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.

ASPECTS OF BARBARY SHEEP (Ammotragus lervia)

BIOLOGY IN PALO DURO CANYON, TEXAS

by

GARY GENE GRAY, B.S., M.S.

A DISSERTATION

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Dedication

This dissertation is dedicated to the memory of - Terrill Christian

(18 September 1907 - 23 November 1979)
in recognition of his lifelong love for Palo Duro Canyon;

and to my father

Cecil T. Gray

(26 July 1909 - 19 June 1980)

in appreciation for his love, patience, and loyalty.

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ABSTRACT

Forty-four Barbary sheep (<u>Ammotragus lervia</u>) were introduced into Palo Duro Canyon in 1957-58. This study was conducted 1) to collate the published literature on Barbary sheep, 2) to provide some basic biological data on the Palo Duro Canyon population in the original release area, and 3) to suggest how these data can be applied to species management.

Two methodologies were developed for determining age and/or sex. One involved defining nine age-sex classes based upon combinations of sexually dimorphic characteristics, and age-related variation in body size, horn size, and morphological configuration. This was used to assign Barbary sheep to age-sex classes from field observations. The other method substantiated the use of horn growth checks to estimate age in this species, and provided regression equations for estimating age from horn length.

Regression equations were also developed to estimate weight from horn length. This is the first study in which horn size has been used as a weight estimator.

Population statistics were estimated from 1,246 hours of observation on 271 field days from February 1977 through January 1979. Observations were made from a vehicular blind on the canyon rim, from fixed points on a standard observation route hiked each field day, and during seven helicopter

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censuses of the Dry Creek branch (65 km²) of Palo Duro Canyon. The findings 1) suggested population densities of 0.8 - 3.6 Barbary sheep per km^2 , 2) indicated that about 70 percent of births take place in March and April, but that some par-Els. turition is distributed throughout much of the year, 3) showed a natality rate of about 48 juveniles:100 females, 4) la b/e disclosed an adult sex ratio of 40 males: 100 females, and 5) rente 2mdo J implied that juveniles and subadults comprise about 30 percent of the population, adult males 20 percent, and adult females 50 percent. The survival rate/from birth to oneyear of age approximates 35 percent, is about 77 percent per year for males from one to 3.5 years of age, and is estimated to average 55 percent per year for males from 3.5 to 10.5 years of age.

The topographic distribution of 529 sightings indicated that Barbary sheep range over all levels in Palo Duro Canyon, but spatial utilization is concentrated on precipitous bluffs which form the canyon walls.

Diet studies showed that Barbary sheep are predominately jood browsers, but consume appreciable amounts of plants from the other forage categories in all seasons. The most important food plants were sand shinnery oak (<u>Quercus havardii</u>), mountain mahogany (<u>Cercocarpus montanus</u>), bladderpods (<u>Lesquerella spp.</u>), and blue grama (<u>Bouteloua gracilis</u>).

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Barbary sheep were infected with three species of gastrointestinal helminths (<u>Monezia expansa</u>, <u>Skrjabinema</u> <u>caprae</u>, and <u>Haemonchus contortus</u>). Ectoparasites found included the ticks <u>Dermacentor albipictus</u> and <u>Otobius megnini</u>, and the lice <u>Bovicola fulva</u> and <u>B. neglecta</u>. <u>B. fulva</u> is a new species. Elaeophorosis was also documented in Barbary sheep for the first time, and many animals exhibited crusty lesions or healed scars about the head as a result of infection by Elaeophora schneideri.

Social organization is characterized by female group leadership and group dynamics (size and composition) which is highly variable within a basic pattern reflecting species phenology. Five types of intraspecific aggressive behavior and six vocalization types were described, and social ontogeny was delineated.

Several adaptive features of Barbary sheep biology were described and discussed, and a number of considerations relevant to species management were presented. The high degree of variability associated with each aspect of Barbary sheep biology reviewed or studied suggests that this species may be able to adopt a colonial (\underline{r}) or equilibrium (\underline{K}) strategy depending upon population density and habitat conditions.

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15. Composition of Barbary sheep groups encountered on the Dry Creek study area in Palo Duro Canyon during ground surveys from the vehicular blind and standard observation route (SOR)

CHAPTER I

BACKGROUND AND INTRODUCTION

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Archeological sites document a diverse fauna of large mammals in what is now the central Texas Panhandle during the late Miocene and early Pliocene epochs of the Tertiary Period, from 10 million to 4 million years B.P. (Schultz, 1978). Fossil remains of many of these animals have been found in or near the Dry Creek branch of Palo Duro Canyon on the Christian and Harrell ranches near Claude (Johnston, 1939; Johnston and Savage, 1955; Savage, 1955). Additional large mammal taxa were recovered from a Pliocene fossil bed in nearby Cita Canyon, and others, including mammoths (<u>Mammuthus</u> sp.) and bison (<u>Bison</u> sp.), were probably Pleistocene immigrants (Schultz, 1978).

The PaleoIndian period in this region, encompassing Clovis, Folsom, and Plano cultures, from about 10,000 to 5,000 B.C., spanned the closing phases of the Pleistocene epoch. These peoples primarily hunted the Pleistocene big game animals, and archeological evidence indicates the PaleoIndians were thoroughly familiar with the Palo Duro Canyon area (Hughes, 1978). Remains of bison and other large mammals from the long drought stage of the Altithermal (5,000 to 2,000 B.C.) during the early MesoIndian period are scarce, and sites marked by distinctive early MesoIndian

artifacts also are relatively uncommon on the High Plains surrounding Palo Duro Canyon, suggesting that the larger game animals and the peoples that depended upon them virtually abandoned the region during this interval. These events provide early evidence for the importance of the Palo Duron Canyon big game resource to human residents of this region.

The Historic period on the South Plains began with the arrival of the Coronado expedition in A.D. 1541, and Pedro de Casteneda, who chronicled that journey, furnished the first written description of Palo Duro Canyon. He called it a "large ravine . . . a league wide from one side to the other, with a little bit of a river at the bottom . . . " (Winship, 1896:237). Expeditions by José Mares, Pedro (Pierre) Vial and Francisco Xavier Fragoza, and Captain Francisco Amagual also traversed Palo Duro Canyon between 1787 and 1807 (Loomis and Nasatir, 1967). Meanwhile, the region had been dominated by the Apaches until about 1700 when they were replaced by the Comanches (Hughes, 1978). Palo Duro Canyon was undoubtedly a major camping ground for both tribes because it provided water, wood, protection from winter winds, and a naturally stockaded buffalo hunting area (Griggs, 1978).

The first Anglo-American exploration of Palo Duro Canyon was conducted by a military detachment under the

leadership of Captain Randolph Marcy in 1852. They encountered prairie dogs (Cynomys ludovicianus), pronghorn (Antilocapra americana), prairie chickens (Tympanuchus sp.), quail (Phasianidae), white-tailed deer (Odocoileus virginianus), a cougar (Felis concolor), two black bears (Ursus americanus), and a bobcat (Felis rufus) during 11 days in the canyon (Marcy, 1854:49-61). Pioneer rancher Charles Goodnight had to drive an estimated 10,000 buffalo (Bison bison) from the canyon's upper reaches in 1376 before beginning his cattle operation, which became famous as the JA Ranch (Burton, 1928: 26). He also attempted unsuccessful stockings of moose (Alces alces) and elk (Cervus elaphus) during the 1880's.

Game was scarce in the canyon during the first half of the twentieth century, probably because of the screwworm (<u>Cephenemyia hominivorax</u>) problem and the drought years of the 1930's (T. Christian, personal communication). For this reason the Texas Parks and Wildlife Department (TP&WD) released 268 mule deer (<u>Odocoileus hemionus</u>) in Palo Duro Canyon from 1949 through 1951 (DeArment, 1971). Native wild turkeys (<u>Meleagris gallopavo intermedia</u>) from the Clear Fork of the Brazos River were also stocked at three sites in the canyon during this three-year period. A decade following these releases neither species showed much promise of increasing to huntable population levels and the decision was made to introduce the exotic aoudad, or Barbary sheep

(<u>Ammotragus lervia</u>). This determination was partly influenced by the apparent success of a 1950 aoudad introduction in the Canadian River gorge of northeastern New Mexico (Ogren, 1962:17; 1965:8).

