THESIS

THE ECOLOGY OF DESERT BIGHORN SHEEP IN COLORADO

Submitted by

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In partial fulfillment of the requirements

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ABSTRACT OF THESIS

THE ECOLOGY OF DESERT BIGHORN SHEEP IN COLORADO

Desert bighorn sheep (Ovis canadensis nelsoni & mexicana) were transplanted into western Colorado in 1979, 1980 and 1981. The ecology of these sheep following transplanting was studied during 1982 and 1983. The population increased 18%, from 34 to 40 sheep, during this period. Minimum natality rates of 71% and 75% were observed. Survival of lambs born in 1982 to 1 year of age was at least 70%. Three of 4 suspected lamb losses occurred during the fall and winter months. Five adult mortalities were recorded. Two of these were predator related and occurred within the first few months of transplanting.

Timing of reproductive activities was significantly delayed during the first year following transplanting. Ewes bred in Arizona and transplanted to Colorado in 1981 lambed significantly earlier in 1982 than they did in 1983 after breeding in Colorado. During 1982, ewes from the 1979 and 1980 transplants lambed significantly later than the ewes released in 1981. No significant differences in reproductive seasons were evident between transplant groups during 1983.

Ewes preferred inner-canyon habitats for lambing. They most often selected ledges at the bases of sheer canyon walls and above steep talus slopes. All sites were located on escape terrain. A moderate degree of fidelity of ewes to lambing sites used in previous years was observed.

The seclusion period of ewes during the lambing season varied with the social status of individual ewes. Dominant females remained alone for less time, both before and after parturition, than did subordinate females. Movements of ewes with lambs following parturition varied with the ewe's home range size. Long-distance moves were first recorded with 2-week old lambs.

Dispersal of sheep following transplanting appeared to be influenced by winter weather conditions and by association with other bighorn. Both factors seemed to decrease movements. Dispersal patterns exhibited immediately following release influenced ultimate home range size. Sheep released in 1981 centered activities around the areas explored initially following transplanting.

Overlapping home ranges were observed for both rams and ewes, ranging in size from 4.6 to 44.7 km^2. Home range sizes of ewes varied significantly among release groups and with habitat-use patterns. Coefficients of association were generally low in the herd. Bighorn ewes associated in direct proportion with the amount of range shared.

Bighorn use of aspect differed between the winter-spring and summer periods. Use of inner-canyon habitats appeared to be related to canopy coverage of trees and shrubs.

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I wish to end by thanking those who are most responsible for my accomplishments. Special thanks to my wife Renee for her love and interest and for the many sacrifices she made during these years. Thanks to my parents, Paul and Jeanne, for making it all possible. And a final note of appreciation to my grandfather, Hayes Englert, for fostering my interest in wildlife and the outdoors.

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CHAPTER I

INTRODUCTION

The decline of bighorn sheep (_Ovis canadensis_) populations in the western United States has been detailed by Buechner (1960). Bighorn numbers in North America fell from an estimated historic high of 1.5 to 2 million in the early 1800's (Seton 1929) to less than 45,000 in 1974 (Wishart 1978). Reasons commonly given for this drastic decline include overharvest, habitat alteration, forage competition with livestock, and disease (Russo 1956, Buechner 1960). Monson (1980) estimated that only 15,000 to 20,000 desert bighorn (_O. c. nelsoni_, _O. c. mexicana_, _O. c. cremnobates_, _O. c. weemsi_) presently inhabit the continent.

Bighorn transplant programs were begun by the 1920's (Wishart 1978) in response to declining numbers and are now considered crucial to management of the species (Geist 1975). These efforts have met with variable success, some producing viable populations and others resulting in small relict-like populations or total loss of sheep (Trefethen 1975). Transplant guidelines have been developed (Wilson et al. 1975), evaluated (Rowland and Schmidt 1981) and revised (Wilson and Douglas 1982). Determination of areas of historic range or otherwise suitable habitat is often mentioned as a prerequisite to successful introduction.

The question of historic presence of bighorn sheep in extreme western Colorado is subject to debate. Buechner (1960) included this area as historic range and Monson (1980) believed desert bighorns once extended into Colorado from Utah along the Colorado River. The study area was not considered historic range by Cowan (1940), Moser (1962) or Bear and Jones (1973). The discovery of bighorn skeletal remains near Thompson, Utah (Dalton and Spillett 1971) and in adjacent Montrose County, Colorado (Kasper 1977) support the contention that extreme western Colorado should be considered historic range. The presence of petroglyphs (Stroh and Ewing 1964) and pictographs (Denny 1976) of bighorns in and near Colorado National Monument is indirect evidence of this. Bauer (1977) examined the existing habitat and concluded desert bighorns could be successfully introduced into the Colorado River canyon country.

History of the Colorado Transplant

In an attempt to establish desert bighorn sheep in areas of suitable habitat and possibly historic range, the Colorado Division of Wildlife, U.S. National Park Service and the U.S. Bureau of Land Management initiated efforts to introduce the desert bighorn to western Colorado. Sheep used in the transplant efforts were obtained from the states of Arizona and Nevada in return for Rocky Mountain bighorns (*O. c. canadensis*). Rowland (1979) reviewed the genesis of the project.

The goal of the introduction is to establish a viable herd of desert bighorns in the Colorado National Monument area. If successful, the herd will be used as a source of stock for establishing sheep in other potential historic habitats within Colorado. When densities become great enough to support both trapping and limited harvest, sport hunting on non-NPS lands may be permitted (U.S. Bureau of Land Management 1977).

Justification

The need for close monitoring of introductions has been expressed by many (Trefethen 1975, Rowland and Schmidt 1981). Modern radio telemetry equipment has made intensive followup of transplants more practical and efficient. Few bighorn transplants have been monitored closely from the onset and much information on herd establishment following such efforts has been lost. The Colorado transplant project has been studied closely since the initial release (Ravey 1984) and information gained should prove useful in increasing transplant effectiveness.

Sound management of ungulates, either native or introduced, relies upon determination of population demography (Taber and Dasmann 1957, Streeter 1970, Gilbert 1978). The importance of lamb survival in influencing bighorn population change was noted by Stelfox (1976). Schoonveld (1975) stated that lamb survival was the factor most limiting Colorado bighorn populations and expressed need for research in this area. Information on transplant status, herd structure, movements, habitat use patterns and identification of critical habitat is also noted among research needs (Trefethen 1975, Graff 1980).

Study Objectives

The goal of my research was to provide information necessary for the successful management of the Colorado desert bighorn population. Specific objectives included:

1. To determine herd structure, annual production and recruitment into the yearling cohort.
2. To document temporal changes in the bighorn reproductive cycle following transplanting.
3. To identify critical lambing areas and determine fidelity of ewes to these areas.
4. To determine behavioral associations and herd cohesiveness.
5. To delineate home ranges and habitat use patterns.

Hypotheses were generated prior to investigation concerning the potential shift in reproductive activities and home ranges. These were:

H1: Ewes from the 1979 and 1980 releases (established ewes) breeding in Colorado will lamb later than ewes bred in Arizona and transplanted in 1981.

H2: The ewes bred in Arizona in 1981 and transplanted to Colorado will lamb later in 1983 than they did in 1982.

H3: During 1982, home range sizes of ewes released in 1981 will be different from those of ewes from the previous releases.

CHAPTER II

STUDY AREA

The Colorado National Monument study area is located in Mesa County, Colorado (Fig. 1) and comprises approximately 670 km^2 of the canyonlands of the Colorado River (Ravey and Schmidt 1981). It extends westward from the Colorado National Monument into Utah and is bounded on the north by the Colorado River and on the south by Glade Park. Elevation rises in abrupt steps from 1350 m at the River to over 2170 m on Black Ridge. Devils Canyon, site of the 1979 and 1981 releases is located 3.2 km southwest of Fruita, Colorado, longitude 108° 45'W, latitude 39° 07'N (Fig. 2).

Climate

Jaeger (1957) considered the Colorado River basin in extreme western Colorado to be part of the Painted Desert. The region is classified as semi-arid desert, characterized by cool winters and hot summers. Mean annual temperature and precipitation recorded at Colorado National Monument are 11°C and 27.9 cm respectively (U.S. Weather Bureau 1940-1965; Environmental Sciences Service Administration 1966-1970; National Oceanic and Atmospheric Administration 1971-1983). The growing season (defined as the period between the last spring and first fall temperatures of 0°C or below) averages 175 days (Spears and Kleven 1978). Mean annual snowfall is 96.5 cm (unpubl. rep., Colorado National Monument, Fruita, CO).

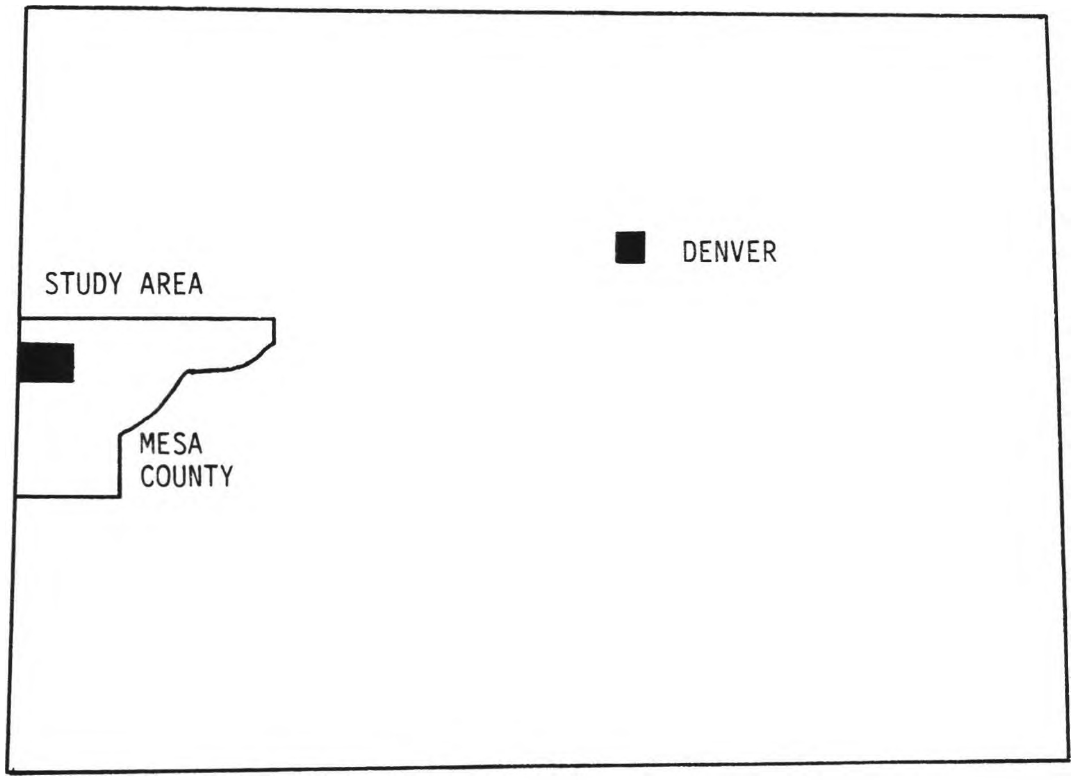

Fig. 1. General location of the Colorado National Monument study area in western Colorado.

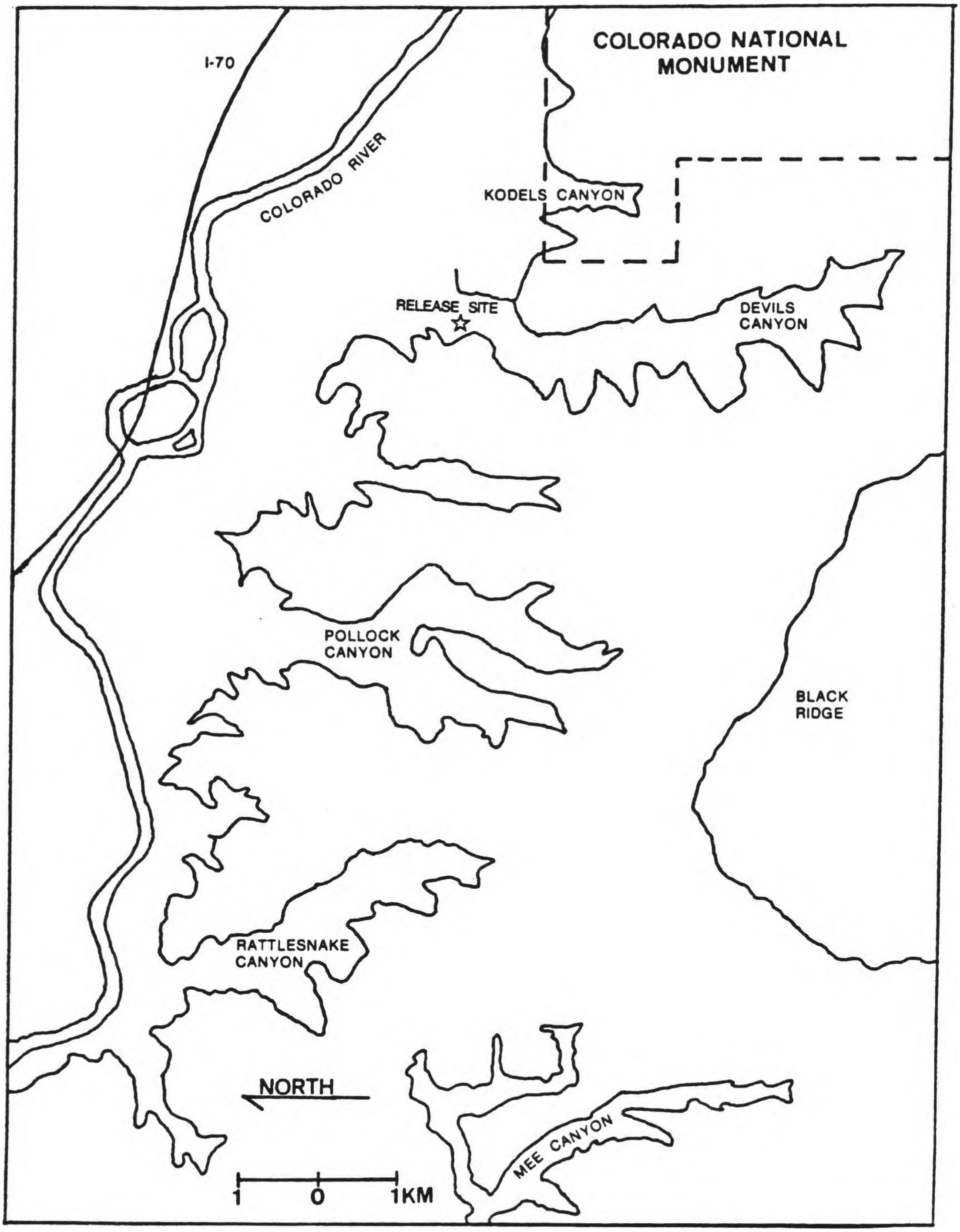

Fig. 2. Locations of the Devils Canyon release area and other canyons used by desert bighorns in Colorado during 1982 and 1983.

