by 100 m^2 (cell size) to obtain the visible area. We used a radius of 50 m to represent the localized area and a 200 m radius to depict the broader scale. We calculated percent visibility by dividing the visible area by the total area (π * $radius^2$) and multiplying this value by 100.

We described terrain ruggedness for a spatial neighborhood around each point location using a routine developed by J. M. Sappington et al. (USGS, Quantifying landscape ruggedness for animal habitat analysis: a case study using desert bighorn sheep in the Mojave Desert, 2002, unpublished data) We used an ArcView script to calculate the 3-dimensional dispersion of vectors normal to grid cells composing each landscape following Pincus (1956), Hobson (1972), and Durrant (1996). Their technique results in a dimensionless ruggedness number that ranges from 0 (flat) to 1 (most rugged), we multiplied each value by 100 to obtain a percentage of the theoretical maximum. We selected a 90 * 90 m neighborhood to represent the localized area and a 310 m X 310 m area to depict a broader scale.

We used SPSS software for Windows (version 10.0, Chicago, Illinois, USA) for the statistical analyses. For each continuous variable, we made 4 comparisons: parturition versus pre, parturition versus post, parturition versus random, and post versus pre. For each female we calculated the difference between respective categories (i.e., blocking for individual). We graphically examined the distributions for outliers (Ramsey and Shafer 2001) and conducted a 1-sample *t*-test on the differences. Outliers were retained in analyses, however they did not affect the outcome of any comparisons. For categorical variables we visually examined the distributions for differences among categories. We calculated Pearson's correlation coefficient (Field 2000) for all pairs of continuous variables, however the correlation coefficients were < 0.60 for all pairs so we did not remove any variables.

Parturition site fidelity occurred on only 1 occasion. Therefore, even though we had > 1 year of data for 8 females, we treated each year as an independent selection of resources, with the exception of 1 female that exhibited site fidelity in 1999 - 2000. For this female, we averaged site characteristics between years for continuous variables. For presentation of categorical data, we randomly selected 1 pre and post site for this female.

RESULTS

Parturition Site Fidelity

We located 38 parturition sites from 27 females (16 radiocollared). Because we averaged site characteristics for 1 female, our effective sample size was 37 parturition sites, 37 random sites, 21 pre, and 21 post sites. For 8 females we located parturition sites in $\geq$ 2 years. The average distance between consecutive parturition sites for an individual female was 6.5 km (95% C.I. = 3.7 - 9.3). One female returned to the same parturition site as the previous year, however the following year she used a parturition site 5.5 km away. The maximum distance between consecutive parturition sites was 14.5 km.

Parturition and Random

Compared to random sites, parturition sites were located on southwest (SW) aspects more often and less on northeast (NE) aspects (parturition: northwest [NW] = 30%, SW = 41%, southeast [SE] = 16%, NE = 14%; random:

NW = 35%, SW = 27%, SE = 5%, NE = 32%). Parturition sites were closer to patches of 60% slope than random sites ($\bar{d}$ = 57 m, 95% CI = 29 – 86 m, t_{36} = -4.07, 1 sided $P < 0.001$; Table 1), but results were inconclusive for proximity to 100% slope patches ($\bar{d}$ = 60 m, 95% CI = - 24 – 145 m, t_{36} = - 1.43, 1 sided P = 0.080; Figure 1). Parturition sites were higher in elevation than random sites by an average of 51.7 m (95% CI = 14.6 - 88.9, t_{36} = 2.82, 2 sided P = 0.008; Table 1). Ruggedness at parturition sites was 2.6% higher (95% CI = 0.9 – 4.3, t_{36} = 3.14, 1 sided P = 0.002; Figure 2) than random sites at the localized scale and 4.6% higher (95% CI = 2.8 – 6.4, t_{36} = 5.21, 1 sided $P < 0.001$; Figure 2) at the broader scale. Parturition sites were steeper than random sites (Table 1), with an average difference of 8.2 degrees (95% CI = 2.6 - 13.8, t_{36} = 2.96,1 sided P = 0.003; Table 1). On average, visibility at parturition sites was 11.8% lower than random sites at a 50 m radius (95% CI = 4.9 – 18.8, t_{36} = - 3.46, 2 sided P = 0.001; Table 1) and 10.9% lower at a 200 m radius (95% CI = 4.2 – 17.6, t_{36} = -3.31, 2 sided P = 0.002; Table 1). Substrate associations did not differ between parturition sites and random locations (parturition: limestone = 43%, granite = 38%, shale = 8%, limestone/granite = 11%; random: limestone = 41%, granite = 41%, shale = 8%, limestone/granite = 11%). Compared to random sites, parturition sites were located on desert scrub/grassland (DS-G) more often (parturition: DS-G = 57%, desert grassland/montane scrub [DG-MS] = 38%, desert scrub/grassland/montane scrub [DS-G-MS] = 5%; random sites: DS-G =

43%, DG-MS = 41%, DS-G-MS = 14%, montane scrub/coniferous woodland [MS-CW] = 3%).

Parturition and Pre

Compared to pre sites, parturition sites were located on NE aspects more often and less on NW aspects (parturition: NW = 30%, SW = 41%, SE = 16%, NE = 14%; pre: NW = 48%, SW = 38%, SE = 14%, NE = 0%). Pre sites were located more frequently on northwest slopes and less frequently on northeast slopes than parturition and post sites (Figure 1). Results were inconclusive whether parturition sites were closer to steep slopes than pre sites (100% slope patches: $\bar{d}$ = 325 m, 95% CI = -175 – 825 m, t_{19} = - 1.36, 1 sided P = 0.095, Figure 1; 60% slope patches: $\bar{d}$ = 24 m, 95% CI = -14 – 62 m, t_{19} = - 1.34, 1 sided P = 0.098, Table 1). Parturition sites were higher in elevation than pre sites, with an average difference of 83.9 m (95% CI = 13.2 - 154.5; t_{19} = 2.48, 2 sided P = 0.022, Table 1). On average, ruggedness at parturition sites was 2.1% higher (95% CI = - 0.2 – 4.4, t_{19} = 1.96, 1 sided P = 0.033) than pre sites at the localized scale and 3.3% higher (95% CI = 0.8 – 5.8, t_{19} = 2.77, 1 sided P = 0.006) at the broader scale. Results were inconclusive ($\bar{d}$ = 5.4 degrees, 95% CI = –2.6 - 13.5, t_{19} = 1.41, 1 sided P = 0.088) whether slope was greater at parturition sites relative to pre sites. Visibility did not differ between parturition sites and pre sites at either scale (50 m: $\bar{d}$ = - 5.0%, 95% CI = - 15.5 – 5.5, t_{19} = - 0.99, 2-sided P = 0.335; 200 m: $\bar{d}$ = - 0.3%, 95% CI = - 10.9 – 10.4, t_{19} = - 0.05, 2-sided P = 0.960). Pre sites were located on limestone/granite substrate more often than parturition sites (parturition: limestone = 43%, granite = 38%, shale = 8%, limestone/granite = 11%; pre: limestone = 38%, granite = 33%, shale = 0%, limestone/granite = 29%). Use of vegetation associations was similar between pre and parturition sites (pre: DS-G = 62%, DG-MS = 33%, DS-G-MS = 5%, parturition: DS-G = 57%, DG-MS = 38%, DS-G-MS = 5%).

