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**Diel activity of female desert bighorn sheep in western Arizona**

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The University of Arizona, 1987

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DIEL ACTIVITY OF FEMALE DESERT BIGHORN SHEEP  
IN WESTERN ARIZONA

by

Jay Allen Alderman

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A Thesis Submitted to the Faculty of the  
SCHOOL OF RENEWABLE NATURAL RESOURCES  
In Partial Fulfillment of the Requirements  
For the Degree of  
MASTER OF SCIENCE  
WITH A MAJOR IN WILDLIFE AND FISHERIES SCIENCE  
In the Graduate College  
THE UNIVERSITY OF ARIZONA

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I would like to dedicate this work to my uncle Gene Alcorn, whose selfless love for nature influenced the lives of many including myself.

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## ABSTRACT

I studied diel activity patterns of female desert bighorn sheep (Ovis canadensis mexicana) in the Little Harquahala Mountains, Arizona, July 1985 - June 1986. Diurnal activity patterns were similar throughout the year. Nocturnal activity patterns were similar for all seasons except spring when activity significantly ( $P = 0.003$ ) decreased. Bighorn sheep were active an average of 39 and 33% of any given hour during the day and night, respectively. Diurnal ambient temperatures and relative humidity were significantly ( $P \leq 0.048$ ) correlated with bighorn sheep activity during all seasons. Bighorn sheep spent a majority of the time foraging in the fall and winter, but spent more time resting during spring and summer. Bighorn sheep obtain water in their food throughout the day; percent moisture content of forage species remained high ( $\geq 32\%$ ) for any given hour of the day throughout the year.

## INTRODUCTION

Diurnal and crepuscular activities of desert bighorn sheep (Ovis canadensis mexicana) have been described (Russo 1956, Devan 1958, Welles and Welles 1961, Welch 1969, Turner 1973, Fonseca and Gonzalez 1976, Leslie and Douglas 1979, Olech 1979, Chilelli and Krausman 1981, Seegmiller and Ohmart 1981, Hansen 1984, McCutchen 1984, Warrick 1985) and generally classified as bedding, foraging, moving, elimination, shelter seeking, grooming, reproducing, and drinking (Augsberger 1970, Fonseca and Gonzalez 1976, Golden and Ohmart 1976, Olech 1979). Desert bighorn sheep are generally considered to be crepuscular with limited nocturnal activity (Koplin 1960, Graves 1961, Hansen 1964, Monson 1964, Simmons 1964, Hailey 1967). Because of this perception, and the difficulty of observing wildlife at night, nocturnal activity studies of bighorn sheep have been limited. Recent technological developments have made it possible to monitor nocturnal animal activity. Miller et al. (1984) used an available-light starlight scope to observe bighorn sheep behavior on moonlit nights within 100 m of a water hole, and Hazam (1987) used an image intensifier pocketscope with infrared lights to observe desert mule deer (Odocoileus hemionus crooki). Krausman et al. (1985) used a digital processor to monitor diel activity of female sheep. These advances have provided insight into nocturnal behaviors of ungulates and suggest that nocturnal activity is common.

Mammals which inhabit deserts are exposed to  $\geq 2$  major interrelated physiological problems: the maintenance of an adequate

water balance and suitable body temperature (Bradley 1963). Water is available to animals from metabolic water formed as a result of oxidative metabolism, preformed water found in food, and surface water (Turner and Weaver 1980). Turner (1973) stated that bighorn sheep require 4% of their body weight/day in water and that this amount could not be obtained from forage during hot, dry periods. However, the Little Harquahala Mountains, Arizona support 15-20 bighorn sheep and free standing water is not available (Krausman et al. 1985). Therefore, it appears that during long periods of little or no rainfall, bighorn sheep in the Little Harquahala Mountains survive on preformed and/or metabolic sources of water (Krausman et al. 1985). Dry food, which at midday contains  $\leq 1\%$  free water, can contain  $\geq 43\%$  water in the early morning (Taylor 1968). Large succulent fruits, tubers and bulbs are also sources of preformed water for desert dwelling mammals (Bodenheimer 1957).

Krausman et al. (1985) demonstrated that 2 female bighorn sheep in the Little Harquahala Mountains were active 34% of any hour during the summer and that neither female drank water during a 10-day study. Given these results, I was interested in determining the relationship between daily activity patterns of bighorn sheep and patterns of forage moisture in plants they consume.

My objectives were to: (1) examine and define diel activity of female desert bighorn sheep, and describe the affect of time of day, season, group size, temperature, relative humidity, and the presence of a lamb on their activity, (2) determine if there are seasonal patterns in the moisture content of key forage species used by bighorn sheep,

and (3) describe any relationships that exist between forage moisture and bighorn sheep activity.

## STUDY AREA

The study was conducted in the Little Harquahala Mountains, La Paz County, Arizona (Fig. 1) 161 km west of Phoenix. The Little Harquahala Mountains encompass 179 km<sup>2</sup> and elevations range from 427 to 940 m.

The Little Harquahala Mountains lie within the desertscrub formation (Lowe 1964). Creosotebush (Larrea tridentata) flats comprise 113 km<sup>2</sup> (63%) of the area (Krausman 1985). Plant species dominating the slopes are brittlebush (Encellia farinosa), creosotebush, littleleaf palo verde (Cercidium microphyllum), and white bursage (Ambrosia dumosa). Littleleaf palo verde, blue palo verde (Cercidium floridum), and ironwood (Olneya tesota) dominate the washes. Additional plant species in the area include ocotillo (Fouquieria splendens), catclaw acacia (Acacia greggii), wolfberry (Lycium spp.), white ratany (Krameria grayi), and desert lavender (Hyptis emoryi). Mammillaria (Mammillaria spp.) and barrel cactus (Ferocactus wislenzii) are 2 succulent species consumed by bighorn sheep (Krausman 1985). Vegetation on the slopes is sparse (13.2 - 20.7% ground cover) (Krausman 1985).