Geology and Soils

Situated on the northeast edge of the Uncompahgre Plateau, the study area consists of numerous steep-walled canyons 100 m or more deep separated by mesas of varying sizes. The characteristic topography resulted from geological uplifting of Precambrian rock during the Pennsylvanian Period followed by sedimentation and finally erosion of Mesozoic Era deposits (Harris 1980). Wind and water erosion continue to influence the present day landscape.

Geologically, the canyons consist of a basement floor of Precambrian granite, gneiss and schist overlain by a layer of sedimentary siltstone, the Chinle Formation. Atop this lies the Wingate Sandstone which forms sheer canyon walls. The Kayenta Formation is found on the canyon rims and separates the Wingate Sandstone from the Entrada Sandstone, or slickrock, which forms a second smaller cliff. The Summerville and Morrison Formations lie above the Entrada and make up the mesas separating the major canyons. The Burro Canyon and Dakota Formations are exposed in the highest areas (Miller and Coale 1969).

Edaphically, the canyons are classified as Rock Outcrop. Soils are sandy and shallow containing many stony areas. Steep slopes contribute to excessive runoff and high erosion. Soils on the mesas are deeper and are classified as Rock Land. The Lazear-Rock Outcrop complex with its characteristic gravelly loams dominates mesas and ridges below 1830 m. The Batterson-Rock Outcrop complex of loamy sands is prevalent on upland hills and ridges. Mesa soils are slightly alkaline and experience moderate to rapid runoff following rains (Spears and Kleven 1978).

Flora

The vegetation of the Colorado River canyonlands is representative of the Great Basin Floristic Province described by Gleason and Chronquist (1964). Overstory canopy coverage of trees is generally less than 40% on the study area (unpubl. survey, U.S. Bureau of Land Management, Grand Junction, CO). Plant species of highest relative importance were determined by Wasser (1977) to be the Utah juniper (Juniperus osteosperma), big sagebrush (Artemisia tridentata) and cheatgrass brome (Bromus tectorum).

The 2-leaf pinon (Pinus edulis)-Utah juniper woodland in association with big sagebrush dominates the overstories of mesas and the higher elevations of canyons. Littleleaf mountain mahogany (Cercocarpus intricatus), Stansbury cliffrose (Cowania mexicana) and mormon tea (Ephedra spp.) are prevalent on the rocky canyon rims. Sagebrush steppe and desert shrub communities dominate the flora of lower elevations. Major overstory plants include sagebrush (Artemisia spp.), rabbitbrush (Chrysothamnus spp.), four-wing saltbush (Atriplex canescens), spiny hopsage (Grayia spinosa), mormon tea and the ever present Utah juniper. Valley floors north of the canyon mouths are dominated by black greasewood (Sarcobatus vermiculatus) and shadscale saltbush (Atriplex confertifolia). Locally abundant shrubs include skunkbush (Rhus trilobata) and cliff fendlerbush (Fendlera rupicola) on inner canyon talus slopes, and single leaf ash (Fraxinus anomala) in washes and drainages.

Important understory species include snakeweed (Gutierrezia sarothrae), Opuntia spp., cheatgrass, Indian ricegrass (Oryzopsis hymenoides), galleta (Hilaria jamesii), needle grass (Stipa spp.), wheatgrass (*Agropyron* spp.), bluegrass (*Poa secunda*) and blue grama (*Bouteloua gracilis*) (Wasser 1977).

Fauna

The diversity of microhabitats in and around the Colorado National Monument study area supports a diverse mammalian fauna. At least 59 species have been noted (Miller and Coale 1969). Common small mammals include the deermouse (*Peromyscus maniculatus*), the pinon mouse (*Peromyscus truei*), and the Colorado chipmunk (*Eutamias quadrivittatus*) (Miller 1964). The desert cottontail (*Sylvilagus audubonii*) and rock squirrel (*Citellus variegatus*) are also abundant. The mule deer (*Odocoileus hemionus*) is the most common ungulate present (U.S. Bureau of Land Management 1977). A small herd of bison (*Bison bison*) was present in Colorado National Monument during the study but has since been removed.

Representative carnivores include the grey fox (*Urocyon cinereoargenteus*), coyote (*Canis latrans*), bobcat (*Lynx rufus*) and mountain lion (*Felis concolor*). The golden eagle (*Aquila chrysaetos*) and red-tailed hawk (*Buteo jamaicensis*) are common avian predators (U.S. Bureau of Land Management 1977).

Land Ownership and Use

The majority of the study area is public land administered by the BLM and NPS. Smaller parcels of private land are located north of the canyon mouths. The Glade Park area south of the study area is mostly private land.

Approximately 29,316 ha of BLM holdings, the Black Ridge Canyons and Black Ridge Canyons West/Jones Canyon-Wrigley Mesa areas, have been proposed for wilderness study (U.S. Bureau of Land Management 1980). All these lands are leased for livestock grazing, principally cattle. Approximately one-half of the available A.U.M.'s are in non-use (U.S. Bureau of Land Management 1977). Private lands in the canyon mouth areas are being increasingly developed for commercial purposes, while those south of the study area are used primarily for ranching or agriculture.

CHAPTER III

METHODS AND MATERIALS

Three transplants involving 36 desert sheep have occurred. Eleven bighorns (*O. c. mexicana*) from the Kofa Game Range were released on 8 November 1979. Sixteen sheep (*O. c. nelsoni*) captured on the Lake Mead National Recreation Area in Nevada were transplanted on 17 June 1980. A third transplant involving 9 ewes (*O. c. nelsoni*) from the Black Mountains in Arizona occurred on 19 November 1981.

Capture, tagging and release methods involved in the 1979 and 1980 transplants were discussed by Ravey and Schmidt (1981). The bighorns transplanted in 1981 were captured by the Arizona Fish and Game Dept. using the helicopter capture technique described by de Vos and Remington (1981). Sheep were immobilized using a Palmer CO2 gun firing a 4 cc dart containing 3.7 mg Etorphine (M-99) and 20 mg Azaperone (Remington 1982). Sheep were transported to Grand Junction, Colorado in a modified horse trailer.

The bighorn were examined by Dr. C. Hibler and Dr. T. Spraker of Colorado State University following arrival. Blood samples, nasal swabs and fecal samples were collected from each animal. Ewes were checked for signs of pregnancy. Age was estimated based on horn size, shape and visible horn rings (Hansen and Demming 1980). All sheep were marked with numbered ear tags (Ritchey Mfg. Co., Brighton, CO) and radio transmitter collars (Telonics Inc., Mesa, AZ). The animals were then trucked to the mouth of Devils Canyon and released.

Intensive field research on the Colorado desert bighorn herd was conducted from 25 January to 28 August 1982 and again from 8 March to 15 May 1983. Research of an extensive nature was conducted from mid-May to late-October 1983.

Monitoring the bighorn following release involved a combination of ground and aerial tracking with radio telemetry equipment as well as interpretation of animal sign. A Telonics Model TR-1 receiver was used. A hand-held directional 2-element H-beam antenna was used for ground tracking. A similar antenna mounted beneath the fuselage of a CDW Cessna 185 was utilized for fixed-wing surveys. The antenna could be rotated by the observer from within the cockpit. A hand held loop antenna was used for helicopter surveys. All antennas were supplied by Telonics.

Bighorns were observed using 7x50 or 8x40 binoculars and a variable power 20-45x spotting scope. Only 1 observation of each marked bighorn was permitted per day. Information on location, weather, group size, sex-age composition, habitat utilization and behavior was gathered during ground observations.

All locations were plotted on 7.5 minute U.S.G.S. topographic maps using the 1,000 m Universal Transverse Mercator system. Grid units of 0.01 km^2 were established and each location was assigned specific X and Y coordinates.

Three accuracy levels for mapping radio location data were recognized. Direct observations were considered accurate to within 50 m. Ground radio positions were obtained by triangulation using at least 2 receiving stations separated 1 km or more. Field experience with the telemetry system indicated accuracy to within 150 m. The third type location was based on aerial positioning. Experimentation with stationary collars indicated an accuracy radius of 300 m.

Population status, herd structure, annual production and recruitment were measured through direct observation. Since all animals in the herd except Colorado-born lambs were tagged, the age classes of unmarked bighorns could be easily determined. A known-minimum population number was developed based on observation of marked animals. A minimum lamb recruitment number was determined based on observations of yearlings in the herd.

Data on the timing and duration of the lambing season were gathered through direct observation of ewes and lambs. Lamb age was determined using morphological and behavioral characters (Hansen 1965a, Hansen and Demming 1980). These estimates were strengthened by comparisons to known-age lambs and frequent observations of radio-collared ewes during the lambing season. Parturition dates were estimated by subtracting the estimated age of lambs from the date of observation. The error criterion applied to parturition dates (Table 1) were based upon the researcher's confidence in his use of the lamb aging technique.

Table 1. Error criterion applied to estimates of desert bighorn parturition dates in Colorado.

Estimated Lamb Age	Potential Error (± days)
Newborn	0
3 days	1
1 week	2
2 weeks	4
1 month	7

General locations of lambing areas used during the study were determined by using the observation or radio location closest to the estimated date of parturition of each individual ewe. Ewes which were not located within 7 days of parturition were excluded. Fidelity of ewes to lambing areas was determined by calculating the distance between lambing sites used in 1982 and 1983 for ewes lambing in both years.

Movements of ewes and lambs from lambing areas following parturition were determined using observation data from ewes radio positioned or observed within 7 days of parturition. Mean distances of observation locations from suspected lambing sites were calculated.

Behavioral associations between all pairs of marked animals in the population were quantified using Cole's (1949) coefficient of association concept. The coefficient of association (CA) is:

$$CA = \frac{2c}{a+b}$$

where c is the number of times individuals A and B were observed together, a is the total number of observations of animal A and b is the total number of observations of animal B. Home range overlaps were calculated in the same manner (after McCutchen 1982). In determining overlap, c represents the home range area shared by individuals A and B, a is the total home range area of animal A and b is the total home range area of animal B.

Home range was considered to be the total area occupied by an individual during a given time period. All locations of sheep were utilized. Home range area was delineated by joining outside points with straight lines to enclose a range area (Mohr 1947). This area was then measured with a planimeter. Geometric centers of activity (Hayne 1949) were calculated.

Habitat types were delineated based upon physiography and topography into 3 categories. These included the Inner-Canyon habitats, the Canyon Rim/Mesa habitats, and the Valley Floor habitat.

The Inner-Canyon habitats were divided into 3 zones (Fig. 3). The Drainage zone occurs in the bottom of major canyons and in smaller side canyons. Most drainages have ephemeral water and lack well developed riparian communities. The Talus zone is located at the bases of canyon walls and is comprised of rocks and boulders of variable size. Slopes range from 20°-60°. The Wingate zone encompasses the canyon walls. A moderate degree of benching is prevalent in the lower one-third of the zone beneath the vertical wall.

The Canyon Rim/Mesa habitats were also divided into 3 zones. The Kayenta ledge zone consists of a combination of flat and precipitous terrain. The ledges vary greatly in width from near 0 to over 500 m in places. The Entrada zone consists of slickrock exhibiting 30°-90° slopes. The Mesa zone lies above the Entrada and consists of rolling hills and flat meadows.

The Valley Floor zone consists of broad level land located north of canyon mouths and extends to the Colorado River.