Parturition and Post

Aspects were similar between parturition and post sites (parturition: NW = 30%, SW = 41%, SE = 16%, NE = 14%; post: NW = 29%, SW = 48%, SE = 14%, NE = 10%). Post sites were closer to patches of 100% slope than parturition sites ($\bar{d}$ = 504 m, 95% CI = 150 - 858 m, t_{19} = 2.98, 2 sided P = 0.008, Figure 1), but there was no difference in proximity to 60% slope patches ($\bar{d}$ = - 2.7 m, 95% CI = -11.5 – 16.8 m, t_{19} = 0.40, 2 sided P = 0.697, Table 1). Parturition sites did not differ from post sites ($\bar{d}$ = - 36.2 m, 95% CI = - 111.4 – 39.0, t_{19} = -1.01, 2 sided P = 0.326, Table 1). Ruggedness of parturition sites did not differ from post sites at either scale (90 m: $\bar{d}$ = 0.7%, 95% CI = -2.1 – 3.6, t_{19} = 0.52, 2-sided P = 0.608; 310 m: $\bar{d}$ = 0.1%, 95% CI = -2.6 – 2.4, t_{19} = -0.08, 2-sided P = 0.935). Slope of parturition sites did not differ from post sites ($\bar{d}$ = - 2.4 degrees, 95% CI = - 11.0 – 6.2, t_{19} = 0.59, 2 sided P = 0.565). Visibility did not differ between parturition sites and post sites at either scale (50 m: $\bar{d}$ = 3.8%, 95% CI = - 7.9 – 15.5, t_{19} = 0.68, 2-sided P = 0.502; 200 m: $\bar{d}$ = 6.1%, 95% CI = - 2.8 – 15.1, t_{19} = 1.43, 2-sided P = 0.168). Compared to post sites, parturition sites were located on granite substrate less and more on limestone substrate (parturition: limestone = 43%, granite = 38%, shale = 8%, limestone/granite = 11%; post: limestone = 24%, granite = 67%, limestone/granite = 10%). Compared to post sites, parturition sites were located on DS-G more often and less on DG-MS (post: DS-G = 33%, DG-MS = 67%, parturition: DS-G = 57%, DG-MS = 38%, DS-G-MS = 5%).

Post and Pre

Compared to pre sites, post sites were located on SW and NE aspects more often and less on NW aspects (pre: NW = 48%, SW = 38%, SE = 14%; post: NW = 29%, SW = 48%, SE = 14%, NE = 10%). Post sites were closer to patches of 100% slope than pre sites ($\bar{d}$ = 843 m, 95% CI = 366 - 1319 m, t_{19} = -3.77, 1 sided $P < 0.001$, Figure 1), but results were inconclusive for proximity to 60% slope patches ($\bar{d}$ = 32 m, 95% CI = - 15 – 78 m, t_{15} = - 1.46, 1 sided P = 0.083, Table 1). Post sites were higher in elevation than pre sites, with an average difference of 89.2 m (95% CI = 11.7 - 166.8, t_{15} = 2.45, 2 sided P = 0.027, Table 1). Ruggedness at post sites was 2.2% higher (95% CI = - 0.4 – 4.8, t_{15} = 1.77, 1 sided P = 0.049) than pre sites at the localized scale and 4.3% higher (95% CI = 1.7 – 7.0, t_{15} = 3.48, 1 sided P = 0.002) at the broader scale. Post sites were steeper than pre sites ($\bar{d}$ = 8.2 degrees, 95% CI = –0.4 - 16.8, t_{15} = 2.03, 1 sided P = 0.03, Table 1). Visibility did not differ between post and pre sites at either scale (50 m: $\bar{d}$ = - 7.6%, 95% CI = - 18.3 – 3.0, t_{15} = - 1.53, 2-sided P = 0. 146; 200 m: $\bar{d}$ = - 4.0%, 95% CI = - 12.9 – 4.8, t_{15} = - 0.97, 2-sided P

= 0.348). Compared to pre sites, post sites were located on granite substrate more often and less on limestone substrate (post: limestone = 24%, granite = 67%, shale = 0%, limestone/granite = 10%; pre: limestone = 38%, granite = 33%, shale = 0%, limestone/granite = 29%). Compared to pre sites, post sites were located on DG-MS more often and less on DS-G (post: DS-G = 33%, DG-MS = 67%, pre: DS-G = 62%, DG-MS = 33%, DS-G-MS = 5%).

DISCUSSION

Site Fidelity

In the Little Harquahala Mountains, Arizona, females returned to the same general lambing site (within 450 m) each year and females never shared lambing sites (Etchberger and Krausman 1999). However, we observed site fidelity on only 1 occasion, when a female returned to the same site (within 20 m) as the previous year. The following year she selected a parturition site 5.5 km away. During 1999 and 2001, we observed 2 females sharing a lambing site on 4 occasions. Desert bighorn sheep were recently translocated to this mountain range and may not have had sufficient time to establish preferred lambing sites.

Habitat Shifts

Our results supported our prediction that parturition sites would be steeper, more rugged, higher in elevation, and closer to 60% slope patches than random sites. However, Creeden (1986) noted that female bighorn sheep used lambing areas that appeared to offer optimal visibility, whereas we found that females used parturition sites with lower visibility than random sites. One explanation is that females with lambs use areas with lower visibility because these areas offer a lower risk of detection by predators. The conflicting roles of visibility and cover in predator avoidance and evasion can be difficult to interpret (Lazarus and Symonds 1992). Bighorn sheep may have difficulty detecting approaching predators in habitat with low visibility, however this terrain may function as hiding cover to reduce their chance of detection by predators. Conversely, high visibility allows for enhanced detection of predators, but the terrain may offer little hiding cover. Interpreting the role of visibility in bighorn sheep habitat selection is further confounded by the variety of methods that have been used for measuring visibility, in particular those that require substantial estimation and are prone to observer expectancy bias (McCarty and Bailey 1992). The approach we used only accounts for topographic obstruction, not boulders or vegetation. The obstruction of visibility from tall vegetation is significant in the highest elevations in the Fra Cristobal Mountains, where there are 1-seed juniper (*Juniperus monosperma*) and scattered Colorado pinyon (*Pinus edulis*) trees. However, this is a relatively small area and is not used by desert bighorn sheep. Caution should be taken when interpreting GIS-based visibility analyses (Maloy and Dean 2001); therefore we suggest that our measurements be interpreted as relative measures of visibility.