Temperature and precipitation data recorded during the study were compared to weather data collected from 1975 - 1986 at the Aguila weather station, Aguila, Arizona (Natl. Oceanic and Atmos. Adm. 1975 - 1986). Weather patterns from July 1985 to June 1986 were similar to those in my study. Seasons were delineated using average temperature and precipitation data collected during the study (Fig. 2).

Total precipitation for the year was 21 cm. Winter (Jan-Mar) was a cool, moderately wet season with an average temperature of 16 C and 5 cm of precipitation. Spring (Apr-Jun) was a hot dry season with a mean temperature of 26.4 C and 1 cm of precipitation. Summer (Jul-Sep) was hot and dry with an average temperature of 30.2 C and 3 cm of rainfall. Fall (Oct-Dec) was cool and wet with a mean temperature of 15.2 C and 12 cm of precipitation.

Potholes scattered throughout the range collected and held water for  $\leq 7$  days after rains. From February 1985 to March 1986, 2 water catchments were developed on the study area, and now provide a permanent source of water to desert bighorn sheep. During the study I monitored the catchments with time-lapse photography and neither were used by radio-collared bighorn sheep.

Although the population appears to be stable, lamb survival has been low since 1979 (Krausman and Leopold 1986). Desert mule deer and wild burros (Equus asinus) also inhabit the Little Harquahala Mountains.

## METHODS

Eight adult female desert bighorn sheep, radio-collared in a previous study (Warrick and Krausman 1987), were available for study in the Little Harquahala Mountains. I randomly selected 6 females to monitor for diel activity patterns. Four females were monitored regularly and 2 were selected as alternates in case 1 of the original subjects died, left the range, or had a collar that failed to work.

When locating bighorn sheep I attempted to remain undetected and get into position where sheep could be observed for long periods of time (Warrick 1985). I used a 30X16 power spotting scope to accurately observe sheep at a distance of  $\leq$  1km. Only observations of undisturbed sheep were used in analyses.

Sunrise and sunset was determined each week using sunrise and sunset tables for Phoenix, Arizona (Gale Research Company 1977). I located 1 female by sunrise and stayed in visual contact with her for  $\leq$  8 hours. On subsequent days I located the same female at the hour I had last observed her on the day before, until a full 24 hour period of activity data was collected each week. Behaviors were classified as bedding, standing, moving, and foraging (Warrick 1985). Heuer Trackmaster stopwatches were used to determine the number of seconds bighorn sheep spent in each of the behavior classes. One stopwatch/behavior class was monitored continuously during observations. As females switched from 1 behavior to another, stopwatches were stopped and started accordingly. Data were collected on 1 female at a time

during observation sessions. At the end of each hour total seconds spent in each behavior class were tallied. Activity was defined as moving and foraging. Sheep were considered inactive when bedded or standing.

Nocturnal data collection was divided into 2 classes: activity (foraging or moving), and nonactivity (standing or bedding). Nocturnal hours were designated as that period when distinction between behavior classes was not possible due to lack of available light. I used a digital processor (Model TDP-1, Telonics, Mesa, Ariz.) (Krausman et al. 1985) to quantify nocturnal activity. Each night the location of the subject animal was determined with radio telemetry. When the most direct signal was obtained the hand held Yagi directional antenna was securely fastened in position to maintain the strongest signal. The digital processor was connected to the receiver and provided high resolution signal strength information from the companion Telonics tracking receiver (Krausman et al. 1985). A 4 place accuracy digital data display measured the time between transmitted pulses in milliseconds. I determined relative activity of collared animals by detecting variations in signal strength resulting from activity which caused changes in transmitter orientation or signal path (Krausman et al. 1985). Deviations in signal strength occurred when animals moved, whereas signal strength remained constant when animals were inactive. Stopwatches were used to quantify seconds of activity on an hourly basis.

One time each season tests for accuracy were made with animals in sight during the day. While an assistant observed a collared female

through the spotting scope I monitored her activity with the digital processor. At the end of the hour total seconds of activity were compared to determine error.

Group size and composition, topographic position, exposure, location and forage plants consumed were recorded. Temperature and percent relative humidity were measured at the midpoint of each hour of observation. Locations of bighorn sheep were plotted on U.S. Geologic Survey topographic maps (scale 1:62,500). Group sizes used in analyses were counts of all individuals present.

Six forage plants (littleleaf palo verde, ironwood, catclaw acacia, desert lavender, white ratany, and wolfberry) were selected for moisture analysis based on their occurrence in bighorn sheep diets in the Little Harquahala Mountains (Seegmiller et al. unpubl. data). For each of the 6 plant species, hourly samples ( $>100g$ ) were collected over a 24 hour period, 4 times/season. Plant material was weighed in a pretared brown paper bag immediately after collection. Samples were maintained for  $\leq 72$  hours at ambient temperatures until received at the Animal Sciences Laboratory, University of Arizona (Morgart et al. 1986). Dry weight was determined by heating samples to a constant weight in a vacuum oven at 35 C (Church and Pond 1977).

Models illustrating the relation of mean hourly percent activity, bedding, standing, moving, foraging, relative humidity, plant moisture, and mean temperature with hour after sunrise were developed using polynomial regression analysis (Neter et al. 1985). To meet the assumptions of normality and homogeneity of variance, an arcsin-square root transformation was used on percent relative humidity and percent

time active, bedding, standing, moving, and foraging (Zar 1984:239-242). Forward stepwise regression was used to determine the appropriate variables to be entered into the regression model. To examine difference for seasonal patterns of activity, a quadratic regression model with indicator variables for season was developed. Pearson product-moment correlation analysis was used to quantify relationships for all possible variables used in the regression. A significance level of 0.05 was used for all statistical tests. All statistical analyses were conducted using SAS software (1985). Data were only included in analysis when behaviors were classified for  $\geq 75\%$  ( $\geq 2,700$  seconds) of each hour.