Canopy coverage of woody species on inner canyon talus slopes was measured using the line-intercept method (Bauer 1943). Four representative stands were selected, one each on north, south, east and west facing slopes. Transects 15.24 m in length were systematically placed at 3.05 m intervals along the slopes. Twenty-seven transects were run on each stand. Preliminary field research indicated that this

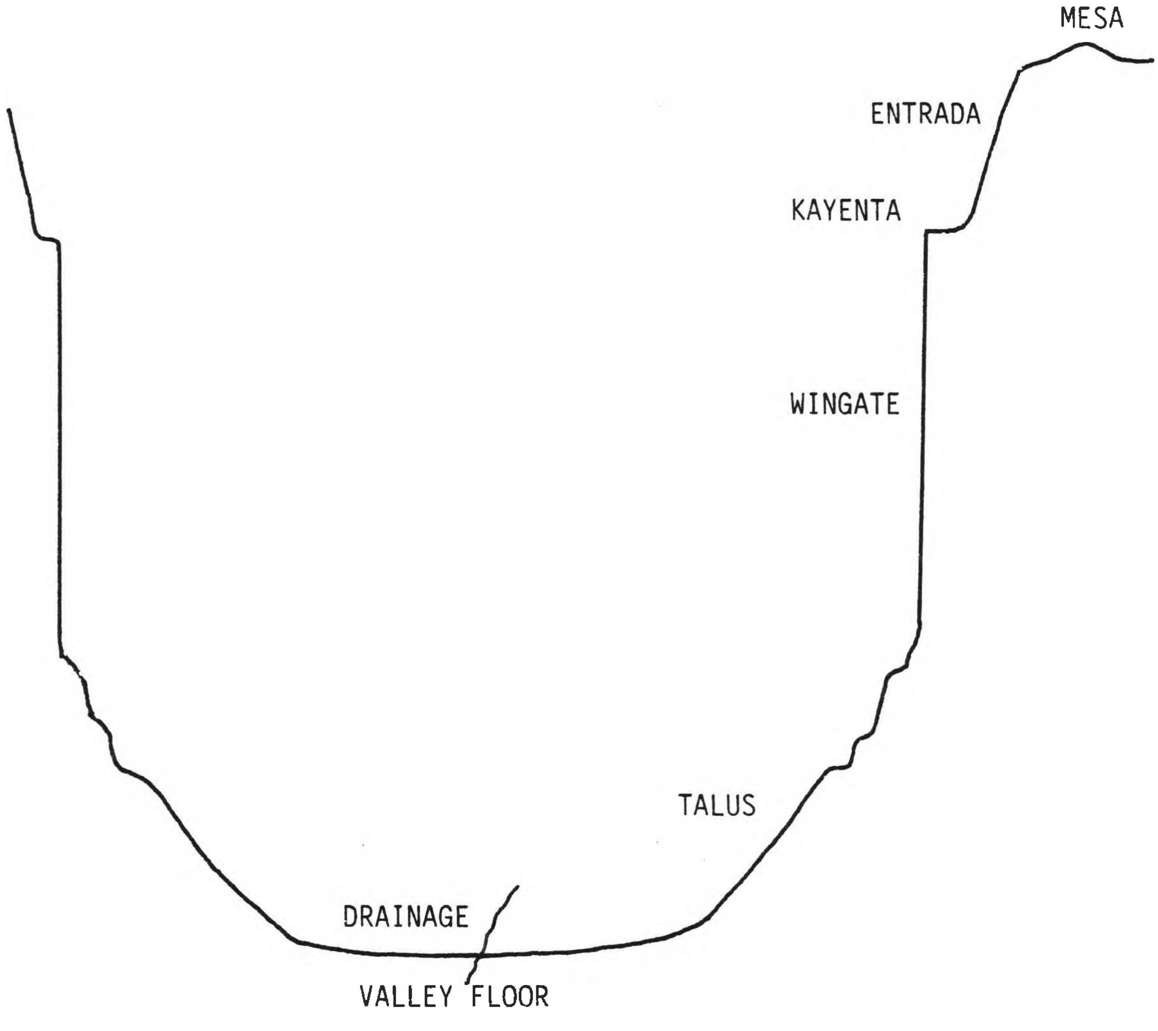

Fig. 3. Relative position of the 7 major habitat zones used by desert bighorns at the Colorado National Monument study area.

number of transects would yield a precision level of 80% in sampling the most variable stand. Transects ran parallel to slope direction to maximize environmental heterogeneity.

Both parametric and non-parametric statistics were employed to test hypotheses. Student's t-tests were used whenever possible. When the assumption of homogeneity of variance was violated, a non-parametric technique, moment approximation (Berry and Mielke 1983) was employed. The significance level used in statistical comparisons was 0.05.

Lambing hypotheses were evaluated by comparing mean dates of parturition for selected groups of bighorn ewes. Lambing dates of ewes were assigned numerical values based upon the Julian calendar, where 1 January = day 1.

The home range hypothesis was tested by comparing mean home range sizes for the established ewes and the 1981 release group during 1982.

CHAPTER IV

RESULTS

There were 1,361 observations logged during the study. Ground observations accounted for 283 sightings of bighorn groups. An additional 137 ground radio positions of instrumented animals were obtained. Nineteen fixed wing flights and 1 helicopter survey resulted in 56 observations of bighorn groups and 98 radio positions.

Population Structure

At least 40 desert bighorns were believed to occupy the Colorado National Monument study area as of October 1983 (Table 2). This estimate was developed by adding the number of lambs observed in 1983 and subtracting mortalities from a known-minimum population of 34 sheep determined in 1982. Lambs born in 1982 but not observed in 1983 were considered mortalities.

Reproduction

A minimum of 30 lambs have been born since the initial release in 1979. One lamb was produced in 1980 and 7 more were documented in 1981 (Ravey 1984). Ten and 12 lambs were observed in 1982 and 1983, respectively.

Five of seven ewes surviving from the 1981 release produced lambs in 1982. An eighth ewe was pregnant at the time of her death. This

Table 2. Summary of the known Colorado National Monument desert bighorn population as of October 1983.

Sheep #	Release Date	Sex	Estimated Age
R-01	1979	F	9.5
Blue 9	1979	F	7.5
R-05	1979	M	6.5
R-08	1980	F	8.0
R-11	1980	F	8.0
R-12	1980	F	6.0
R-17	1980	M	4.0
E.T. 7	1980	F	3.5
E.T. 17	1980	M	3.5
E.T. 18	1980	F	3.5
R-02	1981	F	8.5
R-04	1981	F	6.5
R-06	1981	F	7.5
R-09	1981	F	9.5
R-14	1981	F	8.5
R-16	1981	F	3.5
1980 lamb	--	M	3.5
1981 lambs	--	3M, 1F	2.5
1982 lambs	--	4M, 3F	1.5
1983 lambs	--	12?	0.5

R = denotes radio-collared animals
E.T. = denotes ear tagged animals
? = unknown sex

indicates a pregnancy rate of 75% and an actual natality rate of 71% for this sample of Black Mountain, Arizona ewes.

Five of 7 ewes from the 1979 and 1980 releases were observed with lambs in 1982. This yields a minimum natality rate of 71% for the established population. In 1983, 12 of 16 ewes (75%) on the study area were observed with lambs.

Ewes in the Colorado population are apparently breeding first at age 2.5. This is based on observation of 2 known age ewes, one released as a lamb in 1980 and the other born in Colorado in 1981, during the 1982 and 1983 lambing seasons. These ewes never appeared pregnant, nor were they seen alone with lambs, as yearlings. The production rate of ewes >2.5 years of age was 90% and 92% in 1982 and 1983, respectively.

Lamb Survival

Lamb survival was high during the study. The lone lamb produced in 1980 and 4 of 7 lambs born in 1981 (Ravey 1984) were known to be alive through May of 1983. At least 7 (4 males, 3 females) of the 10 lambs born in 1982 survived and were recruited into the yearling (1+) age class. The yearling:ewe ratio recorded in 1983 was 7:14 or 50%.

Summer mortality of lambs was low during the study. All 10 lambs observed in 1982 were known to be alive through August of that year. One lamb disappeared between August and November. This lamb, a female, exhibited signs of declining health (frequent and prolonged coughing and sneezing spells) during August. A second ewe lamb and a male lamb were lost between November 1982 and March 1983. None of the 4 females

(1 yearling, 2 2-year olds and 1 3-year old) not documented with lambs in 1982 ever exhibited signs of pregnancy that year.

Nine of the 12 lambs observed in 1983 were seen alive during occasional visits to the study area that summer and fall. One lamb was not seen with its ewe when she was observed on 22 August. This ewe and lamb were last seen on 13 June. Nothing can be said of the status of the remaining 2 lambs since their non-radiocollared ewes were not observed after intensive research ended in May 1983.

Adult Mortality

Nineteen mortalities have been recorded since the initial release in 1979. Ravey (1984) reported 14 of these. Five mortalities were noted during this study, claiming 8% and 10% of the non-lamb segment of the populations in 1982 and 1983.

Number 00, an adult ewe from the 1981 release, was found dead on the east rim of Devils Canyon on 2 February 1982. She was apparently killed by a coyote as she traveled through a narrow rock corridor in the Kayenta habitat zone. There was evidence of a struggle and the underside of her radio collar was soaked with blood. A dismembered fetus was found within 2 m of the carcass along with the paunch and a piece of lung tissue. Examination of the femur bone marrow indicated the ewe was in good condition nutritionally. The ewe appeared to have been dead less than 2 weeks.

Number 15, a second adult ewe from the 1981 release, was found dead inside Bangs Canyon, approximately 29 km southeast of the Devils Canyon release site on 24 April 1982. Her carcass was found beneath a pinon pine in a densely vegetated drainage. The skull had 2 tooth punctures, 1 through the left eye orbit and the other in the top of the skull. All ribs on the right side of the carcass were chewed off. The paunch was never found and was apparently separated from the carcass. The bone marrow was firm and cream colored. An Animal Damage Control agent examined the carcass and concluded the ewe had been killed by a mountain lion.

Three mortalities were recorded in 1983. Number 03, an 8.5 year old ram released in 1979 was found dead on a ledge in the Kayenta zone on 31 March. Radiolocation data from aerial surveys indicated no movement since November of 1982. A second ram was reported dead by a group of hikers in Devils Canyon in May. Attempts to relocate the carcass failed, but a photograph taken by the group indicated the ram was approximately 4 years old. This animal was most probably released as a lamb in 1980. The final mortality involved #18, an adult ewe released in 1981. Her carcass was found in October lying in a sparsely vegetated drainage in lower Devils Canyon. Cause of death could not be determined in any of the last 3 cases.

Lambing

Timing of Parturition

Precise estimates of parturition dates were determined for 10 ewes in both 1982 and 1983. Lambing dates were roughly approximated for 2 more ewes in 1983. The lambing period of desert bighorn ewes bred in Arizona and transplanted to Colorado in 1981 extended from February to April 1982 and spanned 53 days (Table 3). The lambing period of ewes released in 1979 and 1980 (established ewes) and bred in Colorado was restricted to the month of April and spanned 18 days. Mean lambing dates for the 2 groups were 16 March and 16 April, respectively, and differed significantly.

The 1983 lambing season began in early March and concluded in late May (Table 4). The mean lambing dates for ewes released in 1981 and for the established ewes were 17 April and 3 April, respectively. There was no significant difference between these mean lambing dates.

The mean lambing dates of the 1981 release group differed significantly between years. There was no significant difference between the mean lambing dates of the established ewes during the same period.

There was also no significant difference between the mean lambing dates of the established ewes in 1983 and the 1981 release group in 1982. The mean lambing dates of these groups were separated by 18 days, however, and the lack of significance was believed due to small sample size.

The number of days between consecutive births in 1982 and 1983 was determined for 7 ewes during the study. This period averaged 399 days (n=3; SD=7.2) for the 1981 release group and 345 days (n=4; SD=28.7) for the established ewes (Table 5).

Lambing Areas

Seven of 10 ewes lambed inside major canyons in 1982 (Fig. 4). Two other ewes selected ledges in the Kayenta habitat zone. The remaining ewe was suspected of lambing in the inner-canyon zone of Rattlesnake Canyon but was not located within 7 days of parturition.

Seven of 12 ewes chose inner canyon habitats for lambing in 1983 (Fig. 5). One ewe again selected a ledge in the Kayenta zone. A ninth ewe lambed on an island-like pedicel of land above Mee Canyon. The

Table 3. Estimated parturition dates of desert bighorns lambing at Colorado National Monument during 1982. Ewes released in 1981 had conceived in Arizona. Established ewes were released in 1979 and 1980.

1981 Release Ewes			Established Ewes		
Date	Error (± days)	*Julian day	Date	Error (± days)	*Julian day
2-26	7	57	4-9	2	99
3-1	7	60	4-12	1	102
3-4	0	63	4-15	1	105
3-26	0	85	4-19	2	109
4-19	0	109	4-26	0	116
3-16	Mean	74.8	4-16	Mean	106.2
	SD	22.1		SD	6.6

*1 January = day 1

Table 4. Estimated parturition dates of desert bighorns lambing at Colorado National Monument during 1983. Established ewes were released in 1979 and 1980.

1981 Release Ewes			Established Ewes		
Date	Error (± days)	*Julian day	Date	Error (± days)	*Julian day
4-7	2	97	3-3	2	62
4-8	1	98	3-14	4	73
4-13	0	103	3-24	4	83
4-22	0	112	4-30	4	120
5-3	2	123	5-6	2	126
**Late May	-	-	**Early May	-	-
4-17	Mean	106.6	4-3	Mean	92.8
	SD	10.9		SD	28.6

*1 January = day 1
**rough approximations

Table 5. Number of days between consecutive lambings of desert bighorn ewes giving birth in both 1982 and 1983 at Colorado National Monument.

1981 Release Group		Established Ewes	
Ewe #	Birth Interval (± days)	Ewe #	Birth Interval (± days)
02	401 ± 9	08	345 ± 5
09	405 ± 8	Blue-9	385 ± 6
14	391 ± 0	11	321 ± 3
		12	328 ± 6
Mean	399 days	Mean	345 days

remaining 3 ewes were suspected of lambing inside Devils Canyon but were not located within 7 days of parturition.

Site-specific data were obtained for 9 ewes observed with lambs estimated to be less than 4 days old. Six of these ewes lambed on ledges or benches in the Wingate habitat zone. A seventh ewe lambed at the top of a steep talus slope immediately below the Wingate Canyon wall. The remaining 2 ewes lambed on narrow ledges in the Kayenta habitat zone.

Ewes lambing in the inner-canyon habitats typically selected sites at the bases of the vertical canyon walls and as high in elevation as the habitat permitted. Lambing sites chosen in the Kayenta zone were located in close proximity to the Entrada sandstone cliff and were characterized by ledges and precipitous rock outcrops.