Thirty-one Barbary sheep were released into the Dry Creek branch of Palo Duro Canyon on the Christian and Harrell ranches southwest of Claude in December 1957, and 13 were liberated in the canyon near Quitaque in February 1958 (DeArment, 1971). Contracts negotiated with farmers and ranchers in areas surrounding the liberation sites provided for protection from hunting for 10 years or until TP&WD studies indicated a population large enough for trial hunting on a controlled basis. The first hunt, 13-15 December 1963, was planned to collect data and stimulate interest in the species as a game animal (Evans, 1964). The season was gradually extended to seven days in 1971 (Evans, 1968; Taft, 1969; Dillard, 1971), and expanded to two weeks in 1978. A total of 3,589 permits have been issued by the TP&WD and 1,125 animals have been legally harvested through 1979 (D. F. Dvorak, pers. comm., 1980). The fees paid by hunters have amounted to a substantial supplementary income for ranchers owning canyonlands (Christian, 1980).

DeArment (1971) summarized data on Barbary sheep collected by TP&WD personnel from 1957 to 1971, but indicated a need for additional information in order to properly manage the species. This project was initiated in January 1976 to help meet that need. Specific objectives of the study are:

 to collate the published literature on Barbary sheep for the use of wildlife biologists and natural resource managers;

2) to investigate several aspects of Barbary sheep biology for the purpose of supplying some basic biological data on the species, through examination of the Palo Duro Canyon population in the original release area 20 years after the introduction; and

3) to suggest how these data can be applied to better manage the species.

CHAPTER II

AMMOTRAGUS LERVIA: LITERATURE REVIEW AND SPECIES SUMMARY

This chapter reviews the important literature on Barbary sheep and summarizes the biology of this species, following the format of the Mammalian Species series published by the American Society of Mammalogists.

Ammotragus Blyth, 1840

Ammotragus Blyth, 1340:13. Proposed as a subgenus of <u>Ovis</u>. Type species <u>Ovis (Ammotragus) tragelaphus</u>. <u>Aegoceros Heughlin, 1861:16.</u> Type species <u>Aegoceros</u> tragelaphus.

Context and Content

Order Artiodactyla, Suborder Ruminantia, Infraorder Pecora, Family Bovidae, Subfamily Caprinae, Tribe Caprini. The genus Ammotragus is monotypic, as treated below.

> <u>Ammotragus lervia</u> Pallas, 1777 Barbary Sheep; Aoudad, Audad, Udad, Arui Mouflon à Manchettes; Mähnenspringer Muflone Berbere; Aŕrui

<u>Ant(ilope)</u> <u>lervia</u> Pallas, 1777:12. Type locality "Africae borealiori propria."

- Ovis tragelaphus Afzelius, 1815:216. Type locality "Mauritaniae."
- Ovis ornata I. Geoffroy Saint-Hilaire, 1827:264. Type locality "près des portes de la ville du Caire" (=Cairo, Egypt).
- Ammotragus lervia Thomas, 1902:13, first use of current name combination.

Context and Content

Context noted in generic summary above. Six subspecies are recognized (Allen, 1939) as follows:

- A. 1. lervia (Pallas, 1777:12). Type locality restricted to 'the "Department of Oran, Western Algeria" by Harper
- (1940:327).
- <u>A. l. ornata</u> (I. Geoffroy Saint-Hilaire, 1827:264), see above.
- <u>A. 1. sahariensis</u> (Rothschild, 1913:459). Type locality "Oued Mya" between El-Golea and In-Salah, 28°30' N., 3° E., Algerian Saharra.
- A. 1. blainei (Rothschild, 1913:460). Type locality "Border of Dongola Province and Kordofan," Anglo-Egyptian Sudan.
- A. 1. angusi (Rothschild, 1921:75). Type locality "Tarrouaji Mt., Asben, 3,100 ft.," French West Africa.
- A. 1. fassini (Lepri, 1930:271). Type locality Garian range, northwestern Libya.

Diagnosis

The following combination of gross morphological characteristics is diagnostic for this monotypic genus: presence of true horns, subcaudal gland, ventral neck mane, and chap hair on front legs of adults (particularly evident on males); absence of preorbital, interdigital, or inguinal glands, and inter-ramal chin beard.

General Characters

Pelage color is rufous or tawny brown with occasional dark brown areas about the head and forequarters. The chin, belly, and inside of legs are whitish, and a circular spot of white hairs frequently occurs on the head between the horns. A fringe of long hair, the mane, extends from under the throat down the front of the neck to the brisket. This hair then bifurcates and continues down the forelegs of mature animals, where it is termed chaps. Although a mane is found on other wild sheep, chaps are peculiar to aoudads. A short erect fringe is present on the back from the base of the neck to just behind the withers.

The head is relatively long with narrow, evenly tapered ears and a small black nose. Eyes are large and distinctive; a horizontal pupil is surrounded by a yellow iris.

True horns (Fig. 1), present on both sexes, are relatively large and moderately long with a moderately high



Fig. 1. Dorsal, ventral, and lateral views of a male Barbary sheep skull from Palo Duro Canyon, Texas, owned by James Standridge. Drawings by Dr. C. David Simpson.

spiral angle (small radius). They are elliptical and keeled in cross section, with a fairly broad frontal surface, exhibit heteronym winding, and have numerous shallow and uniform sulci (rings) as well as periodic growth checks or annuli (Ogren, 1962, 1965; Geist, 1966a; Schaffer and Reed, 1972). Horn points are directed inward, or inward and downward. Horn lengths and basal circumferences rarely exceed 840 and 355 mm in males, and 510 and 205 mm in females.

The neck is robust and the forequarters are more massive than the hind, particularly in males. This appearance is accentuated by the topline, which slopes from the withers. The legs appear to be short and stocky, and hooves are large, blunt, and well developed. Dew claws are usually hidden by chap hair. The tail is 175 to 205 mm long, tufted on the terminal half, and naked underneath (McClellan, 1955). Preorbital, interdigital, and flank glands are absent.

Dimensions of the largest males harvested in New Mexico (Ogren, 1965) were: total length, 196 cm; height, 112 cm; girth, 137 cm; and weight 145 kg. The largest females measured 165 cm, 94 cm, 112 cm, and 63.5 kg. These are significantly larger measurements than have been reported for type specimens from Africa, which were from 94 to 99 cm in height (Clark, 1964).

Distribution (free Marine)

Lhote (1957:88) designated the range as being all the hills of the Sahara, but particularly the Hoggar, Tassili, Ayr (Air), and Tibesti mountains. Barrett (1967) summarized the endemic geographic distribution, indicating the species inhabited all the major mountain massifs of North Africa above 15° (Fig. 2), citing Bigourdan and Prunier (1937), Rode (1943), Brouin (1950), Malbrant (1952), and Edmond-Blanc (1957). Joleaud (1927) also delineated the distribution.

Barbary sheep were present in some European zoological gardens during the last half of the previous century (Ogren, 1965:5), were introduced into the Teutoburger Forest of West Germany (Strasson, 1916), and onto Italian game preserves (Zammarano, 1930). The first importations from Europe to zoos in the United States occurred about 1900 (Ogren, 1965: 6). Barbary sheep readily reproduce in confinement, and surplus zoo stock was eventually sold to private parties. Wild populations in the southwestern United States were derived from groups that were released or escaped from private herds. The larger wild populations are located in Palo Duro Canyon of the Texas Panhandle, the Canadian River Gorge, Canyon Largo, and Hondo Valley of New Mexico, and Santa Lucia mountains of west-central California.



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Fig. 2. Map showing the endemic distribution of Barbary sheep in North Africa and the exotic free-ranging distribution of this species in the southwestern United States.

Fossil Record

Fossil sheep remains recovered from superficial deposits in Europe were referred to as <u>Ovis tragelaphus</u> <u>fossilis</u> by Serres (1848:149), and <u>O. magna</u> and <u>O. primoeva</u> by Gervais (1852:76). Lydekker (1912:310) commented that these were "sheep akin to the modern arui of North Africa." Osborn (1910:433), writing of the Pleistocene in North Africa, mentioned a "wild sheep (<u>Ovis paleotragus</u>) very similar to the existing Barbary sheep."

McBurney (1967) found remains of <u>Ammotragus</u> in Haua Fteah, a large natural cave on the northern coast of Cyrenaican Libya, in a number of deposits which ranged in antiquity from about 85,000 to 2,000 years B.P. Bate (1955) discussed the vertebrate faunas, including Barbary sheep, from Quarternary deposits in Cyrenaica. Vaufrey (1955) noted the species among the Pleistocene fauna in the Maghreb (Atlas massif), and Arambourg (1934) recorded the taxon at Beni Segoual.