## RESULTS

### Diurnal Activity

I collected 669 hours of diurnal activity data from 6 female desert bighorn sheep. There was no significant difference (based on polynomial regression analysis) in the seasonal pattern of activity for female bighorn sheep with or without lambs. Although sheep were active 36, 47, 38, and 35% of the time for the summer, fall, winter, and spring seasons, respectively test of the intercepts from polynomial regression analysis indicate that these differences were not significant. Bighorn sheep activity (Fig. 3) was negatively correlated with mean temperature (Fig. 4) and positively correlated with mean relative humidity (Fig. 5) throughout the year (Table 1).

Bighorn sheep maintained a distinct pattern of bedding (Fig. 3) that remained consistent with no significant seasonal difference. Although sheep were bedded on the average 38, 28, 32, and 33% of the time for summer, fall, winter, and spring, respectively these differences were not significant. The average hourly amount of time sheep remained bedded was positively correlated with mean temperature and negatively correlated with mean relative humidity in all seasons (Table 1).

Mean hourly standing time of female sheep was highly variable. However, on the average females remained standing 23, 19, 22, and 22% of the time during the summer, fall, winter, and spring seasons, respectively and differences were not significant.

Mean hourly standing time of bighorn sheep was negatively correlated with mean temperature in the spring and summer, and was positively correlated in the spring and summer with mean relative humidity (Table 1).

Mean hourly movement rate of female sheep remained constant (4%) for fall, winter, and spring, but increased significantly ( $P = 0.016$ ) in the summer ( $\bar{x} = 10\%$ ). High variability in hourly movement rates among females made it difficult to produce a model illustrating seasonal patterns. Therefore, seasonal means were used to denote significant change in movement rate throughout the year. The degree of movement exhibited by bighorn sheep was negatively correlated with mean temperature, and positively correlated with mean relative humidity in the spring (Table 1).

Foraging among female bighorn sheep followed a distinct pattern (Fig. 3) that remained consistent for all seasons. Although bighorn sheep foraged an average of 26, 42, 34, and 31% of the time during the summer, fall, winter, and spring seasons, respectively these differences were not significant. The amount of time females foraged was negatively correlated with mean temperature all year, and positively correlated with mean relative humidity in the summer, fall, and spring (Table 1).

#### Diurnal Plant Moisture

Catclaw acacia and wolfberry lost a majority of their foilage in the winter and were not suitable for sampling. Due to small sample size they were removed from the analysis. Although mean hourly moisture content of the remaining plants was highly variable (e.g., littleleaf

palo verde) ( Fig. 6) throughout the year, mean water content remained consistently high. High variability on an hourly basis made it difficult to produce a model illustrating seasonal patterns. Seasonal means of plant moisture ranged from 33 to 54% (Table 2).

#### Group Size

Mean group size of bighorn sheep during this study remained small. During summer and fall mean group size was 3 (n = 315) but increased to 4 (n = 299) in winter and spring. There were no significant correlations between mean group size and mean hourly activity of female bighorn sheep.

#### Nocturnal Activity

I collected 506 hours of nocturnal activity data. Observations of bighorn sheep activity by observer agreed with data collected from the processor 93, 93, 95, and 98% of the time for summer, fall, winter, and spring, respectively.

Nocturnal activity of bighorn sheep followed a consistent pattern (Fig. 7) with no significant differences for the summer, fall, and winter seasons. Bighorn sheep were active an average of 39% of the time during these seasons. Activity in spring followed a significantly ( $P = 0.03$ ) different pattern (Fig. 7), and sheep were active 26% of the time. Correlations between nocturnal activity and mean temperature were not significant. However, sheep activity was positively correlated with relative humidity in the summer season (Table 1).

### Nocturnal Plant Moisture

Hourly moisture content of plants at night was highly variable (Fig. 6) throughout the year. Due to this variability no discernable patterns were evident that could be correlated with bighorn sheep activity. Although hourly moisture levels were sporadic, mean water content remained consistently high (range = 32 to 53%) (Table 2).

## DISCUSSION

Variability in temperature, precipitation, and abundance and quality of forage influence diel activity of desert bighorn sheep (Russo 1956, Welles and Welles 1961, Leslie and Douglas 1979, Hansen 1980). Bighorn sheep have acquired behavioral and/or physiological mechanisms to cope with desert conditions (Hansen 1982). Sheep may adjust to hot dry environments with nocturnal activity, and foraging on succulent plants (Krausman et al. 1985). However, I found no significant relationship between seasonal patterns of bighorn sheep activity and forage moisture. Seasonal moisture content of the 4 plants sampled remained consistently high on an hourly basis throughout the year. These data suggest that female desert bighorn sheep may obtain approximately the same amount of water from their food at any given hour of any day. If the hourly moisture content of all forage consumed by bighorn sheep remains consistently high, a biological mechanism for detection of variable plant moisture would not be important. Forage moisture did not account for the pattern of activity observed. These data do not however, reduce the importance of preformed moisture in vegetation, particularly to individuals inhabiting an area void of free-standing water.

Browse species were found to have the highest nutritional value of all plant species sampled in the Little Harquahala Mountains (Seegmiller et al. unpubl. data), and had consistent moisture levels of 32 to 54%. Taylor (1969) found that if oryx (Oryx gazella) and eland

(Taurotragus oryx) forage contained 30% water, both animals could become independent of drinking water. Cacti may provide an additional source of water to bighorn sheep (Russo 1956, Simmons 1963, Warrick and Krausman unpubl. data). Barrel cactus may contain  $\geq 88\%$  water (Seegmiller et al. unpubl. data), and occur in the diet throughout the year (Warrick 1985). During periods of water stress, bighorn sheep may selectively feed on barrel cactus for additional moisture. Use of succulent forage by bighorn sheep is well documented (Russo 1956, Barrett 1964, Browning and Monson 1980, Warrick 1985) however, the potential of these plants to provide a primary source of water (except for occasional rains) has not been determined.