Overstory vegetative density in the vicinities of suspected lambing sites were classified by ocular estimate to be sparse (<10%) in 8 of 9 instances and moderate (10-20%) in the remaining case. All lambing sites were located on escape terrain, defined as rocky,

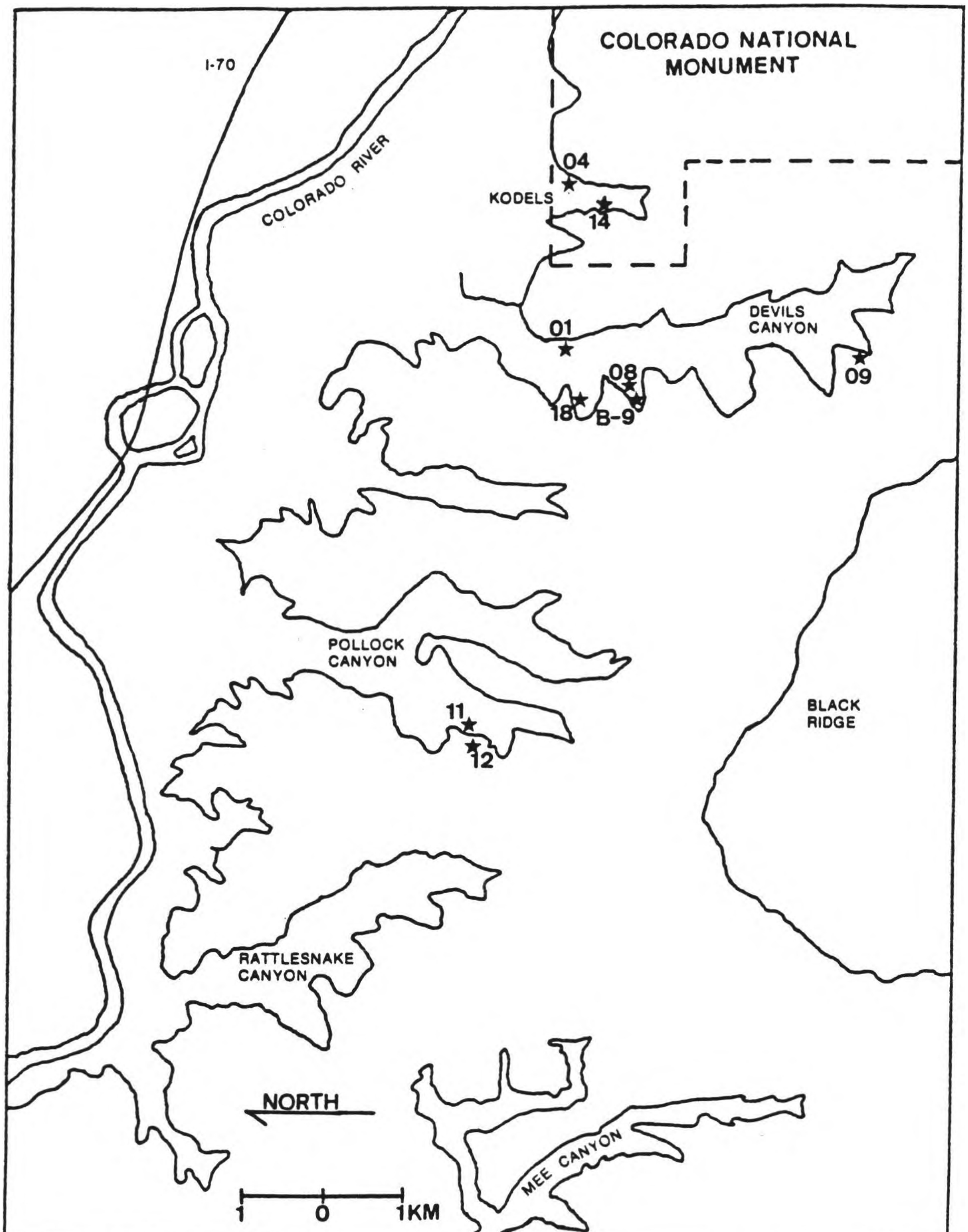

Fig. 4. Suspected lambing sites used by desert bighorn ewes in Colorado during 1982.

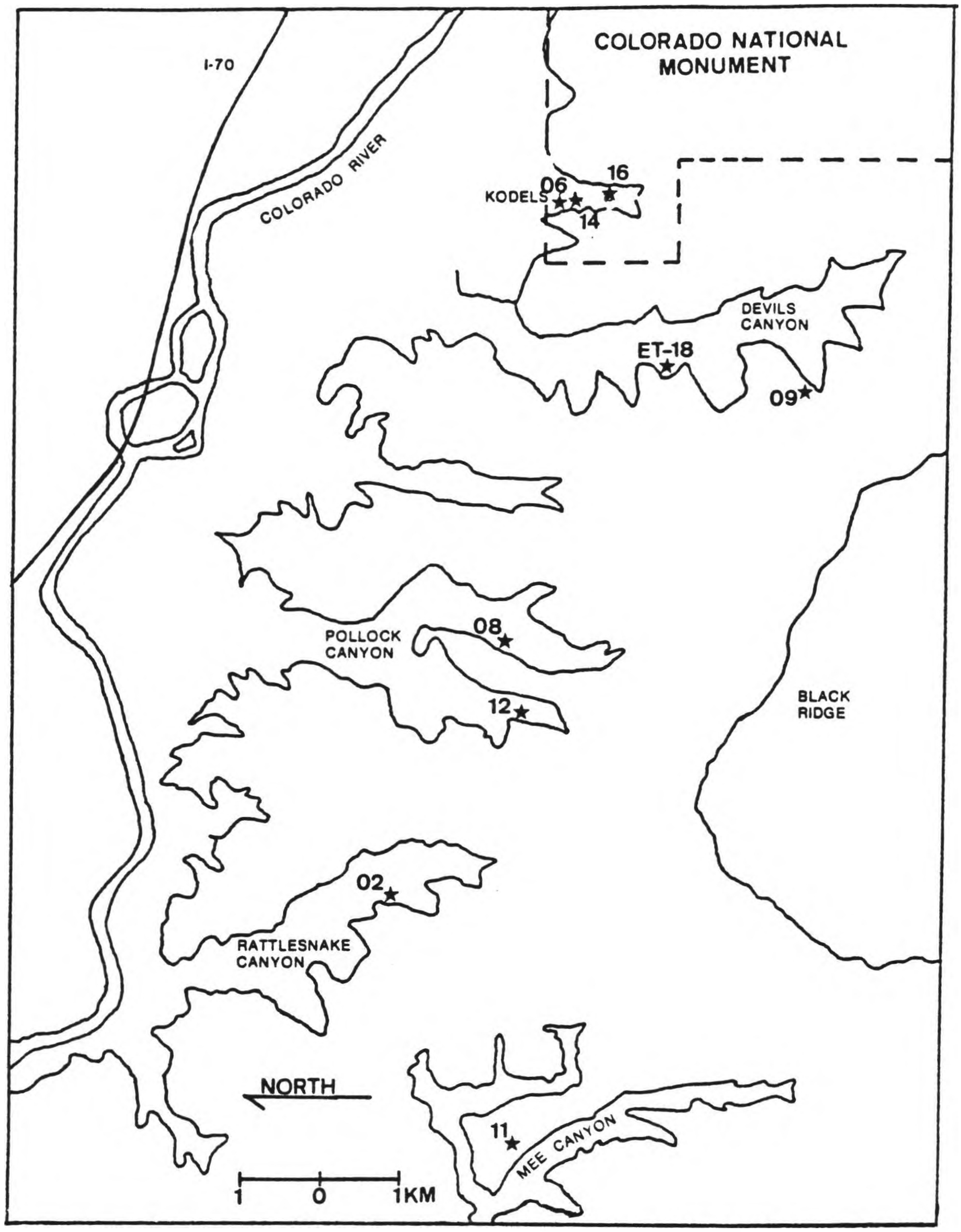

Fig. 5. Suspected lambing sites used by desert bighorn ewes in Colorado during 1983.

precipitous terrain on which a bighorn could be expected to detect and outmaneuver potential predators.

Fidelity to Lambing Areas

Nine ewes lambed in both 1982 and 1983. Three of these ewes lambed in the same general areas in both years, 4 were thought to have used the same major canyon system, and 2 ewes lambed in entirely different areas. Five of these ewes were located within 7 days of parturition in both years (Table 6). The distances between suspected lambing sites for these ewes averaged 2 km.

Table 6. Straight line distances between suspected lambing sites used by desert bighorns lambing in both 1982 and 1983 at the Colorado National Monument study area.

Ewe #	1982 Site	1983 Site	Distance (km)
08	Devils Canyon	Pollock Canyon	3.0
09	Devils Canyon	Devils Canyon	0.6
11	Pollock Canyon	Mee Canyon	5.8
12	Pollock Canyon	Pollock Canyon	0.4
14	Kodels Canyon	Kodels Canyon	0.3

Movements Following Parturition

Ewes were grouped on the basis of habitat use into inner-canyon and canyon rim/mesa categories to evaluate post-partum movements of ewes and lambs from their lambing sites. Mean distances of ewes and lambs from suspected lambing areas were similar for both groups during the first week following parturition but diverged greatly thereafter (Fig. 6).

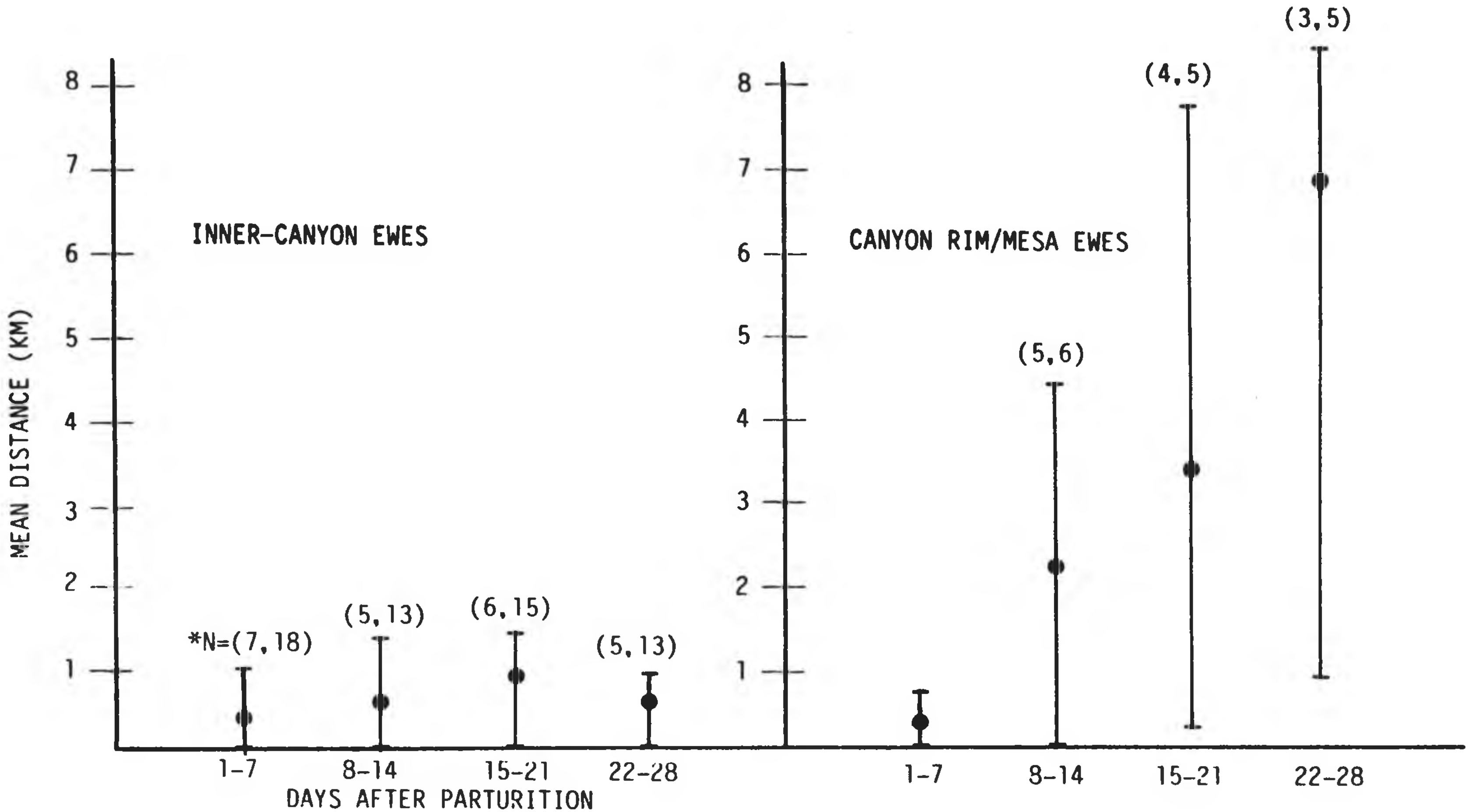

Fig. 6. Weighted mean distances and ranges of movements of desert bighorn ewes with lambs from lambing sites during the month following parturition. *N(7,18) represents 7 ewes located a total of 18 times.

Ewe Seclusion Period

Data from radio-collared ewes which had been observed often in groups prior to lambing were used to determine the length of the ewe seclusion period during the lambing season. The post-lambing seclusion period of dominant ewes (#01, 08, and 14) as determined by group leadership and priority of access to resources, averaged 2.8 days (n=4; SD=1.71; range=1-5). The post-lambing seclusion period of subordinate ewes (#04, 06, 16 and 18) averaged 11.5 days (n=4, SD=6.25; range=5-19). The pre-lambing seclusion period averaged 4 days (n=3; SD=3.0; range=1-7) for dominant ewes and 6 days (n=3; SD=6.9; range=2-14) for subordinate ewes.

Association and Sociality

Group Dynamics

Group size averaged 4 sheep (n=339; SD=2.28) during the study and ranged from 1 to 13 animals per group (Fig. 7). Mixed-sex groups were by far the largest, averaging 6.8 sheep (n=40; SD=2.58). Ewe-juvenile groups, composed of ewes, lambs and yearlings, were the most frequent type of group observed and averaged 3.8 bighorn (n=281; SD=1.91). Ram-only groups were smallest, averaging 1.2 individuals (n=18; SD=0.38).

Group size was smallest during February, peaked in May and stabilized during the summer months (Fig. 8). The May peak coincided with the formation of nursery bands following lambing and incorporation of lambs into existing groups. The largest groups observed formed after lambing and included adult ewes and rams, yearlings of both sexes, and lambs.