Form

The skin is relatively thick, cutaneous glands are rare, and special dermal glands absent (Bourdelle, 1924). Females possess one pair of inguinal mammae.

In general, osteological characteristics are more nearly like those of goats than sheep (Bourdelle, 1924). Sexual

dimorphism in horn size, sinuses, and associated cranial morphology is pronounced. Horn bases are displaced behind the orbit. Schaffer and Reed (1972) made the following observations on the cranial morphology of the species. The male skull is considered to be of an advanced shape among Caprini -- that is, the foramen magnum is located beneath the horn bases and the back of the skull is more nearly vertical, so that the inclusive angle formed by the intersection of a plane along the parietal and supraoccipital bones with the plane of the palate is greater than 70°, and the ratio of parietal length to ventral skull length approximates 0.15. In Barbary sheep this configuration has been achieved by a ventrad rotation of the brain case (Fig. 1). The frontal sinuses are extensive and the septa complex in males, moderately extensive and moderately complex in females; the cornual sinuses are extensive and septa complex in males, extensive and moderately complex in females. The vertebral formula is C 7, T 13, L 6, S 4, Cd 14 (Lydekker, 1913). Incisors are typically goatlike, whereas molars are more nearly sheeplike (Bourdelle, 1924). The dental formula is i 0/3, c 0/1, p 3/3, m 3/3, total 32.

The structure of the hemoglobin (Hb) α polypeptide chain from this species consists of two forms, and both ${}^{I}\alpha$ and ${}^{II}\alpha$ chains closely resemble those of the domestic goat (Huisman, 1974); the β^{B} chain is apparently unique among the Caprini. The Amm-B Hb chain of Barbary sheep was shown to be related to but not identical with Hb B of the domestic sheep, and the Barbary sheep Amm- β^{C} -chain was similar to the sheep β^{C} chain (Huisman et al., 1968). The Hb of Barbary sheep was compared with Hb-I and Hb-II from Dutch Texel sheep and found almost identical to Hb-I in electrophoretic mobility, but of intermediate solubility between Hb-I and Hb-II in a series of phosphate buffers (pH 6.5) of graded molarities (Huisman et al., 1958). Hb-II has a greater affinity for oxygen, originated -- in domestic breeds -- from sheep living at high altitudes, and may be of adaptive significance; Hb-I is characteristic of breeds living at sea level. In an examination of blood proteins by electrophoresis in acrylamide and starch gel, Ammotragus was found to have five distinctly sheeplike biochemical characteristics, seven characteristics in common with both sheep and goats, and 10 unique characteristics (Manwell and Baker, 1977). Barbary sheep serum cholinesterase may be more primitive than either sheep or goat cholinesterase inasmuch as it is more active on butyrylthiocholine and α -naphthyl acetate.

The uterus is bicornate and the semideciduous placenta cotyledonary; an unusual type of corpora luteal scar Ogren (1965:62) frequently encountered was called a corpus veriformis. Ogren (1965:65) described sperm structure and

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Steklenev (1972) compared sperm morphology with other representatives of the Caprinae.

A number of general morphological features can be used to separate <u>Ovis</u> from <u>Capra</u>, and Payne (1968) indicated that <u>Ammotragus</u> shares six of the nine characteristics he inventoried with <u>Capra</u>. Linear body measurements were listed by Rode (1943), Brouin (1950), and Panouse (1957).

Function

Brady and Ullrey (1975) presented serum biochemical and hematological parameters of weaned juvenile Barbary sheep fed an exotic ruminant diet. Serum biochemical and hematological values of captive adults more closely resembled values for white-tailed deer than those of cattle or sheep, and activities of three serum enzymes assayed were also similar to those reported for white-tailed deer (Tumbleson et al., 1970). Meyer (1967) and Huisman et al. (1968) also listed hematological values for <u>Ammotragus</u>, and Huisman and Miller (1972) demonstrated that Hb-B is replaced by another hemoglobin type (Hb-C) during bloodloss anemia whereas a Hb-C-like variant, Hb-C^(na), present in certain nonanemic Barbary sheep, cannot be replaced when the animal is made severely anemic.

Average daily gain in weight of weaned juveniles was not significantly affected by dietary protein level and the

only significant dietary effect on blood parameters was on plasma urea nitrogen (Brady and Ullrey, 1975). The dietary protein requirement for weaned animals did not exceed 13.1% under study conditions, and levels up to 19.6% did not appear to be harmful.

Nouvel et al. (1969) reported the effect of an intramuscular injection of 12 ml of Sédalande (= Halo-anisone), fluoro-methoxyl-phenylpiperazine butyrophenone, on a male; and Hampy (1978) immobilized three males with M99 (etorphine) using M50-50 (diprenorphine) as the antagonist drug.

Ontogeny and Reproduction

Sperm is abundant in the epididymis of older males yearround (Ogren, 1965:65). Most matings are accomplished during an autumn rut, from September through November, but some take place throughout the year. The gestation period is 22 to 23 weeks (Brown, 1936; Lobanov and Treus, 1971), and up to 84% of births occur from March through May (Flower', 1932; Zuckerman, 1953; Lobanov and Treus, 1971). Fourteen mature females collected in New Mexico during the late autumn of 1957 had a total of 17 embryos (1.2 per female); the ratio was 1.6 embryos per female for seven mature females taken in the late winter of 1959 (Ogren, 1965:60). Of 67 females shot during the first eight hunts in Palo Duro Canyon, Texas, 44 (65.6%) were pregnant with 57 fetuses (1.3 per female). One female had triplets, 14 had twins, and 29 contained single fetuses (DeArment, 1971). Fetal sex ratio was 19 males:21 females, with 17 unknowns.

Twins are produced once in every six or seven births under conditions of confinement (Zuckerman, 1953; Blunt, 1963). The sex ratio at parturition is unity and birth weights average 4.5 kg (Blunt, 1963). The neonate is precocial and able to negotiate moderately rugged terrain almost immediately after birth (Ogren, 1965:69). Concurrent lactation and gravidity indicates that lactation overlaps the estrus cycle in some females.

Age of puberty is variable. Ogren (1965:65) found sperm in an ll-month-old male, but not in a 15-month-old male, and a known-age female produced an offspring when only 13 months 12 days of age (Blunt, 1963). On two known occasions a female has produced offspring twice in less than 7 months, and one had three single births within 13 months 4 days (Blunt, 1963). Ogren (1965:59) regarded all females at least 19 months old as being sexually mature.

Dental maturity is apparently achieved rather late. Irruption of the permanent C₁, an incisiform canine, was observed at 65 and 68 months in two known-age animals (Ogren, 1965:31). Longevity has exceeded 20 years in zoos (Ogren, 1965:6), but longevity in the wild probably rarely exceeds 10 years.

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Although Gray (1954:60) indicated that no live births resulting from matings of <u>Ammotragus</u> males to female domestic goats (<u>Capra hircus</u>) had been produced, a viable female from this mating combination was reported by Petzsch (1957a, 1957b) and this hybrid was successfully backcrossed to a Barbary sheep male. Brentjes (1968) suggested that this provides a possible interpretation for the presence of goatlike animals in ancient Egyptian pictographs, and that such hybrids may have been relatively common because of the wide geographic distribution of Barbary sheep.

Ecology

This species inhabits arid and semiarid lands from sea level to at least 945 m in elevation within its endemic North African range (Rothschild, 1921:75) and canyonlands with gorges to 305 m deep at elevations up to 1,829 m in the southwestern United States (Ogren, 1965:10). Habitat utilization is greatest in areas of precipitous topography (Evans, 1967a; Hampy, 1978).