#### Diurnal Activity

The consistent pattern of activity sheep displayed throughout the year may have been strongly influenced by temperature which also followed a consistent pattern (Fig. 4). Temperatures throughout the year were lowest in the first hour after sunrise then gradually increased and reached a peak from the seventh to the twelfth hour before gradually decreasing until dusk (Fig. 4). Sheep generally responded by reducing activity (increasing bedding time) as temperatures increased, then increased activity later in the day once temperatures were lower (Fig. 3). Other studies (Simmons 1969, Welch 1969, McCutchen 1984, Krausman et al. 1985) demonstrated the same general pattern of activity in response to ambient temperatures.

Relative humidity was correlated with sheep activity all year. However, this relationship was probably coincidental. Relative humidity

is strongly correlated with temperature and my data did not suggest relative humidity to have a direct affect on bighorn sheep activity. The use of relative humidity in this study to predict forage moisture and thus sheep activity failed, as plant moisture was rarely correlated with relative humidity for any season.

The consistent patterns of foraging and bedding displayed by females also appear to be influenced by temperature. This seems reasonable, especially in the summer when temperatures are at an annual high. Krausman et al. (1985) found movements of sheep were reduced in the summer. During summer, temperatures were  $\geq 39$  C (the normal body temperature of bighorn sheep) 33% of the time. Activity may also decrease in deer when ambient temperatures are  $\geq 39-41$  C (body temperature of deer) (Anderson 1980, Leopold and Krausman 1987). However, during cooler seasons of the year temperature should have less of an effect on the timing and degree of foraging and bedding, yet the same consistent pattern remained. Leslie and Douglas (1979) noted there was no significant change in activity because of lower temperatures. Although temperature may influence the timing and degree of activity, especially in summer, the real driving force behind consistent patterns of behavior may be intrinsic rather than extrinsic. The physiology of a ruminant may in itself be enough to elicit the consistent hourly behavior observed throughout the year. In ruminants the feeding and ruminating process precludes long periods of complete inactivity, particularly deep sleep, as reduced breathing rates may slow contractions of the reticulum making digestion more difficult (Balch 1955). Some food intake is necessary at relatively short intervals to

"keep the system going" (Balch 1955) for both cold and warm seasons Welch (1969). This suggests that physiological constraints necessitate regularity in diel activity thereby producing a more efficient system through consistent patterns of rest and resource acquisition.

The percent of the hour bighorn sheep spent moving reached a peak ( $\bar{x} = 10\%$ ) in the summer season. My results were similar to a previous study (Warrick 1985) conducted in the Little Harquahala Mountains. Warrick (1985) found that despite a greater abundance and diversity of forage plants after the onset of summer rains, bighorn sheep movement rates remained as high or higher than dry season movement rates. Warrick (1985) maintained that while sheep foraged on many of the same plants throughout the year they selected for the more nutritious new growth during the wet seasons. This increased selectivity may have contributed to the high movement rate seen during the summer season. Rutting behavior also reached a peak during the summer. Breeding activities are 1 of the primary factors which influence movements of desert bighorn sheep (Leslie and Douglas 1979). Rutting behavior has been found to increase movement rates in desert mule deer as well (Clark 1953). In the Little Harquahala Mountains dominant males were commonly observed herding estrous females from one area to another throughout the day. This behavior may have been influenced by the low density of bighorn sheep that are present. Warrick (1985) also found peak movement rates to coincide with the annual rut.

When bighorn sheep are in groups of  $\leq 5$  animals the amount of time spent standing may increase (Berger 1978, Risenhoover and Bailey

1985). Group size during this study remained consistently small. Risenhoover and Bailey (1985) found that sheep in small groups were more likely to interrupt feeding activity and scan their surroundings than were sheep in larger groups. This may explain the high (22%) seasonal average in the amount of time sheep spent standing. Warrick (1985) found that percent time standing increased significantly as group size decreased. However, the variability of this behavior for any given hour is difficult to explain. I expected to find mean standing time to follow a pattern similar to that of foraging due to their close association. Pooling data together without regard to topography or vegetation association might have masked the individual affect these features have on timing and degree of alert behavior.

#### Nocturnal Activity

Few studies have intensely monitored nocturnal behavior of desert bighorn sheep. The majority of nocturnal observations have been made at water holes (Koplin 1960, Hansen 1964, Hailey 1967, Campbell and Remington 1979). In these studies, activity was usually observed just shortly after dark or simply inferred from tracks left during the night. Simmons (1969) stated that bighorn sheep did much of their feeding at night to avoid solar radiation, minimize water requirements, and still satisfy food needs. Geist (1971) also maintained that bighorn sheep grazed extensively at night, because locations of sheep in the morning revealed they had moved during the night. Clutton-Brock et al. (1982), in their study of red deer (Cervus elaphus), offered quantitative evidence of nocturnal activity. They reported females were active 22%

of the time at night and stags were active 37% of the night. Grazing was the primary activity observed. Krausman et al. (1985) found sheep to be active 21% of the time at night. Miller et al. (1984) stated "the most striking feature of the activity budget for 7 hours after sunset was that sheep always maintained a high (15-75%) level of activity". In my study, bighorn sheep were active 39% of the night in the summer, fall, and winter and 26% of the night in spring. These data are similar to that of other ungulates, and provide sound evidence of nocturnal activity in desert bighorn sheep. Activity occurring at night was not influenced by temperature because the same degree of activity occurred in both summer ( $\bar{x}$  temp = 30.2 C) and winter ( $\bar{x}$  temp = 16 C). Plant moisture also was not a determinant because moisture levels were consistently high on a diel and seasonal basis exhibiting no discernable pattern. Because neither of these factors clearly influenced nocturnal activity, other factors including ruminant physiology may best explain the consistent pattern of nocturnal activity observed.