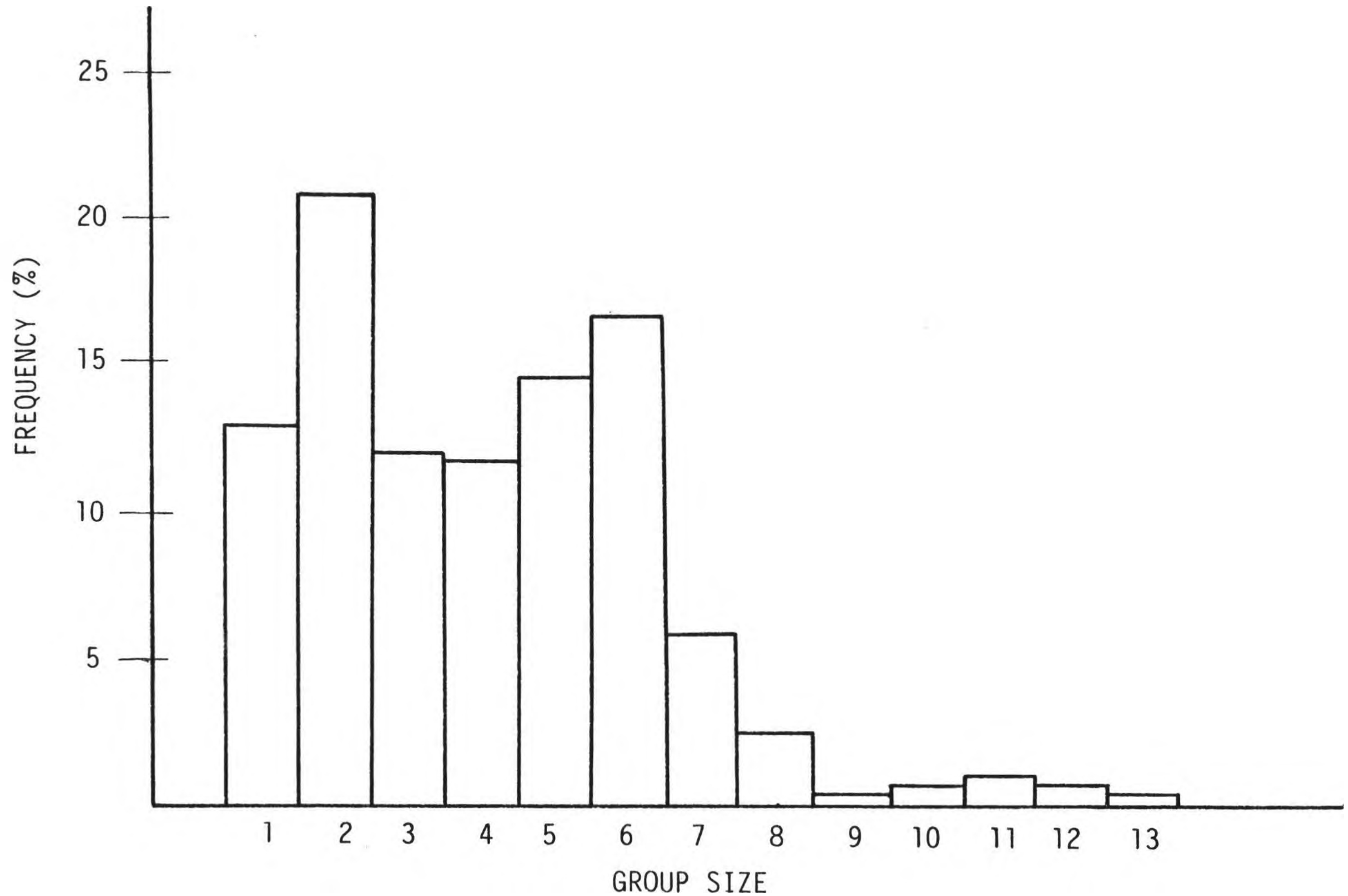

Fig. 7. Group size-frequency distribution of 339 desert bighorn observations recorded at Colorado National Monument during 1982 and 1983.

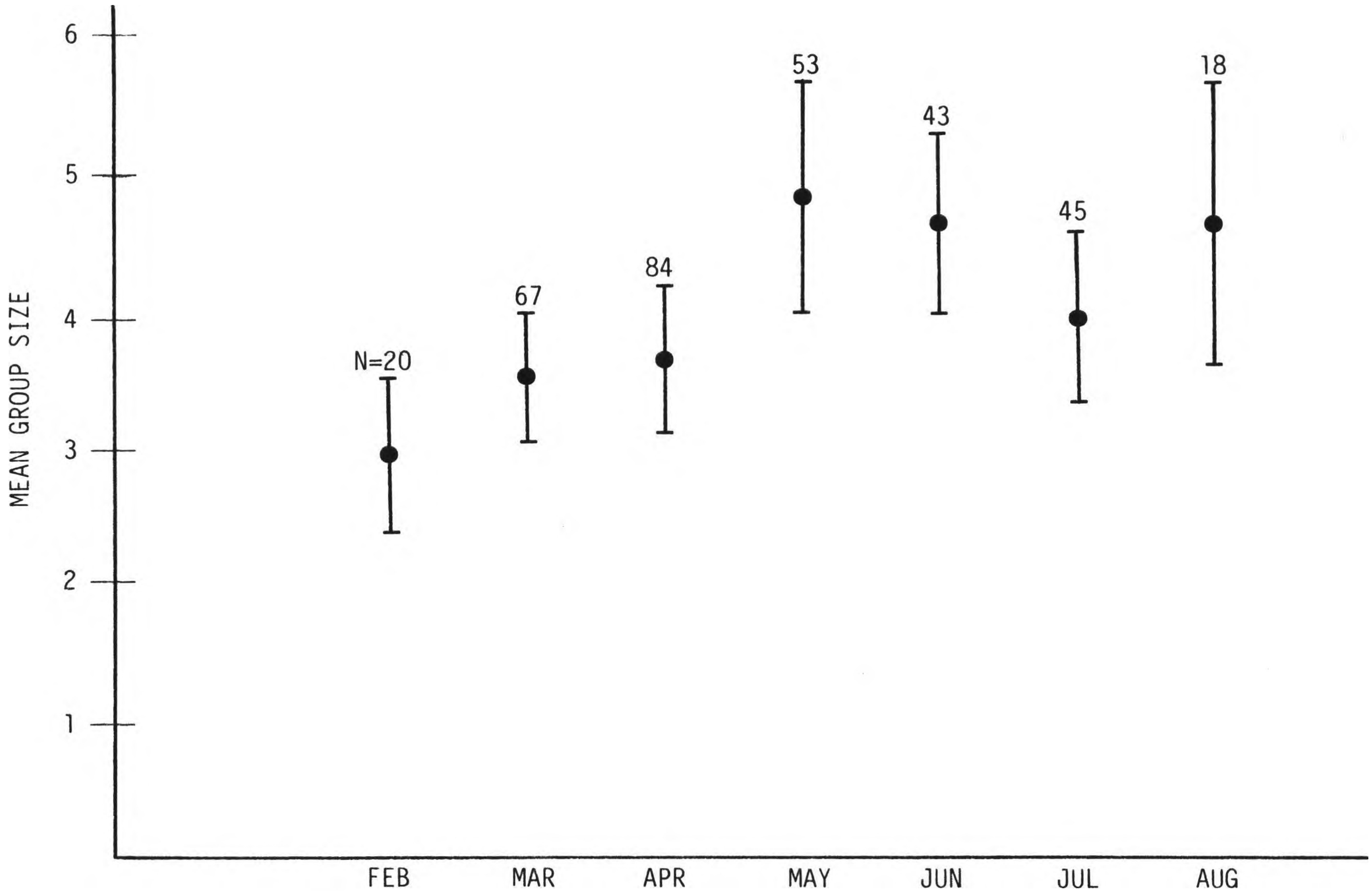

Fig. 8. Mean monthly desert bighorn group sizes (± 2SE) recorded at Colorado National Monument during 1982 and 1983. N = number of groups observed.

Group size and composition also varied between years. A large difference was noted for the month of April between 1982 and 1983 (Fig. 9). This difference was attributed to the delay in lambing exhibited by the 1981 release group in 1983.

Association Among Sheep

Coefficients of association (Cole 1949) between bighorn dyads were quite variable and ranged from 0 to a near-perfect value of 0.96 (Table 7). The mean coefficient of association for the entire herd was 0.11 and among ewes-only was 0.14.

Established ewes exhibited a mean coefficient of association of 0.22. The mean coefficient of association among the 1981 release group was 0.25. The mean coefficient of association between members of these 2 groups was only 0.05 however.

While the mean coefficient of association for the herd was low, social groups of bighorn existed and displayed high degrees of fidelity to their companions. "Groups" were defined as combinations of animals displaying coefficients of association of 0.5 or higher. Four ewe groups were delineated on this basis (Table 8). Numbers 02, 03 and 09 were mostly solitary animals and displayed low indices of association.

Home Range

Dispersal Following Release

Movements of bighorns following the 1981 release varied greatly. An aerial survey conducted the day after the transplant indicated that 6 of 9 ewes remained within 2 km of the Devils Canyon release site. Two of these sheep (#06 and 18) moved south into Devils Canyon and the

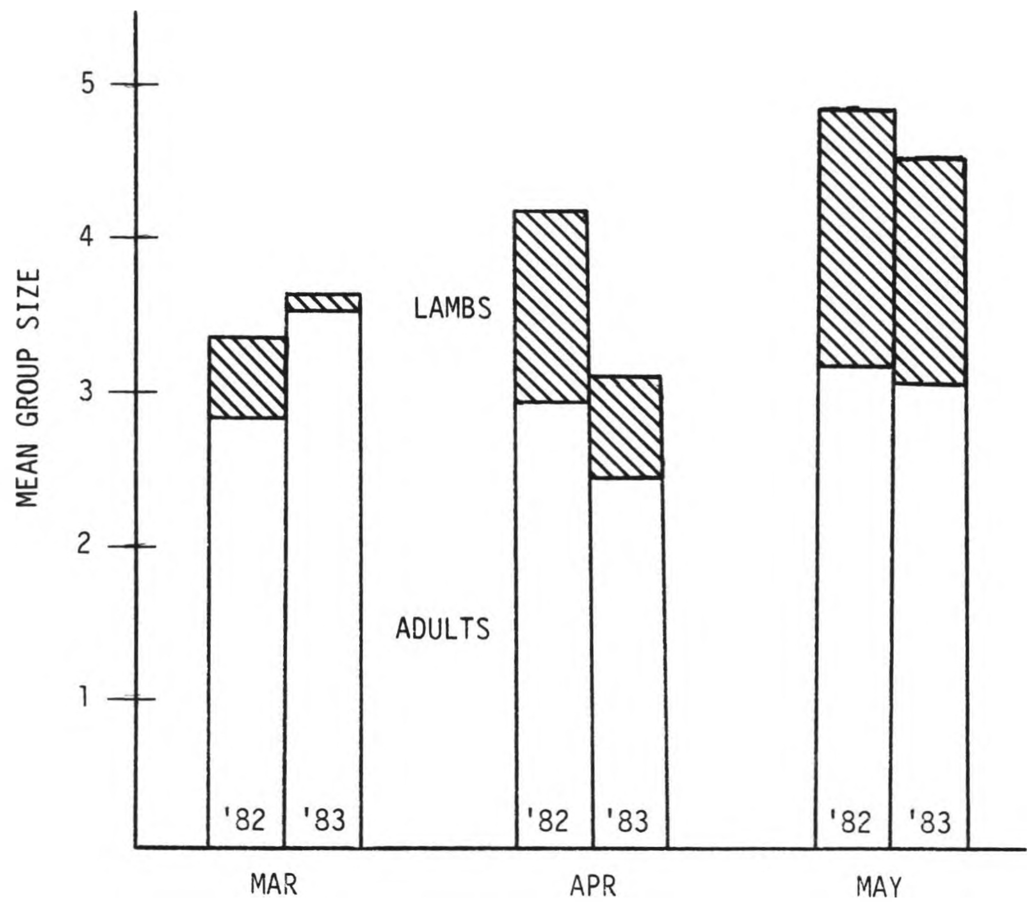

Fig. 9. Mean size and composition of desert bighorn groups in Colorado during the 1982 and 1983 lambing seasons.

Table 7. Coefficients of association among desert bighorn sheep in Colorado recorded during 1982 and 1983.

Bighorn #	1	2	3	4	5	6	8	B-9	9	11	12	14	16	17	18	ET-18
1		0.02	--	0.02	0.12	0.09	0.13	0.14	--	--	--	0.05	0.06	0.21	0.58	0.47
2			--	--	--	--	0.13	0.14	--	--	--	--	--	--	--	--
3				--	--	--	--	--	--	--	--	--	--	--	--	--
4					--	0.77	--	--	--	--	--	0.93	0.87	0.11	--	--
5						0.02	0.13	0.10	0.12	0.10	0.10	--	--	--	0.26	--
6							--	--	--	--	--	0.82	0.83	0.12	0.01	--
8								0.74	0.26	0.11	0.11	--	--	0.23	0.08	0.13
B-9									0.11	0.12	0.12	--	--	0.25	0.11	0.20
9										--	--	--	--	--	0.04	--
11											0.96	--	--	--	--	--
12												--	--	--	--	--
14													0.92	0.12	--	--
16														0.11	--	--
17															0.17	0.29
18																0.54
ET-18																

Table 8. Desert bighorn groups delineated at Colorado National Monument during 1982 and 1983.

Bighorn Group	Mean Coefficient of Association
#01, 18 E.T.-18	0.53
#04, 06, 14, 16	0.86
#08, Blue-9	0.74
#11, 12	0.96

remaining 4 (#00, 04, 06 and 16) dispersed eastward into a small canyon between Devils Canyon and Kodels Canyon. Another ewe (#09) dispersed 4 km southwest onto the Devils Canyon rim. Ewe #15 moved over 5 km southeast into Colorado National Monument. The remaining ewe (#02) dispersed 7 km west into the Rattlesnake Canyon area.