Lambing habitat has been described as the most precipitous and rugged terrain available (Smith et al. 1991, Zeigenfuss et al. 2000). We found that parturition sites were closer to 60% slope patches than random sites (Table 1), but were too far from 100% slope patches for the terrain to function as security cover (Figure 1). Compared to adults, lambs are less capable of outmaneuvering predators and their small size makes them more vulnerable to predators such as bobcats and golden eagles. Golden eagles were the most frequent predator of Dall's sheep lambs (Scotton and Pletscher 1998). In the Fra Cristobal Mountains, there were 4 breeding pairs of golden eagles in 2000 and 2001 (T. Mader, Turner Endangered Species Fund, unpublished data). We frequently observed 1 or 2 eagles circling in the vicinity of bighorn sheep lambs, and we observed eagles diving on lambs. During these attacks, lambs would seek shelter under their mother. We suspect that lambs would be most vulnerable to golden eagles on cliffs or extremely steep slopes. Maneuverability is lowest for bighorn sheep on this type of terrain, making it difficult for a lamb to seek shelter under its mother to avoid the diving eagle. Therefore, the traditional definition of escape terrain may not be well suited for lambs that are vulnerable to avian predators.

Although Etchberger and Krausman (1999) failed to detect changes in habitat use in relation to lambing, we observed changes within the lambing period. The apparent discrepancy may be explained by differences in experimental design. Etchberger and Krausman (1999) pooled observations used throughout the lambing period (i.e., 4 weeks before parturition through 4 weeks after parturition) and compared them to relocations from other times of the year and random sites, whereas we examined habitat selection within the lambing period (i.e., pre vs. parturition vs. post). Our stratified approach is refined because descriptions of habitat relationships are not averaged throughout the lambing period.

The serial progression (i.e., pre, parturition, post) of the data requires consideration of environmental changes (i.e., seasonal plant growth) as an explanation of potential habitat shifts. However, the variability in parturition dates among females (January – May) reduces temporal correlation among the data, thereby decreasing the risk of environmental changes as a confounding factor. Our vegetation maps were crude relative to the complex topography of the mountain range and offer no insight on forage availability or quality, which, given the high energetic costs of lactation (Rachlow and Bowyer 1998), may be important factors affecting habitat use during the lambing period. The demands of lactation may require females to increase water intake. Smith et al. (1991) considered any areas > 1 km from water sources to be inadequate for lambing. In the Fra Cristobal Mountains, freestanding water availability does not have an apparent affect on habitat use during the lambing period because the population did not utilize available freestanding water sources, even with below average spring precipitation (P. D. Bangs, P. R. Krausman, K. E. Kunkel, and Z. D. Parsons, Habitat use by female desert bighorn sheep in the Fra Cristobal Mountains, New Mexico, unpublished data). Succulent vegetation is an important source of water in this population, however we did not quantify the availability of this resource.

Our data did not consistently support our hypothesis that parturition sites would offer greater protection from predation, as traditionally defined (i.e., steeper, more rugged, closer to steep slope patches), compared to pre sites (Figure 1, 2; Table 1). However, parturition sites were higher in elevation and more rugged than pre sites (Figure 2, Table 1). Hiding cover may be an important factor in habitat selection by parturient females. We observed that young lambs (≤ 3 days) do not always flee when threatened; on 12 occasions the female immediately left the area while the lamb laid motionless. In these situations, predator avoidance is more important than predator evasion. If the "freezing behavior" of young lambs is frequently employed, terrain features promoting predator avoidance (e.g., hiding cover) may be more important than terrain features promoting predator evasion (e.g., steep slopes). This would explain the isolation behavior exhibited by parturient females; a solitary female is less conspicuous than a group of bighorn sheep.

As lambs mature, their ability to outmaneuver predators increases and predator evasion may become the primary anti-predation strategy. Our data support the prediction that post sites would offer greater protection from predation (i.e., steeper, more rugged, closer to steep slope patches) compared to pre sites (Figure 1, 2; Table 1). Females used sites close to 100% slope patches during the post period, but not in the pre or parturition periods (Figure 1) or throughout the spring season (P. D. Bangs, P. R. Krausman, K. E. Kunkel, and Z.

D. Parsons, Habitat use by female desert bighorn sheep in the Fra Cristobal Mountains, New Mexico, unpublished data).

MANAGEMENT IMPLICATIONS

Female desert bighorn sheep in the Fra Cristobal Mountains changed habitat use within the lambing period. Due to increasing threats to desert bighorn sheep habitat (e.g., Krausman et al. 2002) and the detrimental effects of disturbance (e.g., Krausman and Leopold 1986), there is a need to better understand or predict habitat use within the lambing period. Future research should incorporate measures of forage quantity and quality, including succulent vegetation, and hiding cover. Identifying habitat relationships during the lambing period requires frequent monitoring (i.e., $\leq$ 3-day intervals) of individual sheep.