Trudell and White (1981) place "adaptable mixed feeders" (e.g., bighorn sheep) mid way between browsers (having high ingestion and rumination rates) and grazers (having low ingestion and rumination rates). Although forage preference of bighorn sheep may change seasonally, the common behavior is that of a generalist herbivore, with browse species being the dominant forage item in the diet throughout the year. Having a smaller ratio between ingestion rate and rumination rate may explain a portion of the consistent seasonal activity I observed. Other factors such as social interaction, age, sex, reproductive condition, and external disturbance (Leuthold 1977) may also play a part

in determining activity patterns of ungulates.

#### Diel Plant Moisture

Vegetation sampling was conducted in desert washes where plants were concentrated and easy to locate throughout the sampling period. Desert wash conditions were found at all elevations throughout the study area and were commonly used by bighorn sheep when foraging. Variability in hourly forage moisture may be a result of physical trauma to plant parts (from sampling) and may produce "bleeding", which can result in osmotic movement of water into the roots (Weier et al. 1974). Water uptake in this fashion generally occurs when plant parts are removed to within a few inches of the ground. Although this factor may have contributed to the variability observed in plant moisture, the moisture content nevertheless, remained consistently high.

Variability of plant moisture at night may be a result of the same conditions affecting plant moisture during the day. Increased relative humidity at night did not significantly increase moisture levels of plants.

#### Management Implications

A low density, stable population of bighorn sheep have survived in the Little Harquahala Mountains without free standing water (Krausman et al. 1985). Because moisture content of plants remains relatively high throughout the day, and because bighorn sheep are capable of reducing daily water requirements through nocturnal activity, it is reasonable to assume that water requirements for this population are met by occasional rains, preformed, and metabolic water. The low density of

bighorn sheep in this range may therefore be a result of their already having reached carrying capacity for the available resources (Krausman et al. 1985). Given these circumstances, development of water sources under the pretense that water is constantly limited in desert environments may be detrimental to some bighorn sheep populations. In the Little Harquahala Mountains where habitat is fair to marginal (Krausman et al. 1985), the addition of water may concentrate animals and promote increased demand on available resources. Water catchments may encourage desert mule deer and wild burros to move in and subsequently compete with bighorn sheep for an already limited resource (Krausman and Leopold 1986). Because desert bighorn sheep are poor competitors (in terms of their being relatively new inhabitants of a desert environment) (Geist 1985) which have evolved for thousands of years without selective pressure from other large grazing ungulates (Bailey 1980) the addition of water may be undesirable.

The addition of water to an area may directly benefit bighorn sheep (Leslie and Douglas 1979) when it has clearly been demonstrated that water is the limiting factor. But until this is documented, efforts to improve habitats by adding water when water is not the limiting factor may only prove expensive and unsuccessful. When making decisions concerning water development, resource managers must give full consideration to the direct and indirect effects permanent water sources will have on the environment as well as the wildlife species being managed.

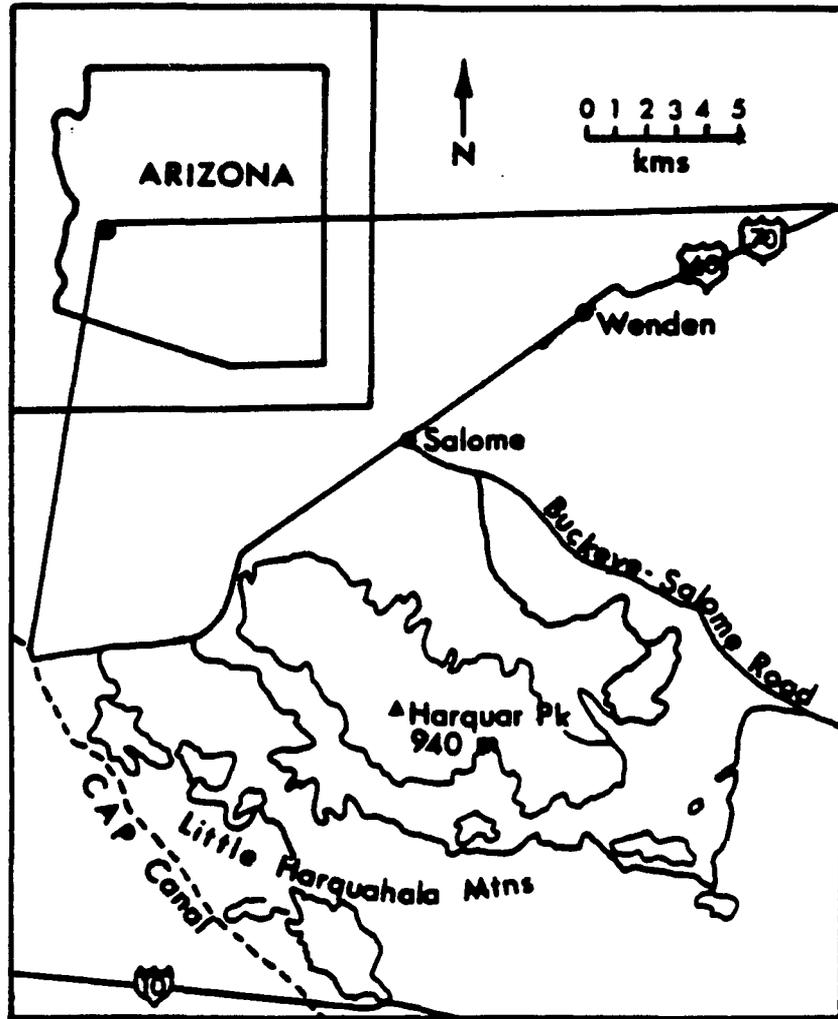


Figure 1. Topographic map of the Little Harquahala Mountains, Arizona, 1987.