Observations and radio positions during the first 3 months after release indicated that the 2 ewes that remained in Devils Canyon were incorporated into a group of established sheep by 1 February. Three of the 4 ewes moving between Devils Canyon and Kodels Canyon remained grouped and stayed in the Kodels Canyon area. They were first known to interact with established bighorn on 26 February. The fourth ewe was found dead on the east rim of Devils Canyon in February.

The 3 ewes dispersing farthest had no known interactions with other sheep immediately following release. Ewe #09 remained on the west rim of Devils Canyon, moving 2 km farther south, and was first seen with other sheep on 24 May. Ewe #02 moved into Rattlesnake Canyon and was first seen with other bighorn on 6 June. Ewe #15 was observed 2 days after release on the east rim of Monument Canyon, over 8 km southeast of the release site. She continued traveling southeast and was radio positioned in Bangs Canyon, 29 km distant on 24 December. She was never observed with other bighorns.

Activity Centers

Bighorns used an area of approximately 125 km2 during the study. This area extended roughly from Kodels Canyon west to Mee Canyon. Centers of activity (Hayne 1949) for 6 ewes or ewe groups and 2 rams were dispersed over a distance slightly greater than 10 km (Fig. 10).

Sheep released in 1981 centered activities around the areas explored initially following release. Ewes #04, 06, 14 and 16 made intensive use of the Kodels Canyon area throughout the study. They used the small canyons immediately east and west of Kodels Canyon frequently and the Kayenta zone west to Devils Canyon occasionally. They were only rarely observed on the mesa south of Kodels Canyon or in the valley floor habitat north of the canyon mouth. Use of the valley floor coincided with the greenup of large areas of cheatgrass in the spring of 1983.

Ewes #01, 18 and E.T.-18 made intensive use of the inner-canyon zone of Devils Canyon during the study. Relocations in the winter, spring and early summer were concentrated in the northern half of the canyon and its many sidecanyons. Use shifted in mid-summer to the southern half of the canyon, possibly in response to restricted water availability. In late July they concentrated activity in an alcove at the extreme head of Devils Canyon near a permanent spring.

Ewe #09 concentrated her movements on the southwest rim of Devils Canyon, utilizing the Kayenta and Mesa habitat zones exclusively. Relocations were clustered on the rims of 2 sidecanyons in both 1982 and 1983. She was observed on the rim of the west fork of Pollock

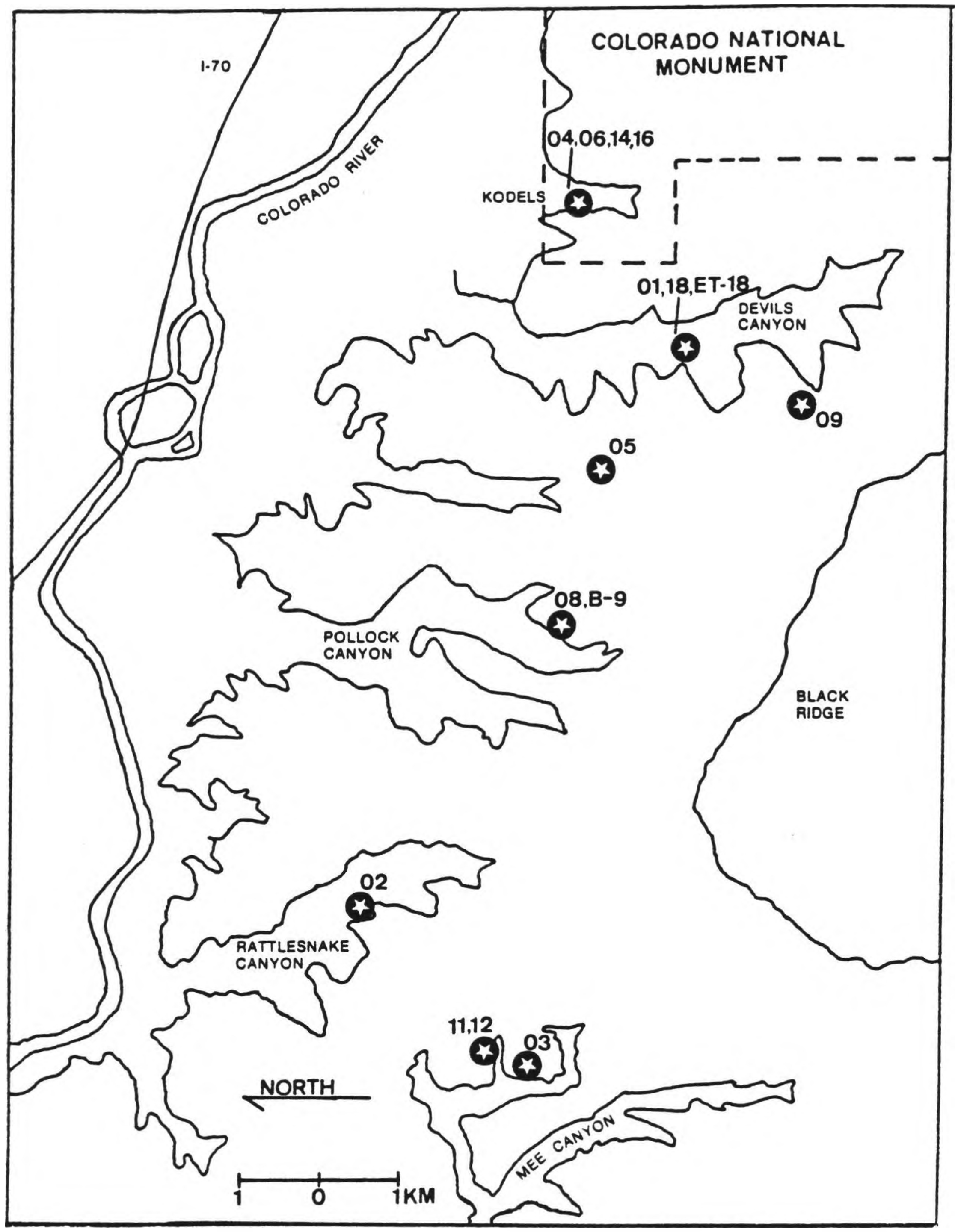

Fig. 10. Centers of activity of individuals or groups of sheep at the Colorado National Monument study area during 1982 and 1983.

Canyon during the summer of 1983 but had moved back to Devils Canyon by October.

Ram #05 was observed most frequently inside and on the west rim of Devils Canyon. He also used the mesa habitat westward to Mee Canyon and was known to associate with all females occupying the canyon rim/ mesa habitats.

Ewes #08 and Blue-9 were known to use Devils Canyon, Pollock Canyon, Rattlesnake Canyon and Mee Canyon during the study. Nearly 60% of observations of these ewes were in the Kayenta and Mesa habitat zones. The large volume of habitat covered in their travels was reflected in their large home ranges. They were the only ewes making contact with all sheep inhabiting Devils Canyon and the lands to the west.

Ewe #02 established her home range in the inner-canyon zone of Rattlesnake Canyon. She was only located once outside that immediate area. That was in November of 1982 when she was observed with #08 and Blue-9 on the west rim of Devils Canyon. She returned to Rattlesnake Canyon by March 1983.

Ewes #11 and 12 were most frequently located in the canyon rim/ mesa habitats of Mee Canyon. They also were known to use the canyon rims and inner-canyon habitats of Pollock Canyon occasionally and the mesa between the 2 canyons.

Ram #03 used the canyon rim and mesa habitats of Mee Canyon intensively during the study. He also used the mesas above Pollock Canyon and the flat open-park habitat south of Black Ridge. He was observed with an injured foreleg in April 1982 and had not regained full use of the leg in August of that year when last seen alive.

Home Range Size

Overlapping home ranges were noted among both ewes and rams. Home range size was highly variable among ewes and ranged from 4.6 km^2 to 44.7 km^2 during the study. Ram home ranges were more similar (Table 9). Home ranges of ewes occupying the canyon rim/mesa habitat zones (#08, Blue-9, 09, 11 and 12) were significantly larger than home ranges of the remaining ewes which occupied the inner-canyon habitats. Home ranges were larger in summer than in spring for both rams and ewes.

Table 9. Home range sizes of marked desert bighorns in Colorado during 1982 and throughout the entire (1982-83) study.

Animal No.	Sex	1982 Home Range Size (km^2)	No. Locations	1982-83 Home Range Size (km^2)	No. Locations
01	F	8.0	61	21.4	75
02	F	9.4	40	9.8	57
03	M	27.0	34	27.0	34
04	F	3.5	85	4.7	115
05	M	23.9	16	23.9	17
06	F	4.6	78	6.1	108
08	F	44.7	41	44.7	62
Blue 9	F	30.8	21	30.8	24
09	F	3.5	39	11.2	64
11	F	27.1	31	31.4	44
12	F	25.8	30	28.2	43
14	F	3.5	84	4.7	113
16	F	3.5	85	4.6	115
18	F	5.3	59	6.8	79
E.T. 18	F	3.1	26	5.5	34

Home ranges of the newly released ewes averaged 4.8 km^2 (n=7; SD=2.19) in 1982. The mean home range size of the established ewes was 23.2 km^2 (n=6; SD=15.32) during the same period. This difference was significant.

Home range expansion was calculated by comparing the average home range size in 1982 with the average cumulative home range size determined following completion of research in 1983. The mean cumulative home range size of established ewes was 16% greater than the mean home range size determined in 1982. The mean cumulative home range size of the 1981 release group was 44% greater than the home range size calculated for these sheep in 1982. Neither of these differences were statistically significant.

Home Range Overlap

Home range overlap among bighorn pairs ranged from 0 to a perfect 1.0 (Table 10). The mean value for the herd was 0.21 and among ewes-only was 0.22. The mean overlap value among established ewes was 0.37 and among the ewes released in 1981 was 0.30. The mean home range overlap between these groups was only 0.14 however. Bighorn ewes associated in direct proportion to the amount of range shared.

Spatial segregation of rams and ewes was not evident during the spring and summer months in the Colorado herd. There appeared to be some behavioral segregation however. Despite overlapping range with 6 ewes, #03 had no documented association with them. Younger males appeared to associate with ewes more than did #03. Because these rams did not have functional radio collars they were usually seen only when accompanied by radio-collared ewes. The large number of observations of ewes and infrequent sightings of rams suggest at least limited segregation between them.

Table 10. Home range overlap among desert bighorn sheep in Colorado during 1982 and 1983.

	Bighorn #															
Bighorn #	1	2	3	4	5	6	8	B-9	9	11	12	14	16	17	18	ET-18
1		0.28	0.01	0.19	0.37	0.28	0.46	0.53	0.47	0.10	0.10	0.19	0.17	0.19	0.47	0.41
2			0.12	--	0.16	--	0.34	0.42	0.16	0.26	0.27	--	--	--	--	--
3				--	0.31	--	0.51	0.42	--	0.79	0.73	--	--	--	--	--
4					--	0.81	--	--	--	--	--	1.00	0.95	0.29	0.06	--
5						0.05	0.69	0.50	0.49	0.25	0.21	--	--	0.07	0.23	0.24
6							0.02	0.03	--	--	--	0.81	0.83	0.44	0.28	0.21
8								0.82	0.31	0.51	0.46	--	--	0.03	0.15	0.15
B-9									0.41	0.46	0.43	--	--	0.04	0.15	0.15
9										--	--	--	--	--	0.16	0.17
11											0.95	--	--	--	--	--
12												--	--	--	--	--
14													0.95	0.29	0.06	--
16														0.29	0.04	--
17															0.25	0.26
18																0.89
ET-18																

Habitat Use

Data on habitat utilization were gathered from 287 ground observations of bighorn groups. Habitats where dead animals were found were included. Sheep were divided into inner-canyon and canyon rim/mesa categories. The inner-canyon sheep utilized the Wingate and Talus zones most. The canyon rim/mesa sheep utilized the Kayenta and Mesa zones predominantly (Table 11).

Bighorn use in relation to aspect differed between the winter/spring (Jan.-Apr.) and summer (May-Aug.) period (Table 12). Relative use of south- and east-facing slopes was highest during the winter and spring months. Use of the cooler north-facing slopes was highest in summer.

Bighorn use in relation to overstory dominance was investigated on inner-canyon talus slopes. Canopy coverage was highest on north-facing slopes, intermediate on east- and west-facing slopes, and lowest on south-facing slopes (Fig. 11). Relative dominance of trees was highest on north and west aspect slopes. Over 72% of bighorn observations in the Talus zone were on the more open south- and east-facing slopes (Fig. 12).

Table 11. Desert bighorn use of major habitat zones at Colorado National Monument. Sheep were divided into groups based upon overall habitat use patterns.

Habitat Zone	Inner-Canyon Sheep N	Inner-Canyon Sheep %	Canyon Rim/Mesa Sheep N	Canyon Rim/Mesa Sheep %
Mesa	5	2.2	19	31.7
Entrada	3	1.3	9	15.0
Kayenta	11	4.8	24	40.0
Wingate	110	48.5	8	13.3
Talus	84	37.0	0	0
Drainage	10	4.4	0	0
Valley Floor	4	1.8	0	0
Total	227	100%	60	100%

Table 12. Seasonal use of aspect by desert bighorns at Colorado National Monument during 1982 and 1983.