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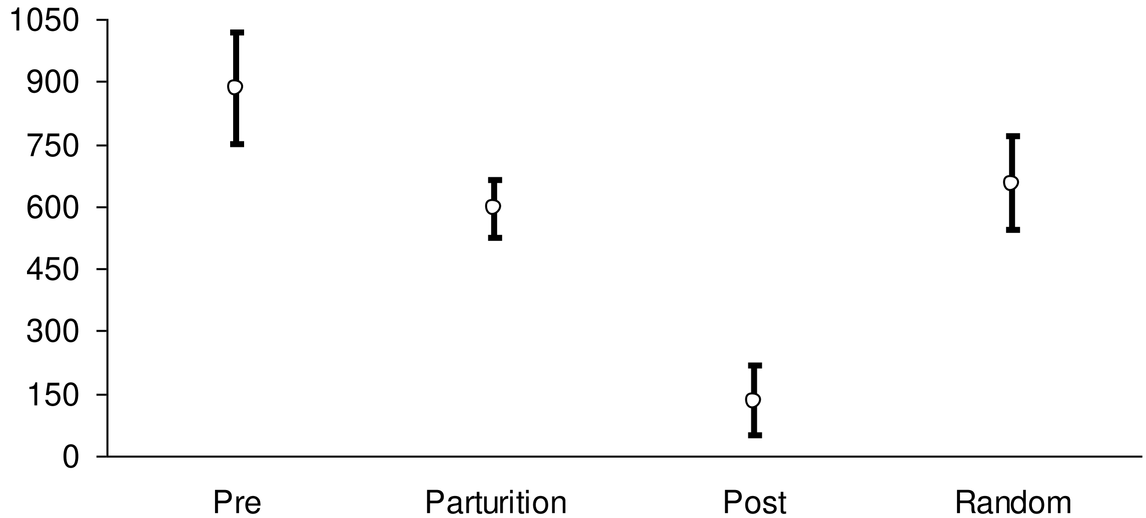
List of Figures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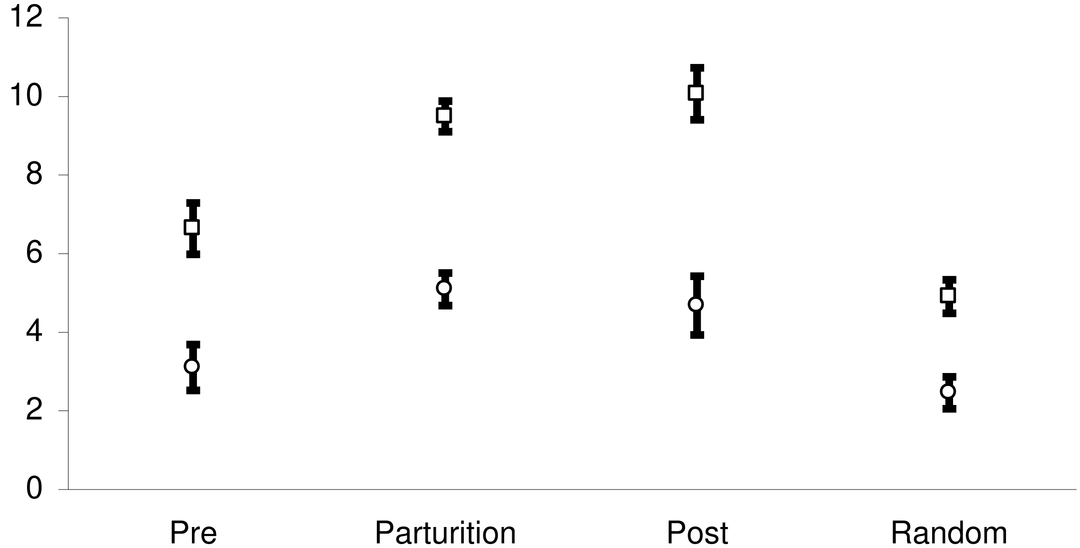
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Table 1. Physiographic characteristics of female desert bighorn sheep locations, Fra Cristobal Mountains, New Mexico, 1997-2000. Site categories refer to pre-parturition (*n* = 20), parturition sites (*n* = 37), post-parturition sites (*n* = 20), and random sites (*n* = 37) located 500 m from parturition sites. Variables are elevation (m), distance (m) to steep slope ($\geq$60%) patch ($\geq$ 1 ha), slope (degrees), and visibility (%) within a 50 m (Visibility 50) and 200 m radius (Visibility 200). Subject means were normalized (Field 2000) among pre, parturition, and post categories.

	Pre		Parturition		Post		Random	
Variable	$\overline{X}$	SE	$\overline{X}$	SE	$\overline{X}$	SE	$\overline{X}$	SE
Elevation	1726	18.6	1787	12.2	1822	18.1	1735	21.8
Slope patch 60	29.9	11.7	9.1	3.8	3.6	6.5	66.3	13.4
Slope	30.3	2.01	34.7	1.32	37.5	2.12	26.5	2.18
Visibility 50	50.5	2.50	46.4	1.79	43.1	2.88	58.2	2.39
Visibility 200	26.1	2.52	26.0	1.60	21.3	2.03	36.9	1.97

Appendix B

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RH: Desert bighorn habitat use • *Bangs et al.*

HABITAT USE BY FEMALE DESERT BIGHORN SHEEP, FRA CRISTOBAL MOUNTAINS, NEW MEXICO

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Abstract: Desert bighorn sheep (*Ovis canadensis* spp.) were translocated from a captive population to the Fra Cristobal Mountains of south-central New Mexico in 1995. Desert bighorn sheep are listed as an endangered species by New Mexico, with a statewide population estimate of 166 individuals. The Fra

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Cristobal population has been monitored since 1997 to assess habitat use patterns. Numerous studies have described habitat use by desert bighorn sheep, however they often lack individually identifiable sheep, are short-term, and are not stratified by season. We compared habitat characteristics of spring and autumn female desert bighorn sheep radiolocations to random locations within a composite home range. We developed a geographic information system to derive aspect, distance to steep slopes, elevation, slope, substrate associations, terrain ruggedness, and visibility. Habitat characteristics at bighorn sheep locations were similar between seasons. Bighorn sheep locations tended to be steeper, more rugged, closer to patches of 60% slope, and had lower visibility than random sites. We developed seasonal logistic regression models that incorporated distance to 60% slope patches, ruggedness (spring model only), slope, substrate, and visibility.

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Key words*:* desert bighorn sheep, habitat use, New Mexico, Ovis canadensis.

Since the 1800s, the distribution and abundance of desert bighorn sheep (*Ovis canadensis* spp.) populations has declined significantly due to an array of anthropogenic activities (e.g., livestock overgrazing, unregulated hunting, and diseases from domestic sheep, Krausman 2000). At the end of the twentieth century, encroaching human development, urbanization, and the rapid increase in backcountry recreational activities are imposing additional threats to desert bighorn sheep habitat (U.S. Fish and Wildlife Service 1999, Papouchis et al. 2001, Krausman et al. 2002). Several bighorn sheep populations are listed as endangered at the federal (e.g., peninsular bighorn [*O. c. cremnobates*], Federal Register Volume 63, No. 52. 1998) or state level (e.g., desert bighorn [*O. c. mexicana*], New Mexico Department of Game and Fish [NMDGF] 1995). As of 2001, the estimated number of desert bighorn sheep in New Mexico was 166 (E. M. Rominger, and E. Goldstein, New Mexico desert bighorn census report: autumn 2001, unpublished data).