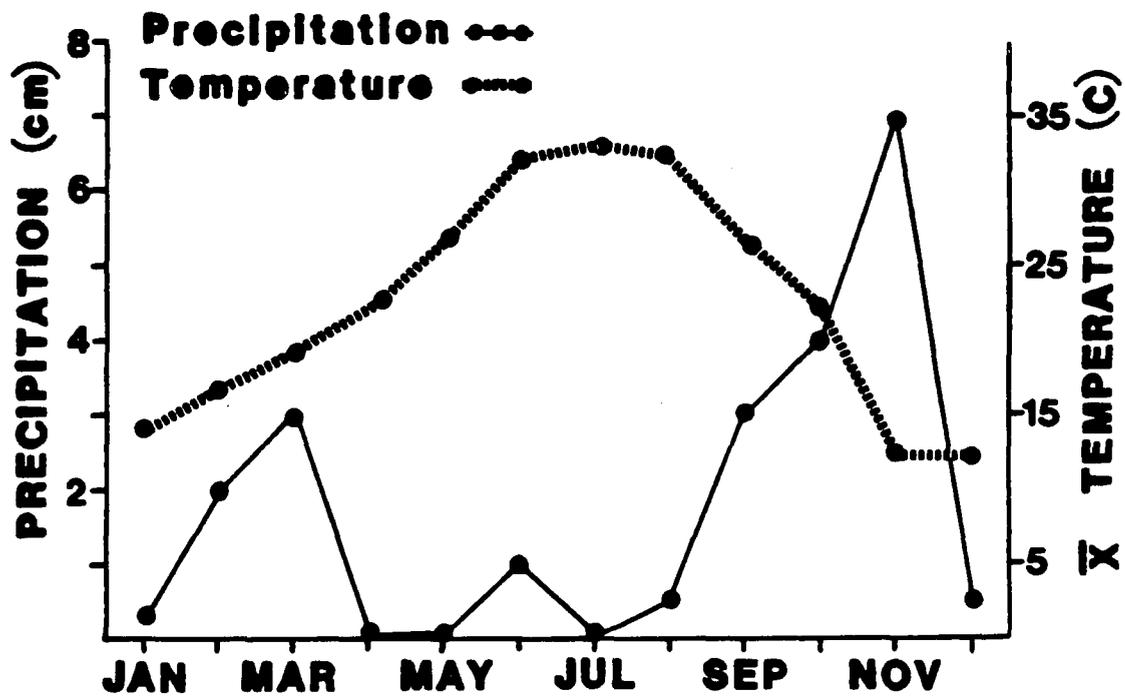


Figure 2. Average temperature (●...●) (C) and precipitation (●—●) (cm) in the Little Harquahala Mountains, Arizona, July 1985 - June 1986.

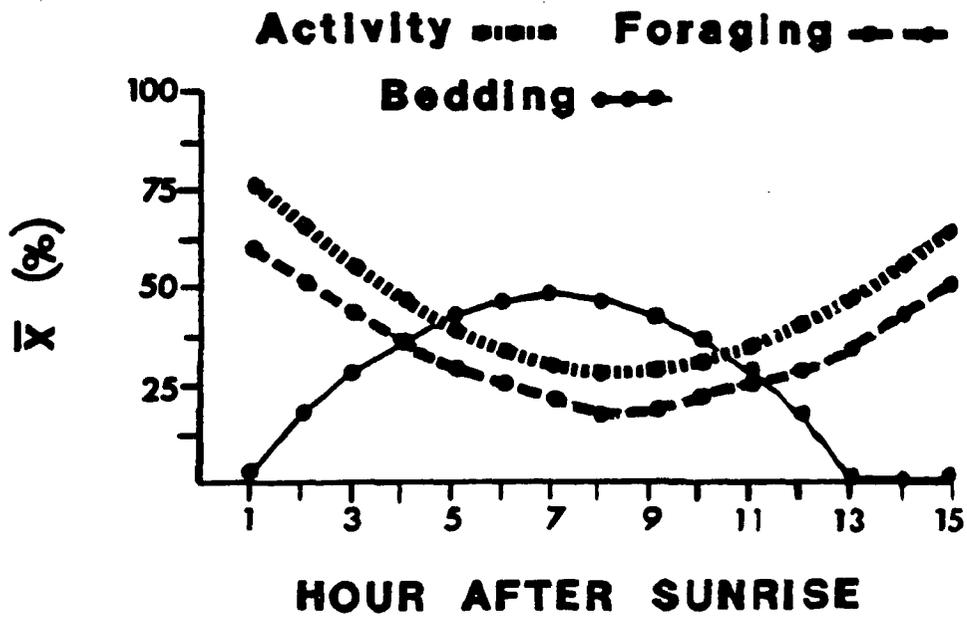


Figure 3. Diurnal regression models ( $Y = a + B_1 X_i + B_2 X_i^2$ ) of mean (%) activity, foraging, and bedding pooled over all seasons in the Little Harquahala Mountains, Arizona, July 1985 - June 1986.