The major spring food plant in New Mexico is mountain mahogany, <u>Cercocarpus montanus</u> var. <u>breviflorus</u> (54.3% rumen content by volume), followed by grasses (25%), forbs (13.8%), and other browse (5.6%). Trace foods totalled 1.3 percent. Summer foods included mountain mahogany (31.5%), wavyleaf oak, <u>Quercus undulata</u> (30%), grasses (26%), forbs (8.8%), and

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other browse (3%). The autumn diet featured wavyleaf oak (54.3%), grasses (29%), forbs (12.4%), and other browse (4.1%); whereas the principal winter food category was grass (86%) supplemented by small amounts of browse (10.9%) and forbs (2.4%) (Ogren, 1962, 1965). Mountain mahogany and wavyleaf oak accounted for half the food volume of 79 plants identified. An analysis of stomach contents from 109 animals collected in late autumn or early winter hunting seasons in Palo Duro Canyon, Texas, from 1963 through 1970 (DeArment, 1971) revealed the following woody plants to be important dietary components during this season: sand shinney oak, Quercus havardii (contained in 66.9% of the stomachs), honey mesquite, Prosopis glandulosa (53.2%), yucca, Yucca angustifolia (24.9%), mountain mahogany, Cercocarpus montanus (33.9%), juniper, Juniperus sp. (24.8%), netleaf hackberry, Celtis reticulata (13.8%), and black willow, Salix nigra (13.8%). Principal forbs were western ragweed, Ambrosia psilostachya (13.8%) and buffalobur, Solanum rostratum (10.1%); and grasses, little bluestem, Schizachyrium scoparius (18.4%), silver bluestem, Bothriochloa saccharoides (15.6%), and blue grama, Bouteloua gracilis (14.7%). Research in progress at Palo Duro Canyon, based primarily on fecal pellet analysis, suggests that woody browse is the most important forage class in the spring (53% relative frequency), summer (68%), and autumn (48%), whereas browse (42%) and grass

(43%) are equally important during winter months (Simpson et al., 1978). Forbs were the preferred forage of a tame animal whose food habits were observed on the Edwards Plateau of Texas (Ramsey and Anderegg, 1972).

A few animals from an introduction at Palo Duro Canyon, Texas, dispersed up to 32.3 km (20 miles) from the release site within 5 to 7 months (DeArment, 1971). The home range of radio-collared adults in Palo Duro Canyon (Hampy, 1978) was 0.98 km² (0.38 miles²) and 2.64 km² (1.02 miles²) for one male during the winter as determined by minimum home range (MHR) and topographic home range (THR) methods, respectively. Summer MHR size was 19.26 km² (7.44 miles²) and summer THR was 30.85 km² (11.91 miles²). Two adult females exhibited a mean winter MHR of 2.09 km² (0.81 miles²) and THR of 4.57 km² (1.76 miles²); and these two plus one additional female had a mean summer MHR of 12.98 km² (5.01 miles²) and THR of 16.69 km² (6.44 miles²). Abrupt seasonal movements of as much as 23.4 airline km (14.5 miles) also were observed.

Interspecific competition has not been documented but it is likely that <u>Ammotragus</u> would have an advantage over most other ungulates in regions where such interactions are possible. Concern has been expressed for the future of the desert bighorn sheep (<u>Ovis canadensis</u>) in the southwestern United States should Barbary sheep invade much of the desert bighorn's range (Barrett, 1967b; Simpson et al., 1978). Predation does not have a significant impact upon populations within its exotic range (Ogren, 1965:69; DeArment, 1971:15).

Thirteen helminth parasite species were reported from two Barbary sheep (Allen et al., 1956), and 17 helminth species were recovered from seven host animals (Allen, 1960), all collected in New Mexico. Experimental cross-transmission of the abomasal worm, <u>Haemonchus</u>, suggested that the strain from wild Barbary sheep is less pathogenic than the strain from domestic sheep (Allen et al., 1958; Samson et al., 1964). A louse, <u>Bovicola neglecta</u>, described from zoo animals is apparently host-specific for <u>Ammotragus</u> (Kéler, 1942:77; Werneck, 1950:81). A new species of louse recovered from free-ranging Barbary sheep in Palo Duro Canyon, Texas, was named <u>Bovicola fulva</u> by Emerson and Price (1979). The winter tick (<u>Dermacentor albipictus</u>) also was taken from New Mexico hosts (Allen et al., 1956; Allen, 1960).

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Five of seven adult males from New Mexico showed positive reactors to the agar precipitin test for bluetongue (BT) (Trainer and Jochim, 1969); and serologic reactors to infectious bovine rhinotracheitis (IBR), BT, and epizootic hemorrhagic disease (EHD) were found in three, six, and three individuals, respectively, of 12 from the Palo Duro Canyon population (Hampy et al., 1979). Fifteen fatal cases of mycoplamosis were recorded from Barbary sheep in the Frankfurt

Zoo (Brack, 1966; Ernø et al., 1972). Naturally occurring coronary and aortic atherosclerosis was discovered during necropsies of two adults that died at the St. Louis Zoo (Wallach and Middleton, 1970), and the lesions were more extensive than those reported to be naturally occurring in most other species. Seven animals died of Johne's disease, paratuberculosis (causative agent <u>Mycobacterium paratuberculosis</u>), also at the St. Louis Zoo, and two additional infected animals were euthanized (Boever, 1976).

Increasing numbers of people, improved transportation, the development of Saharan oil and mineral resources, and constant hunting pressure by some native tribes suggest that North African Barbary sheep population levels will continue to decline. Indeed, the Egyptian subspecies, <u>A. 1</u>. <u>ornata</u>, may already be extinct (Heinemann, 1972:493).

Nomadic peoples of the Sahara have depended on Barbary sheep for meat, hide, hair, sinews, and horns, and this species was considered to be of greater value to the economy of the Ahaggar Tuareg than other types of game (Nicolaisen, 1963:157). In the southwestern United States the species is important to the economy of game ranches, which produce animals for commercialized sport hunting (Schreiner, 1968; Teer, 1975). Wild populations in New Mexico and Texas provide challenging hunting opportunities rarely equaled by other big game, and supplement ranchers' incomes through the sale of hunting trespass rights, guide services, and use of camp facilities.

Traditional hunting and capture methods feature spears, stalking, disguises, artificial blinds or hides, use of dogs, running down with camels, and traps of the wheel or torsion type (Nicolaisen, 1963:158). In Texas, Barbary sheep have been roped with a lasso from a moving truck, driven into a net stretched across a game escape trail or immobilized when struck by a drug-containing syringe dart fired from a Cap Chur gun out of a helicopter while in flight (Hampy, 1978). The most successful censuses have been accomplished using helicopters, although several population parameters can be estimated from repeated observation of groups at aggregation sites.

Behavior

Stable dominant-subordinate relationships existed between all members of the herd at the New York Zoological Park (Katz, 1949), and the social hierarchy was one of linear descent through males, females, and juveniles. The dominance status among juveniles seemed to be determined by the strength of the pair bond between a juvenile and its mother, as reflected by the social distance between them. As the pair bond disappears, the dominance status of a juvenile establishes itself in its peer group. Group

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leadership was not related to dominance status, and the leader was always an adult female. Males were more timid than females when confronted with novel or potentially dangerous situations, and their following of females under such circumstances may partially reflect the conditioning of following females during conflict situations associated with the rutting season. A feed box experiment indicated differences in social distance between various pairs of males, reflected in the extent of food sharing and number of aggressive interactions.

The intraspecific threat posture consists of turning the head so the horns are directed toward a conspecific (Hamdy and Schmidt, 1972). An alpha male also may intimidate conspecifics by raising the fringe hair over the withers, licking his muzzle, and uttering a low gutteral growl. Intraspecific aggressive behavior is typically ritualized and of two major types (Katz, 1949; Haas, 1959; Schaffer and Reed, 1972:12). One, the head-on charge, is ordinarily confined to interactions between males and may feature a closing velocity up to 81 km/h (50 mph) (Schaffer, 1968), with both animals remaining quadrupedal on impact. The other involves close butting and head shoving, or hooking the horns, neck, flank, or belly of the conspecific from a parallel position, followed by twisting or gouging motions. The torque caused by such rotational movements has probably contributed to

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adaptive selection for musculature that resists rotation of the head (Schaffer, 1968), producing disproportionate development of the neck and forequarters in males. Fighting of both types was also common among females, but rarely involved charging an adversary. Displaced aggression was common, frequently continued chain-wise to other individuals, and was influenced by physical proximity and lower social status of recipients (Katz, 1949).