In October 1995, the NMDGF translocated 37 desert bighorn sheep (24 F, 13 M) from a captive population at the Red Rock Wildlife Area in southwestern New Mexico to the Fra Cristobal Mountains. Although it is unknown whether desert bighorn sheep historically occupied the Fra Cristobal Mountains, the area was selected because other mountain ranges in New Mexico had problems with psoroptic mites (*Psoroptes spp.*), exotic animals such as Persian wild goats (*Capra aegagrus*) and aoudads (*Ammotragus lervia*), domestic sheep, feral goats, or public opposition (NMDGF 1995). The Fra Cristobal Mountains provided privately owned habitat with public support for the translocation (Krausman et al. 2001).

In 1997, Turner Endangered Species Fund (TESF) began a monitoring program to study population dynamics of bighorn sheep in the Fra Cristobal Mountains. Relocation data from the radiocollared bighorn sheep provided an opportunity to evaluate habitat use. Numerous studies have examined broad scale habitat use by desert bighorn sheep, however studies are often short term (≤ 1 year), lack individually identifiable sheep (i.e., radiocollared), and are not stratified by season (McCarty and Bailey 1994). Many habitat use studies are further limited by having a coarse spatial resolution (e.g., 3 –4 km^2 unit of analysis, Cunningham [1989], Andrew et al. [1999]) relative to the complex and variable terrain used by desert bighorn sheep. Our objective was to incorporate multiple years of bighorn sheep relocation data to describe seasonal habitat use in a spatially refined context.

STUDY AREA

The privately owned Fra Cristobal Mountains (33.25 – 33.5° N, 107.05 – 107.15° W) were located in Sierra County, approximately 32 km northeast of Truth or Consequences, New Mexico. The range was an east-tilted horst block ~ 24 km long by 5 km wide with an elevation range of 1,400 to 2,109 m (Nelson 1986). Five apron water catchments capable of holding ~ 19,000 L and a few ephemeral springs were located on the range. Precipitation at Elephant Butte Dam (16 km south of range, 33° 09’ N, 107° 11’ W, elevation 1395 m) averaged 23.6 cm annually (Figure 1, data obtained from National Climatic Data Center, National Oceanic and Atmospheric Association, Asheville, North Carolina, USA). Desert scrub and desert grassland were the predominant vegetation associations. Montane scrub was found at higher elevations, typically between 1,850 and 1,950 m. A limited amount of coniferous woodlands was at the highest elevations. The mountain range has ~ 65 km^2 of desert bighorn habitat

(Dunn 1994) and supported ~ 50 desert bighorn sheep during the study. No known domestic sheep herds occurred within 50 km of the range. Predators within the study area were cougars (*Puma concolor*), golden eagles (*Aquilo chrysaetos*), bobcats (*Lynx rufus*), and coyotes (*Canis latrans*). Cougars were the primary source of mortality for adult sheep (Turner Endangered Species Fund, unpublished data).

METHODS

In October 1995, the NMDGF translocated 37 desert bighorn sheep from a captive population at the Red Rock Wildlife Area (RRWA) in southwestern New Mexico to the Fra Cristobal Mountains. All sheep (24 females, 13 males) were fitted with VHF telemetry collars (Model 500, Telonics, Mesa, Arizona, USA). The herd was augmented with 7 males from RRWA in 1997. In November 1999, the NMDGF and TESF used a helicopter and net gun (Krausman et al. 1985) to capture and radiocollar 16 females, 9 of which were previously radiocollared.

Intensive ground based monitoring efforts began in July 1997 and continued through August 2000. We attempted to locate each radiocollared female on a near daily basis by telemetry and visual searches with optics. If we could not visually locate the animal, we did not record the observation. We plotted locations on United States Geological Survey (USGS) 1:24,000 scale topographical maps. Monitoring was restricted to daylight hours.

We used ArcView (Version 3.2, ESRI, Redlands, CA) with Spatial Analyst extension (version 1.1, ESRI, Redlands, CA) software to develop a Geographic

Information System (GIS). We obtained digital elevation models with 10-meter spatial resolution from the USGS. We used existing maps of substrate association (M. E. Miller. 1999. Vegetation of the Fra Cristobal Range, Southern New Mexico, Turner Biodiversity Division, Truth or Consequences, New Mexico, USA), based on the classifications of Neher (1984) and Nelson (1986).

Other layers included aspect, distance to steep slopes, elevation, slope, terrain ruggedness, and visibility (i.e., proportion of surrounding area not obstructed by topography). The distance to steep slope measurement was selected to represent proximity to security cover. Escape terrain for desert bighorn sheep has been defined numerous ways, typically with a minimum slope steepness of 60 – 100% and often with subjective descriptions of topographic ruggedness (e.g., rock outcroppings or cliffs, McCarty and Bailey 1994). To prevent unreliable comparisons, we avoided subjective descriptions. Minimum size requirements of 1.6 – 2 ha have been proposed for escape terrain patches (Tilton 1977, Armentrout and Brigham 1988), however McCarty and Bailey (1994) suggest these sizes may be arbitrary. Because of the uncertainty in defining escape patches, we delineated security cover as ≥ 60% and ≥ 100% slope, both incorporating a minimum patch size of 1 ha. This approach does not incorporate ruggedness, which may be an important component of escape terrain (McCarty and Bailey 1994); therefore we refer to these areas as steep patches.

We performed a viewshed analysis (Sorenson and Lanter 1993) in ArcView to calculate visibility. We selected an offset height of 1.5 meters to approximate the eye level of a bighorn sheep. We calculated the number of cells visible in a 250 m radius around each location, and multiplied the cell count by 100 m^2 (cell size) to obtain the visible area. We calculated percent visibility by dividing the visible area by the total area (π * radius^2) and multiplying this value by 100.

We described terrain ruggedness for a 6.25 ha spatial neighborhood (250 m X 250 m) around each point location using a routine developed by J. M. Sappington et al. (USGS, Quantifying landscape ruggedness for animal habitat analysis: a case study using desert bighorn sheep in the Mojave Desert, 2002, unpublished data). We used an ArcView script to calculate the 3-dimensional dispersion of vectors normal to grid cells composing each landscape following Pincus (1956), Hobson (1972), and Durrant (1996). Their technique results in a dimensionless ruggedness number that ranges from 0 (flat) to 1 (most rugged), we multiplied each value by 100 to obtain a percentage of the theoretical maximum.

If our data contained >1 location/individual/day, we randomly selected 1 to minimize temporal autocorrelation. We restricted our analysis to female sheep with $\geq$ 30 locations in each season (n = 20). Seasons were defined as spring (January – June) and autumn (July – December), based on sheep behavior and precipitation (Figure 1). Spring coincides with lambing, which occurs from January through May (TESF, unpublished data) and has relatively low amounts of precipitation (Figure 1). Fall coincides with rutting behavior and contains 76% of average annual precipitation (95% CI= 73 to 80).