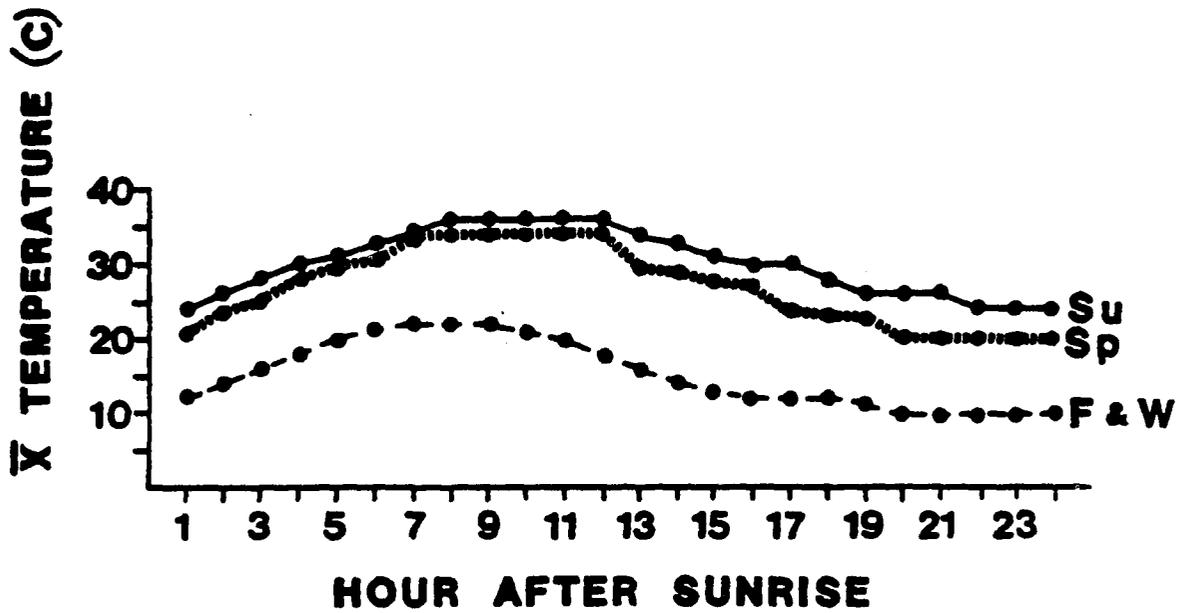


Figure 4. Diel regression models ( $Y = a + B_1 X_i + B_2 X_i^2$ ) of mean temperature (C) for summer (Su), fall (F), winter (W), and spring (Sp) in the Little Harquahala Mountains, Arizona, July 1985 - June 1986.

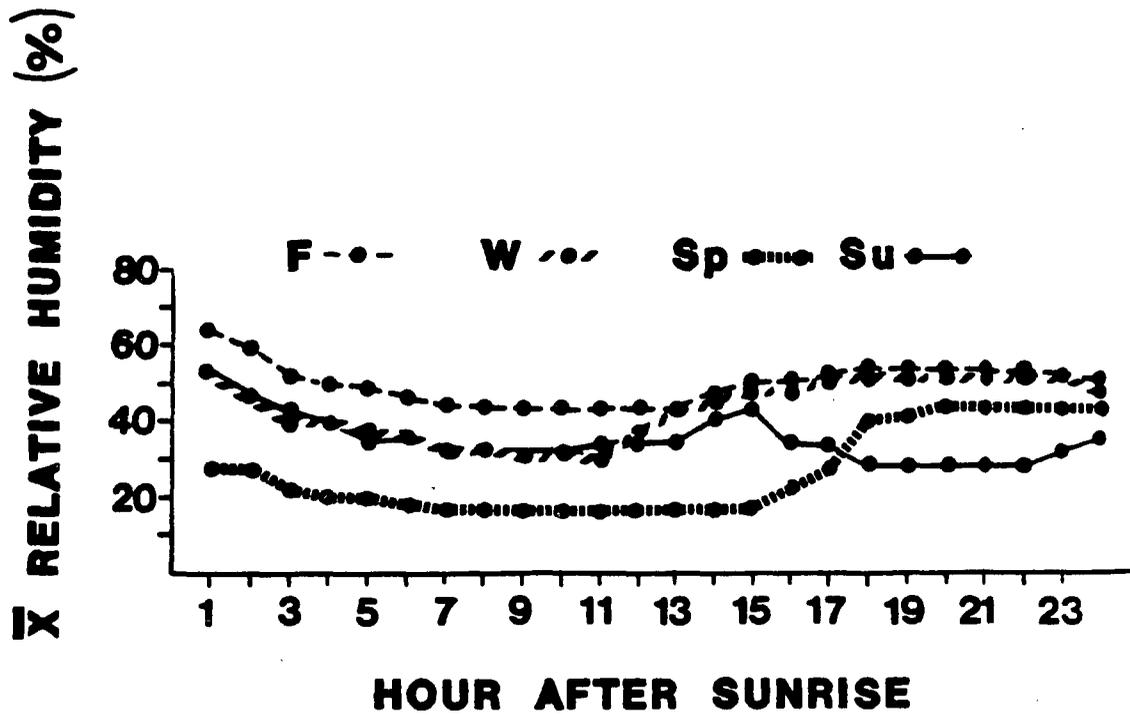


Figure 5. Diel regression models ( $Y = a + B_1 X_i + B_2 X_i^2$ ) of mean relative humidity (%) for summer (Su), fall (F), winter (W), and spring (Sp) in the Little Harquahala Mountains, Arizona, July 1985 - June 1986.