Females defend against suitors during anestrus and are adept at striking them with their horns whether or not a male has mounted (Ogren, 1965:67). Proestrus females appear to excite males, which feed and ruminate less, sniff or lick at female urine puddles and genitalia, and exhibit the typical bovid flehman (graphically pictured in Davis, 1974:262). Sexually aroused males may squat to urinate in a female pos- \odot ture rather than the usual erect or forward-leaning stance, \odot extrude and lick the penis, try to segregate a female by herding actions, and attempt mounting (Katz, 1949; Ogren, 1965:68). During estrus females sometimes lick the sides of a male, and mutual touching of muzzles is frequent. Copula-(')tion is accomplished by mounting, followed by several rapid thrusts, either immediately or several minutes after mounting, and is accompanied by male growls (Ogren, 1965:68). Copulation may be repeated up to 20 minutes later.

Juveniles exhibit a number of recognizable elements of aggressive and sexual behaviors, as well as typical maintenance and comfort postures (Haas, 1959), but these are frequently displayed in inappropriate contexts. Thus the ontogeny of behavior in this species may consist of rearranging many rather elaborate innate patterns into appropriate sequences, rather than a slow development or abrupt emergence of these patterns. Temporal periodicity in behavior embraces fairly regular cycles of alternating activity and rest within the daily regime of herd behavior (Katz, 1949; Haas, 1959; Solbert, 1980), as well as distinctive changes in seasonal patterns (Katz, 1949; Haas, 1959; Johnston, 1980; Solbert, 1980).

Genetics

This species has a karyotype of 2N = 58, FN = 60, composed of one pair of biarmed and 27 pairs of acrocentric autosomes, a large acrocentric X chromosome and a minute biarmed Y chromosome (Nadler et al., 1974). This karyotype is identical in general structure with that of <u>Ovis vignei</u>. The G-band pattern of the biarmed chromosome was indistinguishable from the largest biarmed autosomal pair (pair I) of <u>O</u>. <u>musimon</u>, <u>O</u>. <u>orientalis</u>, <u>O</u>. <u>canadensis</u>, and <u>O</u>. <u>musimon</u> X <u>O</u>. <u>canadensis</u> F_1 and F_2 hybrids. Among the acrocentric chromosomes of <u>Ammotragus</u> were pairs with G-band patterns resembling those seen in biarmed pairs II and III of 2N = 54 wild and domestic sheep. Buckland and Evans (1978a)

reported that, with the exception of a single Robertsonian translocation, the G-band pattern is the same as the goat karyotype, and there is virtually no demonstrable centromeric heterochromatin (Buckland and Evans, 1978b). Karyotypes were published by Heck at al. (1968), Schmitt and Ulbrich (1968), and Nadler et al. (1974).

The F_1 hybrid from a natural breeding of a male with a female domestic goat, <u>Capra hircus</u> (2N = 60), was a 2N = 59 female with a karyotype containing one unpaired metacentric, two unpaired and 27 paired acrocentric autosomes, and two large acrocentric X's (Bunch et al., 1977). The phenotype incorporated features from both species.

Several studies intended to clarify the phylogenetic relationship of <u>Ammotragus</u> to the other Caprini may have only intensified the controversy. Serum protein analyses by Schmitt (1963) and immunoglobulin cross-reactivity studies by Curtain and Fudenberg (1973) indicated a close relationship between <u>Ammotragus</u> and <u>Ovis</u>. The amino acid sequence of various hemoglobin chains examined by Manwell and Baker (1975) showed that <u>Ammotragus</u> hemoglobin more closely resembled that from the domestic goat than that from the domestic sheep, but also exhibited some unique characteristics. But an immunological technique adapted for computer analysis by Hight and Nadler (1976) demonstrated

a closer relationship between <u>Ovis</u> and <u>Capra</u> than between either of these and Ammotragus.

Remarks

<u>Ammotragus</u> may have shared the epithet, Ophion, with <u>Ovis ammon</u> in ancient accounts by Pliny and others (Cuvier, 1827:359). The species was called Tragelaphus by Caius in 1561 (Cuvier, 1827:319; Scortecci, 1957:492), and Lerwee or Fishtall by Shaw (1738). Fishtall may derive from <u>fesh</u>, bristles or mane, and <u>tall</u>, long, hence long mane; or from <u>vehsh</u>, a desert, and <u>tall</u>, wanderer (Cuvier, 1827:320). Common native appelations include aoudad (Mauretania), kebsh (Egypt), and beddan (males only) or tedal/teytal (Nubia) (Blyth, 1839:76).

A succession of generic or subgeneric reassignments, which do not properly belong in the synonomy, may have contributed to confusion about the taxonomy of this species. This nomenclature is included here for the convenience of interested persons.

Ovis (Ammotragus) tragelaphus Blyth, 1840:13. Ammotragus tragelaphus Gray, 1850:40. <u>Musimon tragelaphus</u> Gervais, 1855:192. <u>Aries tragelaphus</u> Lataste, 1887:35. <u>Ovis (Ammotragus) lervia</u> Lydekker, 1898:226. Ovis lervia Anderson and de Winton, 1902:334. Because Barbary sheep sometimes sire live hybrid offspring when bred to goats, and appear to be closer to goats in gross anatomical characteristics, Ansell (1971) and Corbet (1978) have placed Barbary sheep in the genus <u>Capra</u>. I demur from this assignment because the phylogenetic relationships are ambiguous, as noted in the section on genetics.

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CHAPTER III

STUDY AREA DESCRIPTION

Palo Duro Canyon is a major physiographic feature of the Llano Estacado, the Staked (or perhaps, Stockaded) Plain (Griggs, 1978:12), which comprises approximately 51,800 km² (20,000 miles²) of west Texas and eastern New Mexico in a region bounded on the west and south by the Pecos River valley, on the north by the Canadian River, and on the east by the Caprock escarpment (Matthews, 1969; Hood and Underwood, 1978) (Fig. 3). The Canyon is a winding and irregular reentrant gorge, about 97 by 32 km (60 by 20 miles), cut into the escarpment of the eastern High Plains by the erosive action of the Prairie Dog Town Fork of the Red River supplemented by weathering and the gravitationally propelled forces of creep, debris flow, slump, rock slide, and piping.

The steep bluffs of the Caprock escarpment that form the canyon walls are 183 to 244 m (600 to 800 feet) high and expose four major strata -- the interbedded red siltstone, shale and sandstone of the Permian Quartermaster formation forming the floor and lower canyon walls, overlaid by variegated shale and sandstone of the Triassic Tecovas formation, which is overlaid in turn by course, massive quartz sandstone and conglomerates representing the Trujillo formation, and capped by Tertiary Ogallala gravel, caliche, sandstone



Fig. 3. Map showing the Llano Estacado (stippled area) of West Texas and eastern New Mexico, and the location of the study area (dot) in the central Texas Panhandle.

and limestone (Matthews, 1969; Hood and Underwood, 1978). Rocks of the Cloud Chief Gypsum stratum at the canyon head are about 240 million years old but the canyon itself is thought to be less than one million years old. Erosion resistant formations throughout the canyon have been preserved as mesas, ledges, benches, ridge fingers, and hoodoos.

The climate of the northern Llano Estacado, summarized by Wendorf (1975), is characterized by hot summers, cold dry winters, irregular precipitation, and almost constant wind. Amarillo climatological data (U.S. Department of Commerce, 1978) show a mean annual temperature and precipitation of 14.1 C (57.4°F) and 515.1 mm (20.28 inches), respectively. Mean monthly temperatures are most extreme in January (2.2 C, 36° F) and July (25.9 C, 78.7° F), and precipitation means are most extreme in November (13.5 mm, 0.53 inches) and June (87.6 mm, 3.45 inches). Mean annual wind speed is 22 km/h (13.7 mph). The mean dates of last spring and first autumn frosts are 20 April and 28 October, respectively, allowing an average of 190 frost-free days. Class A pan evaporation is 2540 mm (100 inches) (Wright, 1978). The effectiveness of precipitation is considerably diminished by the combination of low relative humidity with high wind velocity and summer temperature, so that the soil is not wetted below a depth of 50.8 - 76 mm (2 - 3 inches)in most years (Lotspeich and Coover, 1962).

The surface of the Llano Estacado is essentially flat but punctuated by a few stream beds and thousands of small playa lakes. Soils are mainly eolian, originating in the Pecos Valley of New Mexico and deposited by southwesterly winds during the Pleistocene (Lotspeich and Coover, 1962; Lotspeich and Everhart, 1962). The differential settling of soil material of varying densities produced a gradient across the region with sandy soils in the southwest grading to silty clay loam and clay loam soils in the northeast. The most pronounced topographic relief is furnished by the eastern escarpment and associated reentrant canyons.