The analysis was a design II, where resource use is defined for each individual but availability is defined at the population level (Manly et al. 1993:6). We defined available habitat based upon the distribution of the sheep (McClean et al. 1998, Grinder and Krausman 2001). We used the ArcView Animal Movement extension (Hooge and Eichenlaub 1997) to generate a 100% minimum convex polygon (MCP) around all female bighorn sheep locations (n = 5,112) and considered any habitat within this polygon to be available for use by female bighorn sheep. We generated an equal number of random points in the MCP and derived their attributes in the same manner as the bighorn sheep locations.

We used SPSS software (version 10.0, Chicago, Illinois, USA) for statistical analysis. To reduce non-normality in the data, we applied a logarithmic transformation to the elevation and ruggedness variables and a square root transformation to distance to steep patches, slope, and visibility. For each continuous variable we calculated the mean value for each female for each season and the mean value of random points. For each season, we compared the mean values of the individuals to the hypothesized values (mean of random points) using a 1-sample t-test. We back transformed the variables to facilitate interpretation. All comparisons statistically significant (α = 0.10) and perceived as biologically significant (Steidl et al. 2000) were retained for model development. For categorical variables we visually examined the distributions for significant differences among categories.

We examined variables for multicollinearity using linear regression tolerance statistics (Field 2000). We conducted a multiple logistic regression analysis for each individual for each season (Erickson et al. 2001). The dichotomous response variable was either a sheep location (coded as 1) or a random location. We randomly selected from our pool of random locations to provide an equal sample size for each individual model. We categorized aspect into east (0-179°; coded as 0) and west (180-359°; coded as 1) facing slopes. We averaged the model coefficients across individuals for each season, effectively treating the animal as the experimental unit and as a random effect (Erickson et al. 2001). We tested whether the mean coefficients were equal to zero by employing a 1-sample *t*-test. We removed any variables that were not statistically significant ($\alpha = 0.10$) and refit the logistic regression models. By averaging the individual models for each season, we obtained models of average selection for the population. We applied this model to the original data to examine the classification accuracy (Hosmer and Lemeshow 2000:156), based on a cutpoint of 0.5.

RESULTS

We obtained 2,423 locations in spring (0 = 121 ± 51.8 [SD]) and 2,689 locations in autumn (0 = 134 ± 54.4 [SD]) from 20 bighorn sheep and used equal numbers of random points. Elevation and distance to 100% slope patch were not included in either seasonal model (Tables 1, 2) and ruggedness was not included in the autumn model (Table 2).

Aspect

The average proportion of bighorn sheep locations on west facing slopes was greater for autumn and spring locations compared to random locations (Tables 3, 4). Aspect use appeared to be similar between spring and autumn seasons (Table 5).

Distance to Steep Patch

Compared to random locations, bighorn sheep locations in spring were 60.4 m closer (95% CI = 58.0 – 62.8, Table 3) to patches of 60% slope and 130.0 m closer (95% CI = 83.4 – 176.7, Table 3) to patches of 100% slope. Compared to random locations, bighorn sheep locations in autumn were 65.8 m closer (95% CI = 64.6 – 67.1, Table 2) to patches of 60% slope and 318.7 m closer (95% CI = 286.8 – 350.6, Table 2) to patches of 100% slope. In comparison to bighorn sheep locations in spring, autumn locations were 6.9 m closer (95% CI = 4.1 – 9.8, Table 5) to patches of 60% slope and 186.1 m closer (95% CI = 122.7 – 249.6, Table 5) to patches of 100% slope. We did not include distance to 100% slope patch in the logistic regression models because we considered the average distance of sheep locations too far (Tables 3, 4) to play a role in predator evasion (i.e., biologically insignificant).

Elevation

Elevation of sheep locations in spring was not significantly different than random locations ($\bar{d}$ = - 1.2 m, 95% CI = -6.1 – 3.7, Table 3). On average, elevation at bighorn sheep locations in autumn was 21.1 m higher (95% CI = 14.0 - 28.2, Table 5) than bighorn sheep locations in spring. Bighorn sheep locations in autumn were higher ($\bar{d}$ = 21.9 m, 95% CI = 18.1 - 25.8, Table 4) in elevation than random locations, but not significant in the logistic regression model (t_{19} = - 1.29, 2-sided P = 0.211).

Ruggedness

In comparison to random locations, ruggedness of bighorn sheep locations in autumn was 1.7% higher (95% CI = 1.6 - 1.8, Table 4), but not significant in the autumn logistic regression model (t_{19} = - 0.232, 2-sided P = 0.819). Ruggedness at bighorn sheep in spring locations was 1.6% higher (95% CI = 1.4 – 1.7, Table 3) than random locations. Ruggedness at bighorn sheep locations in autumn was 0.18% higher (95% CI = 0.03 – 0.33, Table 5) than bighorn sheep locations in spring.

Slope

On average, bighorn sheep locations in autumn were 11.9° steeper (95% CI = 11.3 - 12.4, Table 4) than random locations. Bighorn sheep locations in spring were 8.9° steeper (95% CI = 8.3 – 9.5, Table 3) than random locations. Slope of bighorn sheep locations in autumn was 3.1° steeper (95% CI = 2.4 - 3.8, Table 5) than bighorn sheep locations in spring.

Substrate

Substrate associations were not used in proportion to availability in either season. Alluvium substrate comprised 8% of random locations, however no desert bighorn sheep locations occurred on this substrate. Random sites were located on limestone substrate more often (50%) than bighorn sheep locations in spring (25%, SD = 4) or autumn (37%, SD = 6). Random sites were located on granite substrate less frequently (15%) than bighorn sheep locations in spring (40%, SD = 5) or autumn (35%, SD = 8). Random sites and desert bighorn sheep locations were similar in the use of shale (random: 10%; spring: 14%, SD = 4; autumn: 14%, SD = 5), limestone – granite (random: 15%; spring: 17%, SD = 5; autumn: 10%, SD = 2), and other (sandstone or volcanic cinders) substrates (random: 3%; spring: 4%, SD = 2; autumn: 3%, SD = 1). Alluvium and limestone were significant in the logistic regression models (Tables 1, 2). Alluvium was selected against in both seasons and limestone was selected against in spring.