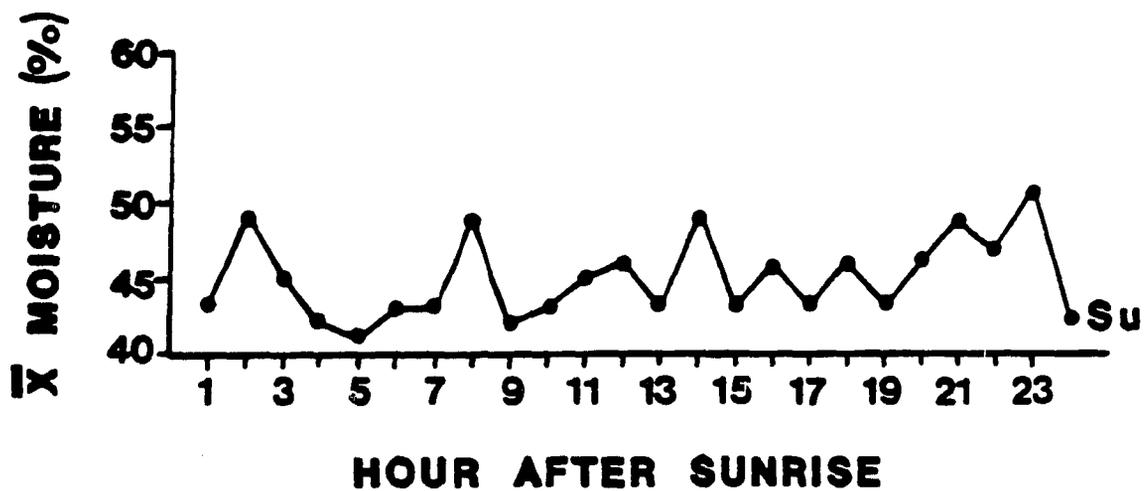


Figure 6. Mean hourly moisture content (%) of littleleaf palo verde for summer (Su) 1985, in the Little Harquahala Mountains, Arizona.

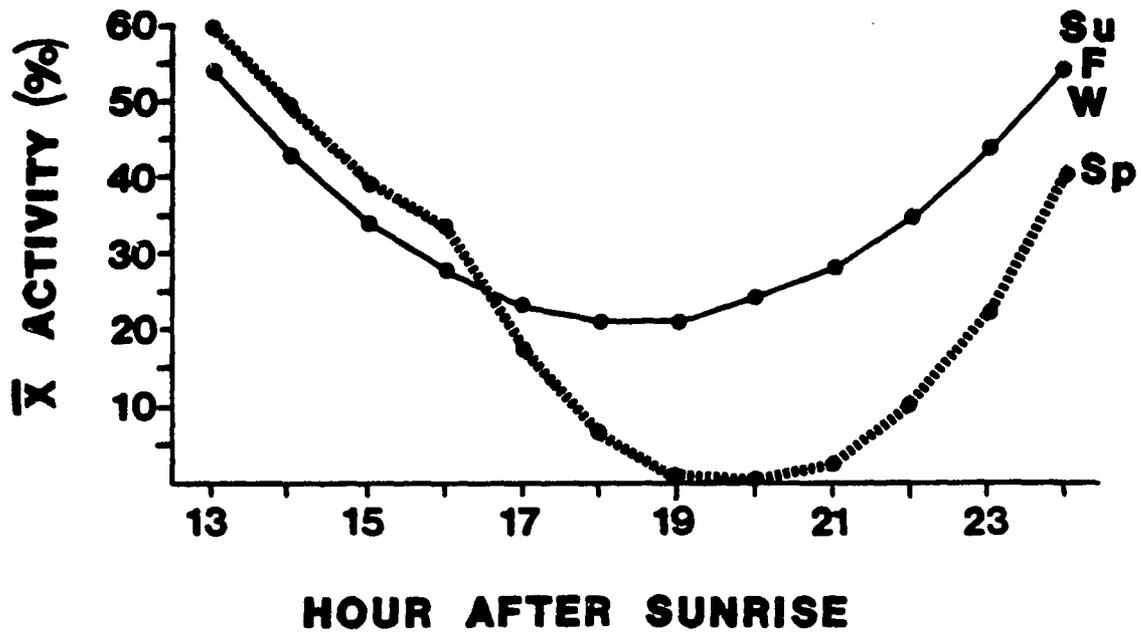


Figure 7.. Nocturnal regression models ( $Y = a + B_1 X_i + B_2 X_i^2$ ) of mean activity (%) for summer (Su), fall (F), winter (W), and spring (Sp) in the Little Harquahala Mountains, Arizona, July 1985 - June 1986.

Table 1. Pearson product-moment correlation (r) coefficients and P values (P) for diurnal and nocturnal (\*) relationships between sheep activities (%), temperature (T) and relative humidity (RH) (%) in the Little Harquahala Mountains, Arizona, 1985-86. All correlations are significant ( $P \leq 0.05$ ).

Season	Activities	T		RH	
		r	P	r	P
Summer	Active	-0.82	=0.00018	0.84	=0.000088
Summer	Active			0.71	=0.032*
Fall	Active	-0.91	=0.00025	0.71	=0.021
Winter	Active	-0.78	=0.0077	0.62	=0.048
Spring	Active	-0.80	=0.00034	0.79	=0.00045
Summer	Bedding	0.85	=0.00006	-0.85	=0.00006
Fall	Bedding	0.87	=0.001	-0.64	=0.046
Winter	Bedding	0.80	=0.0054	-0.66	=0.037
Spring	Bedding	0.81	=0.00025	-0.80	=0.00034
Summer	Standing	-0.63	=0.011	0.60	=0.018
Spring	Standing	-0.71	=0.003	0.66	=0.0074
Spring	Moving	-0.55	=0.033	0.53	=0.042
Summer	Foraging	-0.83	=0.00012	0.84	=0.000088
Fall	Foraging	-0.90	=0.00038	0.84	=0.0023
Winter	Foraging	-0.73	=0.016		
Spring	Foraging	-0.82	=0.00018	0.81	=0.00025

Table 2. Mean seasonal forage moisture (%) (diurnal/nocturnal), relative humidity (RH) (%), and temperature (T) in the Little Harquahala Mountains, Arizona, 1985-86.

Forage species	Moisture							
	Summer		Fall		Winter		Spring	
Littleleaf palo verde	45/46		47/47		42/42		42/43	
Ironwood	53/50		53/52		48/46		52/52	
Desert lavender	48/51		54/52		54/53		45/47	
White ratany	36/36		37/37		33/32		33/34	
	RH	T	RH	T	RH	T	RH	T
	32/40	33/28	48/61	18/12	40/54	19/13	20/32	29/24

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