Five range sites were delineated by the U.S. Department of Agriculture, Soil Conservation Service (SCS) on the Dry Creek study area (34° 58' N., 101° 31' W.) which is situated along the northern rim, 38 km (23.6 miles) southeast of Amarillo in Armstrong County (Fig. 4), at an elevation of 1,048 m (3,438 feet). These range sites correspond to horizontal belts on a vertical rim-to-floor transect. Each site is characterized by a distinctive combination of geological strata, soil types and topography, and the vegetation reflects this diversity along with differences due to slope aspect.

The Deep Hardland of the High Plain above the canyon is nearly level and fertile with moderately deep clay loam or silty clay loam soil (Jacquot et al., 1965). Short



Fig. 4. Map of the Dry Creek study area in Palo Duro Canyon showing the location of the standard observation route (SOR). The area covered by the aerial censuses is enclosed by the upper contour line and the bottom border of the map.

grasses predominate, including such climax decreasers as blue grama, vine mesquite (<u>Panicum obtusum</u>), western wheatgrass (<u>Agropyron smithii</u>), and sideoats grama (<u>Bouteloua curti-</u> <u>pendula</u>), and increasers like buffalograss (<u>Buchloe dacty-</u> <u>loides</u>) and silver bluestem. Forbs include common sunflower (<u>Helianthus annuus</u>), blueweed sunflower (<u>H. ciliaris</u>), silverleaf nightshade (<u>Solanum elaeagnifolium</u>), buffalobur, and prairie coneflower (<u>Ratibida columnaris</u>), along with such woody species as honey mesquite, cactus (<u>Opuntia spp.</u>), and yucca (Yucca spp.).

A Mixed Land Slope, just below the High Plain, abuts the canyon rim. Sandy loam soils here are variable in depth and fertility is low. Grasses again dominate the climax vegetation, including sideoats grama and little bluestem, with some sand bluestem (<u>Andropogon hallii</u>) and Canada wildrye (<u>Elymus canadensis</u>); increasers include blue grama, hairy grama (<u>Bouteloua hirsuta</u>), and silver bluestem. Yucca, juniper, mountain mahogany, and sand shinnery oak are also present.

The Rough Breaks of the canyon wall and bluffs below the rim consist of nearly vertical caliche, gypsum, and sandstone escarpments. Soil material is mostly calcareous, partly weathered sediments from the High Plain. Many areas are nearly bare, but most of the plants present are decreasers -- sand bluestem, little bluestem, sideoats grama, blue grama, black grama (<u>Bouteloua</u> <u>eriopoda</u>), and scattered forbs -- due to the inaccessibility of the site to domestic livestock.

The Shallow Redland of the canyon floor is gently sloping to rolling, with clay loam and fine sandy loam soils, which are generally shallow and punctuated by outcrops of sandstone and shale. Climax decreasers make up most of the vegetation, including sand bluestem, little bluestem, Indiangrass (<u>Sorghastrum nutans</u>), switchgrass (<u>Panicum virgatum</u>), and needle-and-thread (<u>Stipa comata</u>). Increasers are black and hairy grama, buffalograss, silver bluestem, and threeawns (<u>Aristida</u> sp.), whereas mesquite and juniper are invaders.

The Bottomlands, composed of loamy alluvial deposits, occur in draws and along stream beds on the canyon floor. Switchgrass and inland saltgrass (<u>Distichlis spicata</u>), numerous forbs, sedges (<u>Carex sp.</u>), horsetail (<u>Equisetum laeviga-</u> <u>tum</u>), and occasional cottonwood trees (<u>Populus deltoides</u>) typify the vegetation in these areas.

Wright (1978) traced the development of the flora of this region, Rowell (1967) inventoried the vegetation of the Texas Panhandle and South Plains, and Hampy (1978) surveyed plants on the Dry Creek study area.

CHAPTER IV

CRITERIA FOR AGE AND SEX DETERMINATION

Two methodologies were developed for determining the age and/or sex of Barbary sheep. The first was developed in order to be able to identify age and sex classes in the field without handling animals or even approaching them closely. The second involved an examination of the relationship of horn growth to age, and requires that specimens be examined for the purpose of counting horn growth checks and measuring horn lengths.

As Walther (1973) indicated, it is frequently unnecessary for the wildlife researcher studying ecological or ethological problems in the field to determine the precise age of an animal. However, distinguishing between sexes, and the recognition of some age classes, can be important. Nine age-sex classes are defined here as a prerequisite to investigations of population dynamics and behavior of unmarked free-ranging Barbary sheep.

Bovid horn growth is continuous throughout life, but the rate of growth varies, producing periodic tranverse ridges or growth checks, possibly in response to a drastic reduction or temporary cessation of linear horn growth dur-/ ing the autumn or winter rut (Cowan, 1940). These growth checks, or annuli, have been used as an age criterion for

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Rocky mountain goat (<u>Oreamnos americanus</u>) (Brandborg, 1955), European bouquetin (<u>Capra aegagrus</u>) (Couturier, 1961), bighorn sheep (<u>Ovis canadensis</u>) (Taylor, 1962; Geist, 1966b), Dall sheep (<u>Ovis dalli</u>) (Hemming, 1969), Himalayan thar (<u>Hemitragus jemlahicus</u>) (Caughley, 1965), and African tragelaphines (Simpson, 1972). Simpson (1971) suggested that many African antelopes showed a submature and a post-mature growth form, but this pattern is not apparent in Barbary sheep. Ogren (1962:91, 1965:50) presented data that suggest horn growth checks can be used for aging purposes in this species. The present study included a further examination of the applicability of this technique to Barbary sheep, measured the mean growth -- or expected horn increment -- for different aged animals, and investigated the suitability of estimating age from horn length.

Methods

Field Identification of Age-Sex Classes

Barbary sheep sightings during a preliminary reconnaissance of the study area, 22 July - 23 August 1976, and during the initial phase of fieldwork, February through April 1977, provided the basis for establishing age-sex classes from observed physical and behavioral characteristics. Observations were aided by 8X, 40 mm binoculars and a 15-60X, 60 mm spotting scope, and complemented by examination and measurement of hunter-shot animals brought into private hunting camps, trophy head mounts, and skulls with horns intact. Ear length appeared to be constant between sexes and among animals of various sizes, and a <u>t</u>-test was used to evaluate this feature as a constant for estimating horn lengths of animals observed through binoculars or spotting scope.

Horn Growth and Aging

The allometric growth of Barbary sheep horns was examined in a sample of 24 males and 18 females, including hunter-shot animals, trophy head mounts, and skulls with horns intact. Total horn length was measured from the proximal tip of the horn sheath, along the flat frontal surface, and around the outer circumference of the curve to the point. Distances between successive growth checks were measured along the keeled inner arc of the horn sheath because growth checks were magnified along this shorter circumference, which facilitated identification of check midpoints and minimized problems associated with abrasion on the frontal horn surface. Estimated age, based on the number of growth checks (assuming spring parturition and the production of one growth check each autumn; Ogren, 1962:91, 1965:50), was designated the dependent variable and regressed against independent variables of cumulative horn growth at each

successive growth check and total horn length. A least squares regression analysis performed by a Statistical Analysis System (SAS) program (Barr et al., 1976) on the IBM 370 computer at the Texas Tech University Computer Center was used to evaluate null hypotheses (H_0) of no significant relationship between estimated age and cumulative horn growth at successive growth checks or total horn length. Null hypotheses were rejected for values of $\alpha < 0.05$.

Results

Field Identification of Age-Sex Classes

Intraspecific differences leading to definitions of age-sex classes were established from sightings of 12 groups composed of 75 animals (mean = 6.3, range = 1 - 19) during the preliminary study area reconnaissance, observation and comparison of 1,374 individuals comprising 72 groups (mean = 19.1, range = 1 - 69) from a vehicular blind in a field adjacent to the canyon during 48 observation hours in the first three months of fieldwork, and sightings of 64 groups totalling 629 animals (mean = 9.8, range = 1 - 43) from a standard observation route (SOR) along the canyon rim during 173 hours of search observations also conducted in the initial phase of fieldwork. These observations were complemented by examination and measurement of 45 specimens (26 males, 19 females). Ogren's (1962:96, 98, 1965:46, 48) data suggest that adult ear length is achieved by juveniles as young as 3.5 months of age, and my measurements indicated no difference between sexes (T = 0.212; \pm .05, 11 = 2.201), so ear length was adopted as a basis for estimating horn lengths of animals observed through binoculars or spotting scope.