Aspect	January-April No. Observations	%	May-August No. Observations	%
N	5	3.7	31	23.1
NE	7	5.2	8	6.0
E	54	40.3	35	26.1
SE	16	11.9	16	11.9
S	23	17.2	12	9.0
SW	3	2.2	3	2.2
W	25	18.7	26	19.4
NW	1	0.8	3	2.2
Total	134	100%	134	99.9%

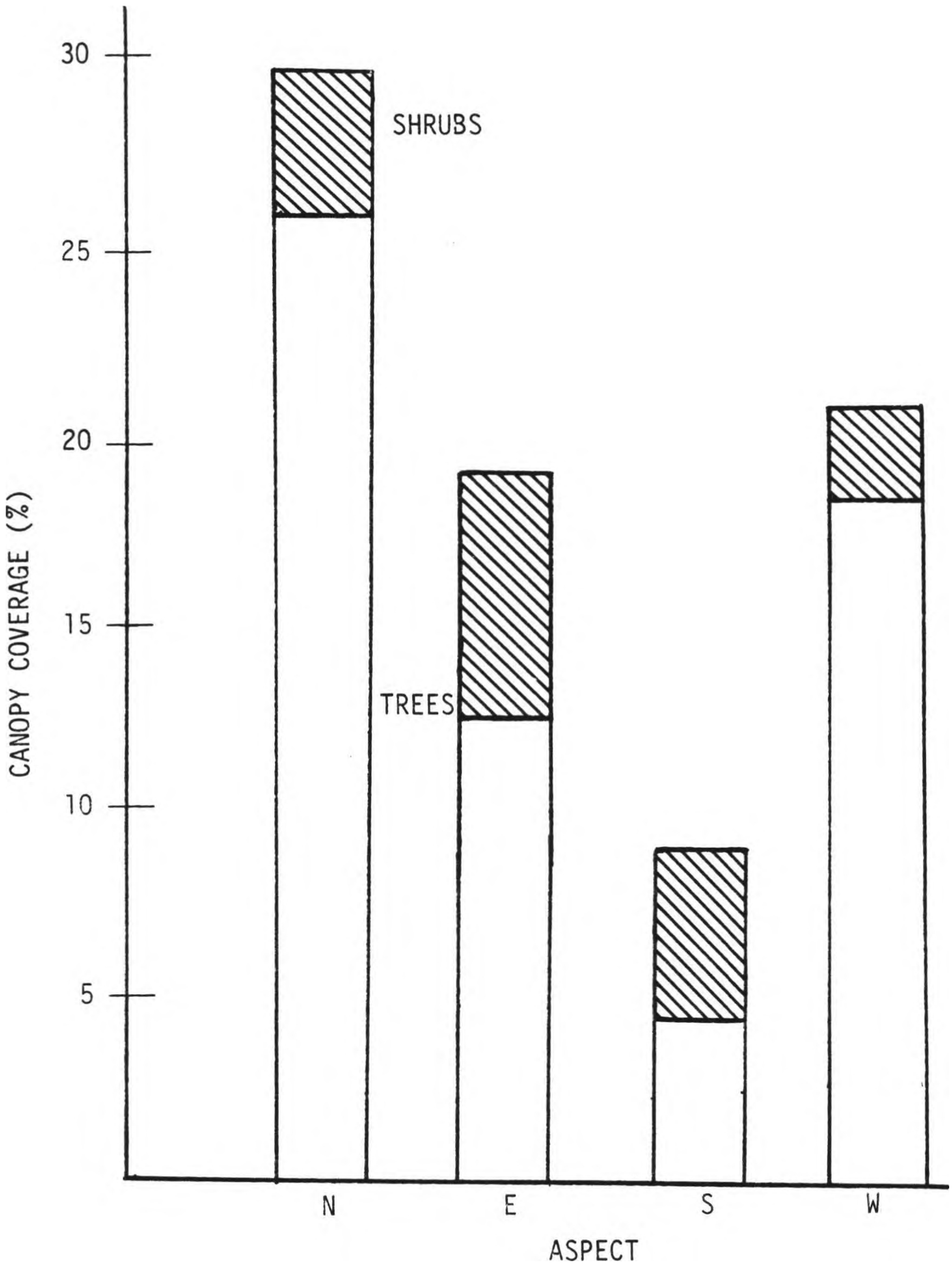

Fig. 11. Canopy coverage of woody vegetation in relation to aspect on inner-canyon talus slopes at the Colorado National Monument study area.

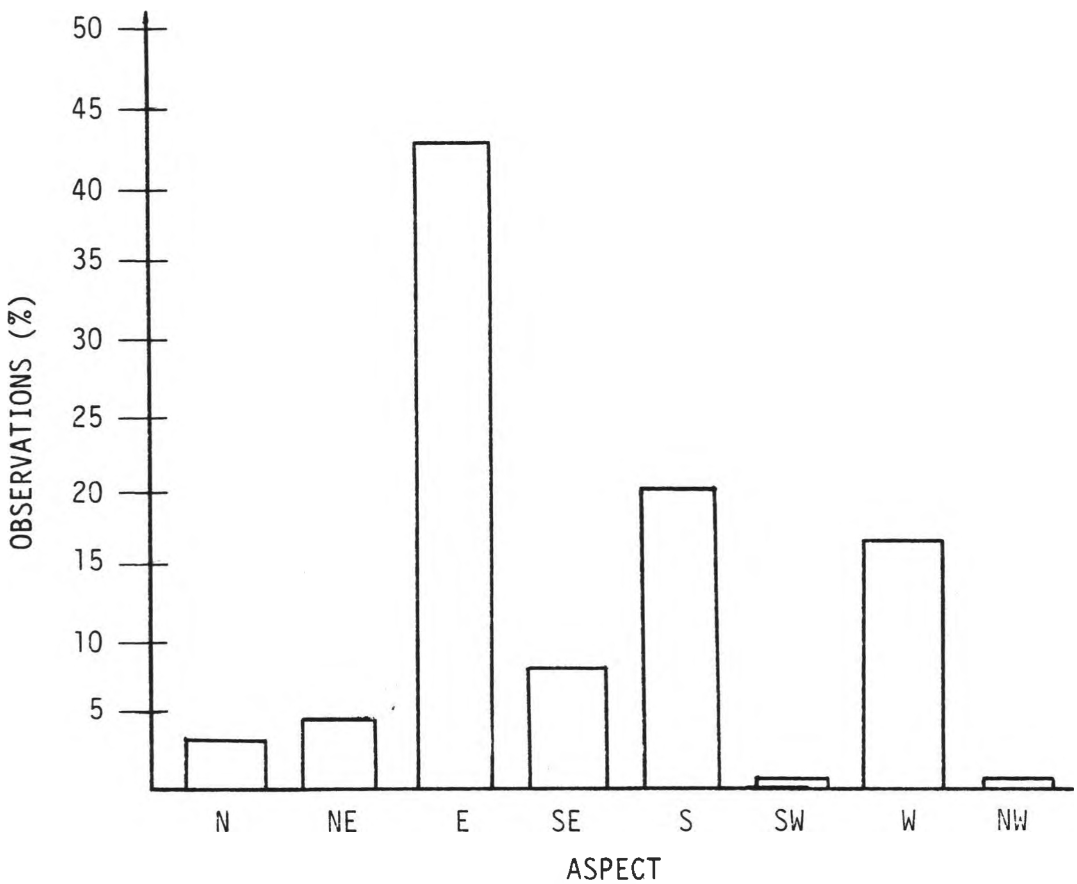

Fig. 12. Frequency of observation of desert bighorn groups in relation to aspect on inner-canyon talus slopes at Colorado National Monument during 1982 and 1983.

CHAPTER V

DISCUSSION

Population Dynamics

Ungulates often respond to release into unoccupied habitat by rapidly increasing population size (Klein 1968, Caughley 1970). The Colorado desert bighorn population experienced a net growth of 18%, from 34 to 40 sheep, between August 1982 and October 1983. While the observed growth rate is lower than that reported for sheep introduced onto Wildhorse Island, Montana (Woodgerd 1964) it is indicative of a healthy expanding herd responding to suitable habitat. The lower productivity of desert ecosystems (Barbour et al. 1980) and the presence of competing ungulates and predators probably precluded attainment of the high rates of increase noted on Wildhorse Island.

Reproduction

Lamb production rates in bighorn herds have been reported to vary little among years (Stelfox 1976, DeForge and Scott 1982) although exceptions have been noted (Witham 1983). Lamb:ewe ratios in the Colorado desert bighorn herd were similar in 1982 (71:100) and 1983 (75:100), both being slightly below the management potential of 80:100 given by Demming (1963). The presence of female lambs and yearlings in the population constrained production ratios in both years.

Lamb survival is thought to be the most important factor influencing bighorn population trends (Stelfox 1976, McQuivey 1978, Goodson 1978). Survival of at least 70% of the lambs observed in 1982 to 1 year of age is substantially higher than the lamb survival rate of 21% reported by Bradley and Baker (1967) for an established but slowly declining desert bighorn population. The yearling:ewe ratio of 50:100 observed in this study during 1983 is greater than that often reported for stable bighorn populations (e.g., McQuivey 1978).

Mortality

Mortality among wild sheep is characteristically low between the ages of 2 and 9 years, increasing greatly with age beyond this point (Buechner 1960, Bradley and Baker 1967). Given the current age structure of the Colorado desert bighorn herd (Table 2), adult mortality can be expected to continue at the observed level or increase slightly as older animals die out at an increasing rate.

Predation accounted for at least 2 of 5 adult mortalities recorded during the study. Both of these losses involved ewes released in 1981 and occurred within 5 months after transplanting. Lack of familiarity with the new habitat and individual dispersal following release probably increased the vulnerability of these animals to predation. High levels of predation following release have been observed by McCutchen (1982).

Timing of Parturition

Timing of reproductive activities in animals is governed largely by the necessities of the young (Marshall 1956). The onset and duration of the breeding season in bighorn sheep is ultimately controlled by the need to allow sufficient time for lamb growth prior to the limiting season while at the same time coinciding births to optimal thermal and nutritional conditions (Geist 1974, Wehausen 1980). When transplanting sheep into different environments one might expect to see a shift in the onset of estrous and subsequent lambing period, thus concentrating births during the period most favorable to lamb survival.

It was hypothesized that the ewes bred in Colorado would lamb later than the ewes which bred in Arizona and were transplanted to Colorado in 1981. The ewes bred in Colorado did lamb significantly later than the ewes bred in Arizona and the null hypothesis of no difference in the timing of the breeding season between the 2 groups was rejected.

It was also hypothesized that the ewes released in 1981 would lamb later in 1983 than they did in 1982, thus delaying breeding activities in autumn, 1982 in response to their new environment. Lambing did occur significantly later in 1983 and the null hypothesis of no change in the timing of reproduction following transplanting was rejected.

Although based on limited sample size, the breeding season of these bighorns was significantly altered within a year in response to changed environmental conditions. Demming (1961) also noted rapid temporal changes in bighorn reproduction following transplanting. The documented shift in the reproductive cycle of the 1981 release group brought them into synchrony with the lambing period exhibited by desert bighorn ewes breeding in Colorado from 1980 (Ravey, personal communication) through 1983.

The mean lambing date of ewes breeding in Colorado occurs after the onset of spring vegetative growth in late-March on the study area (U.S. Bureau of Land Management 1976, unpbl. phenological data, Grand

Junction, CO). The ultimate importance of spring vegetative growth in determining breeding seasons in bighorn sheep has been widely recognized (Geist 1974, Bunnell 1982, Thompson and Turner 1982).

While the onset of breeding has been significantly delayed, the sheep have retained a long lambing period characteristic of other desert bighorn populations. Higher selective pressures on lambs born early and late in the season (Geist 1971) should eventually limit the length of the breeding season.

Factors Influencing Reproductive Timing

The major proximate stimuli regulating the timing of reproduction in ungulates are photoperiod (Yeates 1949, Hafez 1952, Schulte et al. 1980), temperature (Dutt and Bush 1955) and nutrition (Verme 1965). A fourth factor influencing the onset of estrous in domestic sheep is the presence of males (Schenkel 1954). Photoperiod is usually considered the most important of the 4 factors (Sadleir 1969).

The observed delay in breeding activities following transplanting was believed to be caused by a combination of photoperiod, temperature, nutrition and possibly other unknown factors acting in concert. Ram presence did not appear to be important. The effects of temperature and nutrition could not be quantified.

Photoperiod alone was not believed responsible. The capture and release sites are separated by approximately 3° latitude and differences in length and rate of change of daylight between the 2 sites during the breeding season are relatively small (Nautical Almanac, U.S. Naval Observatory, Sunrise and Sunset Tables for Grand Junction, CO and Las Vegas, NV). Demming's (1961) observations show that the influence of photoperiod can be overruled by other environmental factors. He reported a delay in the timing of reproduction after transplanting bighorns from British Columbia to Hart Mountain, Oregon. If photoperiod alone was acting these sheep should have begun lambing earlier, not later as observed.

Comparison with Other Populations

Thompson and Turner (1982) analyzed temporal patterns of reproduction in bighorn sheep. Bighorn populations were divided into northern and southern categories along an ecotone between 36 and 37 degrees latitude based upon the timing and duration of lambing seasons. Lambing seasons are typically shorter and begin later in the year in northern populations.

The Colorado desert bighorn transplants involved sheep from southern populations released into a northern environment. Parturition data indicates that the herd possesses lambing characteristics intermediate between Thompson and Turner's (1982) northern and southern categories. Continued retention of these characteristics would suggest that a graded continuum originally separated reproductive timing in North American bighorn populations. Bunnell (1982) gave evidence for a continuum based on altitude. The latitudinal breaking point described by Thompson and Turner (1982) may be a result of the extirpation of low elevation Rocky Mountain bighorn populations which once occupied the continent.

The lambing period of the Colorado desert bighorn herd begins earlier and extends longer than those of the state's Rocky Mountain bighorn herds described by Moser (1962). Moser's (1962) generalizations were based on data from high elevation herds however. Parturition data for a low elevation Rocky Mountain bighorn population in Colorado (Risenhoover 1981) are more similar to those of the desert bighorn herd.

Lambing Behavior

For lambing purposes, ewes preferred inner canyon habitats offering abundant escape terrain and few visual obstructions. Most ewes lambed at the bases of sheer Wingate sandstone canyon walls. Wilson (1968) also noted high use of similar habitat for lambing purposes in the canyonlands of southeast Utah. These areas are nearly inaccessible and provide optimal visibility, favoring the bighorn's adaptations for predator evasion.