Visibility

On average, visibility at bighorn sheep locations in autumn was 5.7% lower (95% CI = 5.1 – 6.3, Table 4) than random locations. Visibility at bighorn sheep locations in spring was 4.7% lower (95% CI = 4.3 – 5.2, Table 3) than random locations. Visibility was not different between bighorn sheep locations in autumn and spring ($\bar{d}$ = - 0.8%, 95% CI = -1.5 – 0.0, Table 5).

Model Classification Accuracy

Sensitivity (i.e., percentage of presence responses predicted correctly) was 80.4% for spring (n = 2,423) and 75.5% for autumn (n = 2,689). Specificity (i.e., percentage of absence responses predicted correctly) was 69.1% for spring (n = 2,423) and 74.9% for autumn (n = 2,689).

DISCUSSION

Habitat characteristics at bighorn sheep locations were similar in both seasons. Sheep locations tended to be steeper, more rugged, closer to patches of 60% slope, and had lower visibility than random sites. Although bighorn sheep primarily used western aspects in both seasons (Figure 2), this may be misleading because the range is an east-tilted horst; the western flank of the range provides the greatest structural relief with the steepest and most rugged terrain (Nelson 1986).

Previous studies found that desert bighorn sheep in New Mexico tended to remain within 1.6 km of freestanding water (Sandoval 1979, Bavin 1982, Elenowitz 1983). Despite below average precipitation during the study (Figure 1), we did not observe female bighorn sheep utilizing the catchments. However, bighorn sheep were observed using mineral salt licks situated near the drinkers on several occasions. We suspect that female desert bighorn sheep in this population rely primarily on succulent vegetation to meet their water requirements, as reported elsewhere (e.g., Watts 1979).

Visibility is an important habitat feature for bighorn sheep because predators are detected visually (Krausman et al. 1999). Foraging efficiency is greater in areas with higher visibility (Risenhoover and Bailey 1985), and bighorn sheep may avoid areas with large boulders (Krausman and Leopold 1986) or abandon areas when growth of dense vegetation obstructs visibility (DeForge 1980, Krausman et al. 1996). The obstruction of visibility from tall vegetation is a problem only in the highest elevations in the Fra Cristobal Mountains, where there are 1-seed juniper (*Juniperus monosperma*) and scattered Colorado pinyon (*Pinus edulis*) trees. However, this is a relatively small area and is not used by desert bighorn sheep.

Because of accuracy limitations of GIS-based visibility analyses (Maloy and Dean 1991) our results should be interpreted as relative measures. Although bighorn sheep locations tended to have lower visibility than random locations (Tables 3, 4), we suspect these results were confounded with ruggedness and slope. Obstruction of visibility due to topography would be minimal on flat terrain, and higher on irregular (i.e., rugged) or mountainous terrain.

Bighorn sheep locations were close to 60% slope patches in both seasons (Tables 3, 4). Bighorn sheep locations tended to be too far from 100% slope patches to aid in predator evasion (Tables 3, 4). However, patches of 100% slope may be important for females with lambs in the 30-day period following parturition (P. D. Bangs, P. R. Krausman, K. E. Kunkel, and Z. D. Parsons, Habitat use during the lambing period of desert bighorn sheep, unpublished data).

Although our seasonal models were successful in discriminating between sheep locations and random points, the models were not internally or externally validated. This was an observational study, therefore causation cannot be inferred and inferences should be restricted to female sheep in this population.

MANAGEMENT IMPLICATIONS

The translocation of desert bighorn sheep to the Fra Cristobal Mountains appears successful as the population has increased to over 70 individuals (TESF, unpublished data), and is currently the largest desert bighorn sheep population in New Mexico (E. M. Rominger, and E. Goldstein, New Mexico desert bighorn census report: autumn 2001, unpublished data). The population growth was likely facilitated by intensive monitoring of radiocollared bighorn sheep and removal of individual cougars (by NMDGF) that killed bighorn sheep. Because of the precariousness of desert bighorn sheep in New Mexico, we recommend that intensive monitoring efforts continue on the Fra Cristobal Mountains, particularly if predator control tactics are changed or abandoned.

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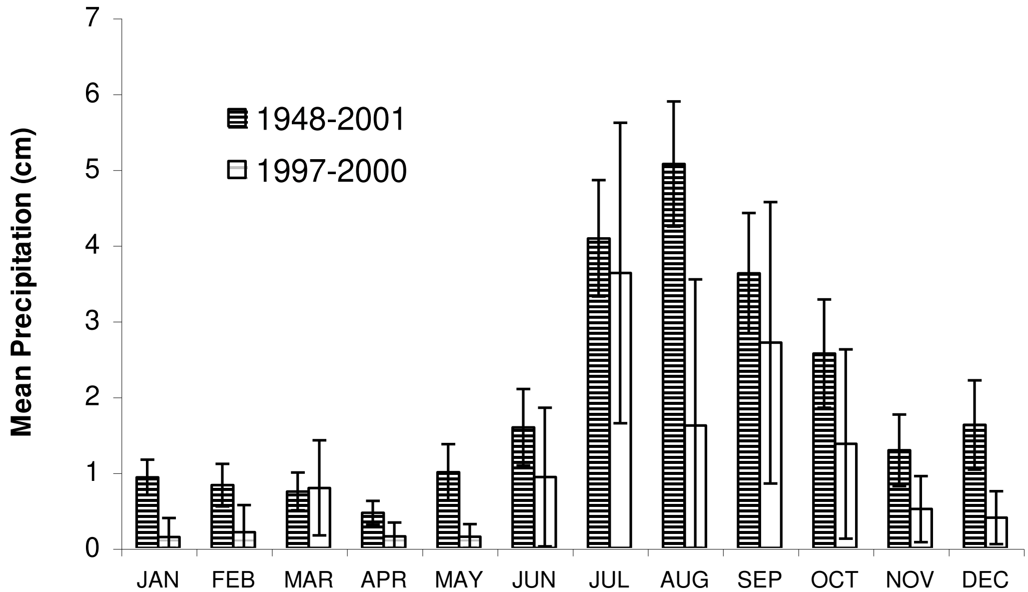
List of Figures

Figure 1. Average monthly precipitation (cm) at the Elephant Butte Dam, located 16 km southwest of the Fra Cristobal Mountains, New Mexico. Bars represent a 95% confidence interval about the mean.

Figure 2. Average proportion (bars represent ∀ 1 SD) of locations of 20 female desert bighorn sheep and random locations occurring on eastern or western facing slopes in the Fra Cristobal Mountains of New Mexico, 1997-2000.