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Differentiation of age-sex classes was based upon combinations of sexually dimorphic physical and behavioral characteristics, and age-related variation in body size, and morphological and configuration as noted below.

Young juvenile (Fig. 5a). Animals in this class were not separated by sex for the purposes of this study although Solbert (1977) stated that it is possible to sex them behaviorally from urination posture. Young juveniles are readily recognizable by their small size, generally equal to or less than 711 mm (28 inches) in height at the withers, although this may vary somewhat depending upon season of parturition, range conditions, and sex of the individual. The definitive characteristic is horn length less than ear length, and the age range for members of this class is birth to about 4.5 months.

Older juvenile (Fig. 5b). The members of this class were likewise not segregated by sex. Older juveniles are still distinctly smaller than the older groups, and withers height varies from about 667 mm (26.25 inches) to 787 mm



Fig. 5. Relative horn sizes for young juvenile, older juvenile, and subadult age classes of Barbary sheep which were not differentiated by sex, and for two age classes of adult females. Drawings by Dr. C. David Simpson.

(31 inches) for the same reasons indicated above. The key character is horn length equal to or greater than ear length, but less than two times ear length. Members of this class range in age from about 4.5 to 8 months.

<u>Subadult</u> (Fig. 5c). Again, the individuals in this category were not divided by sex although dimorphic qualities of body size and proportion, some of which began to be evident in older juveniles, are more apparent at this stage. These include a somewhat larger size, stockier build (particularly in the forequarters), and a slightly sloping top line, all attributes of males. Horn length is from two times ear length to about 305 mm (12 inches), or three times ear length. Subadults are obviously larger and older than juveniles but lack the mature size and fullness of body exhibited by adults, and individuals in this class can frequently be categorized by their intermediate appearance. Ages range from about 3 to 15 months.

Males are distinguished from females by the following sexually dimorphic characteristics:

1. Horns are more massive in males than females. Horn measurements from 25 males and 19 females showed that basal circumference (male mean = 303.1 mm versus female mean = 208.4 mm, T = 9.293; $\pm_{.05, 40}$ = 2.021), horn volume (male mean = 1,719.1 cm³ versus female mean = 559.4 cm³, T = 8.39; $\pm_{.05, 40}$ = 2.021), and maximum horn spread (male mean =

618.8 mm versus female mean = 517.4 mm, T = 3.764; $\pm .05$, 40 = 2.021) are all greater in males than females and the experienced field observer ordinarily can distinguish between sexes based on horn size, particularly when other differences are noted.

². The distance between female horn bases appears to be greater than in males despite the fact that the female skull is narrower and smaller.

3. Withers prominence, or dorsal scapular protrusion, is greater in males than_females.

 Mane and chap hair is thicker and more abundant on males than females.

5. Relative abdominal dorsal-ventral depth is greater in females than males; that is, males have a definite belly tuck up, even when compared with nulliparous females.

6. Females assume a squatting urination posture whereas () males normally urinate from an erect or forward-leaning () stance, although sexually aroused males sometimes squat.

7. Adult males try to segregate estrus females by herding actions, but females were never observed to herd even their own young.

8. Mounting attempts by sexually aroused members of both sexes were observed during autumn ruts, so mounting behavior should not be regarded as a reliable male indicator. Given these dimorphic features for differentiating between sexes, age classes within each sex are defined by horn size.

Female class 1 (Fig. 5d). Younger adult females are defined by horn lengths greater than 305 mm (12 inches) but less than 406 mm (16 inches). Field data from Palo Duro Canyon suggest that a female horn length of 406 mm is achieved at about 30 to 36 months, so females of this class are probably 15 months to 3 years of age.

Female class 2 (Fig. 5e). Females with horns longer than 406 mm (16 inches) are assigned to this older class. Although Evans (1967) recorded a female with horns 679 mm (26.75 inches) long, and I measured two with horns over 559 mm (22 inches), female horn length does not ordinarily exceed 508 mm (20 inches). Females in this class are more than 3 years of age.

Larger class 2 females, particularly those bearing titanic horns, can be easily confused with males of class 1. The male profile anterior to the withers tends to dip below an imaginary extension of the topline, producing a pronounced declivity between the neck and withers; this appearance contrasts markedly with a rather even topline in females, interrupted by a modest dorsal withers projection, which serves as an additional guide to distinguishing between these two potentially confusing classes.

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<u>Male class 1</u> (Fig. 6). Males of class 1 have horn lengths between 305 mm (12 inches) and 508 mm (20 inches), and probably range in age from 15 months to about 2.5 or 3 years. Members of this class are sometimes mistaken for class 2 females, and the definition of that category includes a suggestion for separating these classes which can be used to supplement the sexually dimorphic physical and behavioral characteristics listed.

Male class 2 (Fig. 6). Members of this group possess horns ranging in length from 508 mm (20 inches) to 660 mm (26 inches) and are at least 2.5 years old.

Male class 3 (Fig. 6). This category is composed of males with horns 660 mm (26 inches) to 762 mm (30 inches) long. Field data indicate these animals are 3.5 to 6.5 years of age.

Male class 4 (Fig. 6). The largest trophy animals comprise this class, defined by horn lengths greater than 762 mm (30 inches). The largest New Mexico Barbary sheep reported by Ogren (1962:174) had the following dimensions: weight, 145 kg (320 pounds); girth, 1,372 mm (54 inches); shoulder height, 1,118 mm (44 inches); horn length, 838 mm (33 inches); and total length, 1,956 mm (77 inches).

The largest animal from Palo Duro Canyon that I handled during three hunting seasons was harvested in 1976 by John C. Patterson, Jr., Marlin, Texas, and measured, girth, 1,270 mm

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Fig. 6. Relative horn sizes for four age classes of adult male Barbary sheep. Drawings by Dr. C. David Simpson.

(50 inches); left and right horn lengths, 895 mm (35.25 inches) and 845 mm (33.25 inches), respectively, and left and right basal horn circumferences, 350 mm (13.78 inches) and 368 mm (14.49 inches), respectively.

Horn Growth and Aging

Age estimates, based upon horn growth check counts, proved to be highly correlated ($\alpha < 0.0001$) with cumulative horn growth both in males ($\ln \hat{A} = -1.93159 + 0.00742 \text{ C}, R =$ 0.965) and females ($\ln \hat{A} = -2.50184 + 0.01152 \text{ C}, R = 0.965$), where A is age in years and C is cumulative horn growth measured in millimeters between successive growth checks along the keeled inner arc of the horn sheath (Tables 1 and 2, Fig. 7).

Having verified a highly significant relationship between horn growth and age, it was possible to develop equations for predicting age from total horn length. The least squares equation for males is $\ln \hat{A} = 0.002143 \text{ L}$, where <u>A</u> is estimated age in years and <u>L</u> is total horn length in millimeters along the outer arc; this relationship is highly significant ($\alpha < 0.0001$) and accounted for 94.3 percent of the observed variation (\underline{r}^2). The equation for females, $\ln \hat{A} =$ 0.00282 L is also highly significant ($\alpha < 0.0001$) and explains 94.5 percent of the observed variation (\underline{r}^2). These relationships are shown in Figure 8.

arc of the horn sheaths of male Barbary sheep from Palo Duro Canyon, Texas TABLE 1.--Cumulative horn growth at successive growth checks along the keeled inner

				Annu	ilus or	growth c	heck num	ber ^a			
Statistic		1	C1	m	4	5	9	2	8	6	10
Sample size		28	27	26	22		11	5	2	7	1
Age (years) ^D		0.5	1.5	2.5	3.5	4.5	5.5	6.5	7.5	8.5	9.5
Mean annual increment	(unu)	184.9	118.4	77.0	52.5	36.1	25.1	17.4	10.8	6,0	
Standard										•	
deviation	(uuu)	20.2	14.8	14.3	8.4	6.7	3.9	2.2	1.1	I	I
Maximum	(unu)	219.0	144.5	108.0	70.0	54.5	30.5	20.0	11.5	ł	1
Minimum	(uu)	153.0	88.0	52.4	37.5	27.0	19.5	15.0	10.0	I	I
Mean cumulative											
growth	(unu)	184.0	305.3	381.3	432.9	464.8	476.0	499.9	523.5	508.5	514.0
Standard											
deviation	(unu)	20.2	21.4	28.5	34.2	35.2	35.7	30.5	33.2	1	I
1aximum	(um)	219.0	341.0	437.0	504.5	541.0	517.0	537.0	547.0	1	I
4inimum	(umu)	153.0	244.5	308.5	346.0	380.0	407.5	458.5	500.0	ı	I
^a The growth	check 1	nearest t	the horn	point is	number	1.					