Use of traditional lambing areas is frequently reported for Rocky Mountain bighorns (Geist 1971, Butts 1980). This behavior has also been reported for desert bighorns (Wilson 1968, Turner 1981) but is less well developed in areas characterized by pluvial and floral instability (Welles and Welles 1961). The relatively predictable western Colorado environment apparently allows establishment of traditional lambing areas. A moderate degree of fidelity to major canyon systems used in previous years was noted in this study. The lack of fidelity to particular lambing sites was believed due to the large amount of suitable lambing habitat available within each ewe's home range.

Bighorn ewes typically isolate themselves from other sheep before and after parturition. The length of the seclusion period has been reported to range from 1 month (Welles and Welles 1961) to less than 24 hours (Bunnell 1980). The observed seclusion periods during this study were within the range of variation reported in the literature.

The length of the ewe seclusion period appeared to vary with the social status of each ewe. Dominant ewes remained alone for less time than did subordinate ewes. This was especially notable during the post-lambing period. Subordinate ewes appeared to seek out established group leaders and remain in close contact with them even near the dominant animal's parturition time. Dominant ewes did not seek out the subordinates however. This suggests that the urge to follow in bighorn sheep is greater than the urge to lead.

Movements of ewes with lambs following parturition showed that lambs are physically capable of moving long distances over rugged terrain within 2 weeks of birth. Leslie and Douglas (1979) and Geist (1971) reported major moves with lambs at 3 and 4 weeks of age, respectively.

Movements with lambs >1 week of age varied with the mobility of individual ewes. Ewes with greater home range sizes moved greater distances with their lambs following parturition. Since habitat use in bighorn sheep is a function of tradition (Geist 1967, 1971), the progeny of mobile ewes would be expected to adopt larger home ranges themselves. This should promote inter-group mixing within the herd and reduce the probability of developing isolated sub-populations.

Parturition in Desert Bighorn

Parturition in wild bighorn sheep is rarely observed. One observation of a ewe giving birth was recorded during this study. Because of its uniqueness, the event is recounted.

Radio-collared ewe #18 was observed on 19 April 1982 inside Devils Canyon from a distance of approximately 0.7 km through a spotting scope. When first seen at 12:10 pm the ewe was alone and appeared restless, standing up and lying down again frequently. At 1:35 it was first realized that she was giving birth when the ruptured placenta was seen emerging.

The ewe continued to rise, change position and lie down again within an area of approximately 20 m^2. While lying down on her side the ewe held her tail erect, with front legs folded under the chest and rear legs extended out as if standing. She would occasionally contract her body, moving her head and neck ventrally rearward and moving the rear legs forward.

The lamb began to emerge at 1:52 pm. By 1:56 the lamb's head and forelegs were protruding and appeared to be moving. At 1:57 the lamb was born and began struggling on the ground. The ewe stood up at 1:58, apparently breaking the umbilical cord and turned to lick the newborn lamb. The ewe ceased licking the lamb, which responded by attempting to stand. After the lamb struggled unsuccessfully, the ewe resumed licking its head. She then began to paw dirt over the birth spot and surrounding area, then lay down within 1 m of the lamb.

At 2:10 pm the lamb struggled up on its forelegs and the ewe licked it again. The lamb was standing upright on all 4 legs at 2:26 but fell over when it attempted to walk. The lamb was back on its feet at 2:28, walked over to the ewe, and attempted to suckle, first between the ewe's front legs and then between her rear legs. The lamb appeared to find the udder by 2:40 and was nursing. Suckling continued intermittently until 3:20 when the lamb voluntarily ceased suckling and lay down in a sunny area. After surveying the slopes below, #18 lay down at 3:30 within 1 m of her lamb. The observation was terminated at 3:35 pm.

The ewe and her lamb were again observed the following afternoon. The lamb was quite active, jumping around and apparently testing its legs. The lamb would crawl over and jump on its dam, causing her to rise, and then would suckle. The ewe often would squat slightly, permitting the lamb to nurse more easily. When seen 3 days after parturition the lamb was following its dam closely as she foraged and appeared to experiment with eating grasses. Suckling again was observed, in all cases being terminated by the lamb. This behavior changed after a week when the ewe began terminating suckling by walking away while the lamb was nursing.

Association and Sociality

Group size in ungulates is determined by the interaction of many factors, including feeding style, predation pressures and the dispersion of forage resources (Jarman 1974). The degree of visibility afforded by habitat is also an important factor (Risenhoover and Bailey 1980). Group size in the desert bighorn herd studied was considerably smaller than those reported for Rocky Mountain bighorn populations (Butts 1980, Risenhoover 1981) but similar to those of other desert bighorn populations (Golden and Ohmart 1976, Leslie and Douglas 1979).

The observed group size was believed to be due to the interaction between visibility and resource dispersion, influenced by the current low population density. Group size is expected to increase with increasing population density until the potential gains of increasing group size are outweighed by the costs of being in a group (Krebs and Davies 1981).

Bighorn sheep exist in loose herds and exhibit flexible associations (Hansen 1965b). Group integrity is generally considered weak (Blood 1963, Thorne et al. 1979). The high degree of fidelity recorded between certain pairs and groups of sheep during this study may have been due in part to low population density. Leslie and Douglas (1979) suggested that group integrity is enhanced at low population levels due to reduced inter-group mixing. Certain stable bighorn pairs interacted often with other sheep, however, indicating that mutual attraction between individuals is also important in maintaining integrity.

The mean coefficient of association of the entire herd was lower than those reported by others (Leslie and Douglas 1979, McCutchen 1982). Especially notable was the general lack of interaction between the sheep released in 1981 and the established herd. The low level of behavioral association between these 2 groups was probably due to the low degree of home range overlap between individuals. Bighorns from the 1981 release exhibited few interactions with other sheep because they had few opportunities for interaction. There was little evidence to imply conscious avoidance of animals from other releases as suggested by Wilson et al. (1975). Interactions between sheep are expected to increase as home range expansion brings animals into closer contact.

Home Range

Dispersal Following Release

Movements of bighorn sheep following release are often quite variable, some animals being highly mobile while others remain relatively sedentary (McQuivey and Pulliam 1981, deVos 1982, Elenowitz 1982). Movements following the 1981 release followed this pattern of high individual variation. Some general trends in movement were evident however.

Seasonal timing of transplanting appeared to influence movements immediately following release and ultimately home range establishment. Cold weather and above normal snowfall during the 3 months following the November 1981 release were believed important in limiting sheep movements. This in turn aided in habitation of sheep to the immediate area. All ewes eventually established home ranges around the areas pioneered during the 3 months following release. McCutchen (1982) and Ravey and Schmidt (1981) also reported reduction of desert bighorn movements in response to cold and snow.

A second factor thought to influence dispersal was association with other sheep. Ewes which remained grouped or which joined groups of established sheep shortly following transplanting remained close to the release site. Ewes moving farthest following release were not known to interact with other bighorns for over 6 months after release. Action taken to increase the probability of interaction among animals may aid in reducing individual dispersal and promote group formation. Short-term holding pens have been used successfully by Bear (1979) and Ravey and Schmidt (1981) to accomplish this.

Home Range Size

The range of variation in home range size among ewes was greater than that reported by King and Workman (1982) for desert bighorns occupying similar habitats in Utah. The main factors believed responsible for the large differences in home range size were the amount of exploration exhibited by individuals immediately following release, the type of habitat utilized, and the amount of time since release.

The amount of exploration done by individual bighorn immediately following release appears to directly influence ultimate home range size. The ewes occupying the largest home ranges in 1982 and 1983 explored very large areas following transplanting (Ravey 1984). They concentrated activities in the canyon rim/mesa habitat zones following release and continued to use those habitats during this study. Their retention of large home ranges reflects their greater familiarity with the study area.

The ewes occupying smaller home ranges were relatively sedentary following release. Their initial movements were limited by winter weather to inner canyon habitats. They continued to concentrate activities in these areas throughout the study.

It was hypothesized that, during the first year following release, the mean home range size of ewes transplanted in 1981 would be different than the mean home range size of the established ewes. The mean home range size of the 1981 release group was significantly smaller in 1982 and the null hypothesis of no difference in home range size was rejected. The observed difference in home range size between the 1981 release group and the established ewes was believed due to a combination of factors, including lack of familiarity with new habitat (Geist 1967), season and method of release (Ravey and Schmidt 1981), individual variation in the psychological drive to explore (McCutchen 1982) and differences in habitat use patterns.

Home ranges of sheep released in 1981 expanded greatly between 1982 and 1983, indicating that use of adjacent habitats was increasing with time. Home ranges of established sheep expanded at a much slower rate during this period. While the observed increases were probably influenced by sample size bias (Jennrich and Turner 1969) the increase in mean home range size over time of the 1981 release group was considered biologically meaningful.

Use of habitat surrounding the present areas of bighorn occupation is expected to increase gradually. The surrounding environment is similar and contiguous, both topographically and floristically. Neither canyons nor mesas appear to preclude bighorn movements although access points to canyon habitats from mesas are limited. Traditional travel routes are expected to develop as the bighorns expand their range.

Habitat Use

Habitat use exhibited by the bighorns in 1982 and 1983 was roughly similar to that observed by Ravey (1984) in 1980 and 1981 on the Colorado National Monument study area. King and Workman (1982) and McCutchen (1982) reported comparable use of habitat in Utah's canyonlands. The concentration of activities near escape terrain reflects the importance of such areas to bighorns.

Sheep use of aspect changed seasonally, possibly in accordance with thermoregulatory needs. Greater use of south-facing slopes in winter and north-facing slopes in summer would be expected to lower the metabolic costs associated with maintenance of body temperature. Simmons (1969) observed differential use of aspect to avoid heat gain in Arizona bighorns.

A second possible explanation for the seasonal shift in use of aspect is the timing of phenological events. South-facing slopes green up earlier in the spring while vegetative growth begins later on north-facing slopes. Forage conditions would be better on south slopes earlier in the year and on north slopes later in the year.

Bighorn use of aspect also appeared to be influenced by canopy coverage of trees and shrubs. Slopes providing greater visibility received heavier use by sheep. Risenhoover and Bailey (1980) showed that foraging efficiency of bighorn sheep was directly related to visibility.

CHAPTER VI

MANAGEMENT RECOMMENDATIONS

The goal of this study was to provide information useful for successful management of the Colorado desert bighorn population. While many of the following recommendations address management of the Colorado herd, they are applicable to bighorn introductions in other geographic areas.

Reintroductions are crucial to management of bighorn sheep. This study indicates that bighorn sheep are reproductively plastic and, within reason, can be expected to adapt reproductive timing to fit local conditions. These findings have important implications in extending the range of bighorn sub-species into suitable ranges because animals used in restocking efforts frequently come from areas having different phenological regimes. The demonstrated ability to quickly adapt to local conditions indicates that factors other than temporal patterns of reproduction should be emphasized when planning introduction efforts.

Continued monitoring of the herd is recognized as an important and necessary tool for determining population health. Caughley (1970) outlined 4 phases of ungulate population fluctuation following introductions. These include an initial increase, followed by initial stabilization, decline and a final post-decline phase. Monitoring of lamb production and survival should enable managers to determine when the population is beginning to stabilize. Since transplant objectives are to use the herd as a source of bighorn for restocking other habitats, trapping and transplanting operations should begin prior to the onset of the population decline phase.

Population growth in the Colorado herd does not appear to be significantly impacted by predators. Implementation of state or federal predator control operations seems unnecessary at the present time.

Establishment of bighorn populations in the vicinity of the release site is a frequent transplant objective. Wildlife managers may be able to increase the probability of achieving this by combining season of release with release methods that promote group formation. Scheduling of transplants prior to the restrictive season (winter in Colorado) coupled with maintenance of group size appears to foster home range establishment near the release site. Short term holding pens are recommended to reduce individual scattering.

Maintenance of interchange between groups of bighorns occupying different parts of the study area is necessary to prevent development of isolated sub-populations. Two methods are recommended to accomplish this. First, individuals associating with the majority of bighorns occupying the study area should be identified and excluded from future transplants. Marking operations should be conducted periodically to facilitate this. Secondly, land uses which could potentially inhibit movements of bighorns should be prohibited. Until the effects of increased human use on bighorn movements can be determined, upgrading of current access roads to the canyons and mesas west of Colorado National Monument or creation of new roads in the area should be opposed.

Geist (1967) noted that transplanted populations often fail to expand into adjacent suitable habitats. If the desert bighorn herd fails to expand its range naturally with increasing population size, efforts should be implemented to artificially disperse the herd. The recommended method, detailed by McCutchen (1982), is to transport or attract groups of sheep a short distance into adjacent suitable habitat. These sheep can be expected to eventually return to their former home ranges, potentially sharing their increased knowledge with other animals.

Identification of areas of importance to wildlife is the first step in their preservation. Lambing areas have been identified and mapped. Inner-canyon habitats are most commonly used for lambing purposes and must be protected. This protection should include permanent withdrawal of inner-canyon grazing permits for canyon systems known to be used by bighorns for lambing. This would eliminate the potential of disease transmission from domestic sheep and keep forage competition at a low level. Cattle grazing on the mesas should be held at or below present levels. Protection should also include restriction of commercial and residential developments which present a threat to the bighorn herd.

Identification of areas used by bighorns and documented fidelity of ewes to major canyon systems for lambing purposes should increase the efficiency of future monitoring efforts. Surveys during the lambing season should emphasize upper talus slopes and Wingate ledges. Aerial lamb counts should be conducted in mid-May when most lambs are at least 1 month old. If rutting grounds are identified, mid-October surveys could supplement the spring counts.

Monitoring of environmental conditions by land management agencies should not be neglected. These should include inventories of both forage and water resources. Range surveys should be designed specifically to gauge the impact of desert bighorn on forage resources.

The role of genetic diversity in maintaining population health has only recently received serious attention by wildlife managers. Inbreeding often results in reduced genetic fitness, manifested in lowered fecundity of adults and survivability of young (Senner 1980). Future management efforts should be aimed at preserving genetic diversity in the herd. Wilson et al. (1975) recommended the addition of 1 mature ram every 5 years during the first 20 years following herd establishment. This, combined with maintenance of large population size (Pettus 1982) is recommended to insure the health of the desert bighorn population.

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