Mean Precipitation (cm)
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6
5
4
3
2
1
0
1948-2001
1997-2000
JAN
FEB
MAR
APR
MAY
JUN
JUL
AUG
SEP
OCT
NOV
DEC

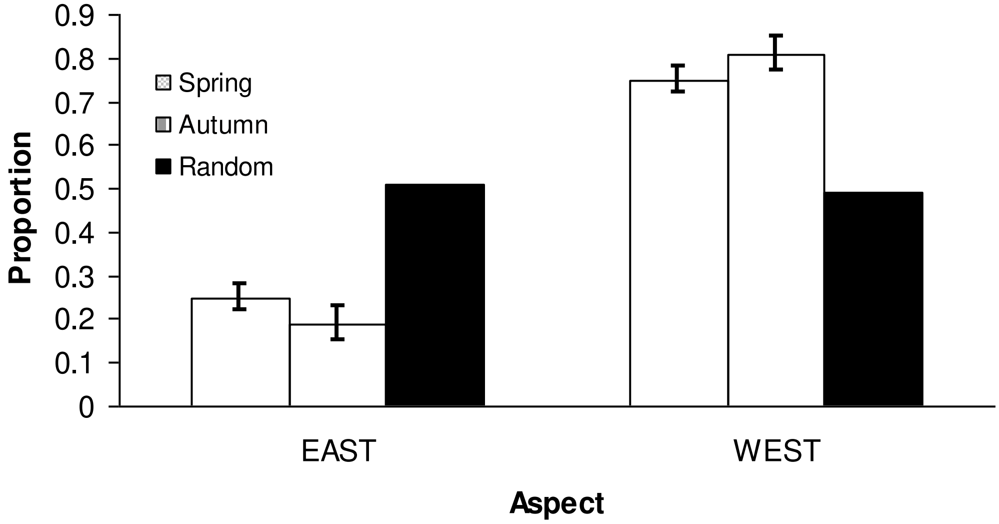
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
Proportion
Spring
Autumn
Random
EAST
WEST
Aspect

Table 1. Coefficients of the logistic regression model of habitat selection in spring for 20 female desert bighorn sheep, Fra Cristobal Mountains, New Mexico, 1997-2000.

Parameter	Estimate	SE	t_{19}	*P*
Alluvium	- 5.945	1.0363	- 5.736	< 0.001
Aspect	0.9390	0.0793	11.847	< 0.001
Constant	-1.280	0.4542	-2.818	0.011
Distance 60	0.0004	0.0001	3.387	0.003
Granite	- 0.174	0.5094	- 0.342	0.736
Limestone	- 1.774	0.511	- 3.473	0.003
Limestone/granite	- 0.426	0.5433	- 0.784	0.443
Ruggedness	0.052	0.0117	4.423	< 0.001
Shale	- 0.135	0.728	- 0.185	0.855
Slope	0.075	0.007	11.367	< 0.001
Visibility	- 0.0240	0.004	- 6.024	< 0.001

Table 2. Coefficients of the logistic regression model of habitat selection in autumn for 20 female desert bighorn sheep, Fra Cristobal Mountains, New Mexico, 1997-2000.

Parameter	Estimate	SE	t_{19}	*P*
Alluvium	- 4.945	0.883	- 5.598	< 0.001
Aspect	1.126	0.066	17.128	< 0.001
Constant	- 2.502	0.571	- 4.381	< 0.001
Distance 60	0.0002	0.0001	1.945	0.067
Granite	0.808	0.631	1.282	0.215
Limestone	- 0.284	0.686	- 0.415	0.683
Limestone/granite	0.304	0.712	0.427	0.674
Shale	1.060	0.748	1.418	0.173
Slope	0.096	0.006	15.478	< 0.001
Visibility	- 0.035	0.006	- 6.190	< 0.001

Table 3. Physiographic characteristics of locations of 20 female desert bighorn sheep in spring compared to random locations, Fra Cristobal Mountains, New Mexico, 1997-2000. Variables are distance to steep terrain patch (distance 60 = ≥ 60% slope, ≥ 1 ha; distance 100 = ≥ 100% slope, ≥ 1 ha), elevation (m), ruggedness (%) in a 250 m * 250 m neighborhood, slope (degrees), visibility (%) in a 250 m radius.

	Spring		Random			
Variable	$\overline{X}$	SE	$\overline{X}$	SE	t_{19}	*P*
Distance 60	18.4	1.14	78.8	2.77	- 53.0	< 0.001
Distance 100	779	22.3	908.6	16.9	- 5.83	< 0.001
Elevation	1684	2.33	1685	2.44	- 0.52	0.612
Ruggedness	3.80	0.06	2.24	0.06	25.5	< 0.001
Slope	26.4	0.29	17.5	0.27	31.1	< 0.001
Visibility	24.8	0.22	29.5	0.37	- 21.4	< 0.001

Table 4. Physiographic characteristics of locations of 20 female desert bighorn sheep in autumn compared to random locations, Fra Cristobal Mountains, New Mexico, 1997-2000. Variables are distance to steep terrain patch (distance 60 = ≥ 60% slope, ≥ 1 ha; distance 100 = ≥ 100% slope, ≥ 1 ha), elevation (m), ruggedness (%) in a 250 m * 250 m neighborhood, slope (degrees), visibility (%) in a 250 m radius.

	Autumn		Random		
Variable	$\bar{X}$	SE	$\bar{X}$	SE	t_{19}[a]
Distance 60	11.5	0.60	77.3	2.56	- 111.3
Distance 100	592.4	15.23	911.1	15.25	- 20.9
Elevation	1705	1.85	1683	2.50	11.8
Ruggedness	3.97	0.04	2.27	0.05	41.9
Slope	29.6	0.25	17.7	0.25	47.5
Visibility	24.0	0.40	29.7	0.27	- 20.9

[a] $P < 0.001$ for all comparisons.

Table 5. Physiographic characteristics of locations of 20 female desert bighorn sheep in autumn compared to spring, Fra Cristobal Mountains, New Mexico, 1997-2000. Variables are distance to steep terrain patch (distance 60 = ≥ 60% slope, ≥ 1 ha; distance 100 = ≥ 100% slope, ≥ 1 ha), elevation (m), ruggedness (%) in a 250 m * 250 m neighborhood, slope (degrees), visibility (%) in a 250 m radius.

Variable	$\bar{d}$	SE	t_{19}	*P*
Distance 60	- 6.9	1.36	- 5.09	< 0.001
Distance 100	- 186.2	30.3	- 6.14	< 0.001
Elevation	21.1	3.39	6.24	< 0.001
Ruggedness	0.18	0.07	2.44	0.025
Slope	3.1	0.33	9.41	< 0.001
Visibility	- 0.76	0.37	- 2.06	0.053