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b Estimated from the number of growth checks assuming spring parturition and the production of one growth check each autumn (Ogren, 1962:91, 1965:50).

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inner arc of the horn sheaths of female Barbary sheep from Palo Duro TABLE 2.--Cumulative horn growth at successive growth checks along the keeled Canyon, Texas

				Annulu	is or grow	vth check	number ^a		
Statistic		1	2	3	4	5	9	7	8
Sample size		19	17	15	10	8	Ŀ	1	-
Age (years) ^b		0.5	1.5	2.5	3.5	4.5	5.5	6.5	7.5
Mean annual increment	(uu)	159.4	98.2	45.8	25.4	18.8	11.0	6.0	5.5
Standard deviation	(uu)	17.2	10.4	12.4	4.6	4.2	2.3	ı	i
Maximum	(uuu)	198.0	114.3	64.5	32.5	27.0	14.3	ł	I
Minimum	(uuu)	131.8	77.5	27.5	19.0	15.0	9.0	I	Ĩ
Mean cumulative growth	(um)	159.4	257.4	304.2	325.1	341.3	340.7	340.0	345.5
Standard deviation	(uu)	17.2	18.1	16.0	15.8	18.6	15.0	I	1
Maximum	(uuu)	198.0	297.0	327.0	345.0	364.5	358.5	I	ì
Minimum	(um)	131.8	226.5	279.5	292.1	309.6	323.9	I	I
ame, account	-1-040		-		-				

The growth check nearest the horn point is number 1.

b Estimated from the number of growth checks assuming spring parturition and the production of one growth check each autumn (Ogren, 1962:91, 1965:50). 51

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Fig. 7. Graphs showing the relationship between age and cumulative horn growth measured at successive growth checks along the keeled inner arc of horn sheaths of male (top) and female (bottom) Barbary sheep from Palo Duro Canyon, Texas.



Fig. 8. Graphs showing the relationship between age and total horn length measured along the outer arc of horn sheaths of male (top) and female (bottom) Barbary sheep from Palo Duro Canyon, Texas.

Discussion

Field Identification of Age-Sex Classes

There is undoubtedly some overlap in ages between adjacent classes, and the unconformity of ages with sizes in male classes 3 and 4 may be considerable due to such intrinsic and extrinsic factors as intraspecific genetic variability and changes in range condition from one year to the next. Poor range condition probably suppresses normal horn growth and one would expect the inhibiting effect to be most pronounced upon juveniles and subadults for which horn grown rates are normally high. This could produce smaller horns at maturity from cohorts exposed to unfavorable environmental conditions when young. Still, size discrimination can be justified for management reasons: larger animals bearing gargantuan horns are preferred hunter trophies and a knowledge of their proportion in the population may influence harvest regulations.

Walther (1973) and Kitchen (1974:11) described how unmarked Thomson's gazelle (<u>Gazella thomsoni</u>) and pronghorn were recognized from variation and individual pecularities in species markings. Barbary sheep exhibit no such patterns and I estimate that less than five percent of the individuals in a population could be recognized from abnormal marks or anomalous horn shapes.
It is not always possible or necessary to distinguish as many nine age-sex classes, depending upon research and/or management objectives and the experience of field personnel, but this study has verified the feasibility of the procedure and later sections validate its utility in investigating population dynamics and the behavior of unmarked animals.

Horn Growth and Aging

The relationship of linear body growth to age exhibited an exponential form in studies of the big brown bat (Eptesicus fuscus) and two chipmunks (Eutamias sp.) reported by Kunz (1974), and Hirshfeld and Bradley (1977), respectively. This exponential description also characterized fetal growth rates in several ungulate species (Robbins and Robbins, 1979), and belongs to a class of biological phenomena exemplified by the Weber-Fechner principal (Sokal and Rohlf, 1969:478; Guyton, 1971:395). That the relationship between age estimates derived from horn growth check counts and horn growth documented here follows this exponential growth pattern constitutes cogent corroboration of Ogren's (1962:91, 1965:50) data, which suggested that horn growth checks can be used to age Barbary sheep and implies that horn growth checks are true annuli in this species. This finding is particularly significant because the tooth cementum annuli technique apparently does not produce a reliable estimate of age for this species (T. Mattson, pers. comm. to C. D. Simpson, 1979)

Several techniques have been developed to estimate the age of bovids including tooth eruption and replacement, tooth cementum annuli, and horn growth checks, but apparently only Riney and Child (1964) have previously used horn length to estimate age. Although variability in the agehorn length relationship may be caused by intraspecfic variation within each sex and the effect of changing range conditions on horn growth, particularly in younger animals that normally display high horn growth rates, these equations indicate that total horn length measurements offer a good technique for estimating Barbary sheep age.

This method is also notable for its simplicity, and provides a means of estimating age that can be used 1) to supplement horn growth check counts, 2) when checks have been obscured by wear, and 3) by hunters and inexperienced wildlife management personnel who may find annulus identification confusing. The technique may also be applicable to other bovid species.

CHAPTER V

WEIGHT ESTIMATION FROM HORN LENGTH

The Barbary sheep is a formidable challenge for wildlife ecologists and hunters because of the precipitous terrain the species typically inhabits. This factor frequently makes transporting a whole or even a hog-dressed animal (all viscera removed but with head, hide, and feet intact; Giles, 1971:80) prohibitively difficult and suggests the need for estimating weight from a linear body measurement.

Linear body measurements have been used to estimate weights of domestic livestock (Ross, 1958, and references therein), African wildlife (Hall-Martin, 1977, and references therein), and North American big game (Blood and Lovass, 1966; McEwan and Wood, 1966; Smart et al., 1973; Rideout and Worthen, 1975). Equations developed by these workers predicted live or hog-dressed weight from body length, girth, or a combination of both measurements.

As Rideout and Worthen (1975) indicated, the weight of wild ungulates is more difficult to obtain than are linear measurements. Although linear body measurements have been used to estimate body weight of domestic and wild animals, no previous work was found where horn size was used as a weight estimator. This chapter describes regression equations developed to estimate hog-dressed weight of Barbary sheep from horn length.

Methods

Barbary sheep horn length and hog-dressed weight were among data collected by TP&WD personnel at hunter check stations operated near Palo Duro Canyon in the 1963 to 1970 seasons, except for 1967. The sample was composed of 81 males and 55 females (Evans, 1964, 1965, 1966, 1967a, 1968; Taft, 1969, 1970).

Measurements were made, in inches, from the proximal tip of the horn sheath, along the flat frontal surface, and around the outer circumference of the curve to the point. Weights were recorded to the nearest pound. A regression analysis of these data was performed on the IBM 370 computer at the Texas Tech University Computer Center using a SAS Institute program (Barr et al., 1976). Calculations for 95 percent confidence bands on the regression lines were based on the procedure described by Anderson and Bancroft (1952:158).

Results

Preliminary graphical plots of the weight-horn length relationship indicated that separate linear regression equations were necessary for males and females. The equation for males is $\hat{W} = 7.12 \text{ H} - 9.62$ ($\underline{t} = 17.57$, 80 df, $\alpha < 0.0001$), where W is hog-dressed weight in pounds and H is

horn length in inches; this relationship accounted for 79.6 percent of the observed variation (\underline{r}^2) . The equation for females, $\underline{\hat{W}} = 4.43 \ \underline{H} + 18.86 \ (\underline{t} = 6.21, 54 \ df, \alpha < 0.001)$, explained about 42 percent of the observed variation (\underline{r}^2) . Regression lines and 95 percent confidence bands are shown in Figure 9.

Discussion

Sources of variation in the weight-horn length relationship probably include variability in body weight due to age, condition (including the effects of tooth wear, disease, and' parasitism), differences in range condition from year to year, intraspecific variation in weight and horn length among members of a given sex and year cohort, and pregnancy in females. Poor range condition also may suppress normal horn growth, and one would expect such an inhibiting effect to be differential for the various year classes and most pronounced upon juveniles and subadults for which horn growth rates are normally high. This could produce smaller horns at maturity from cohorts exposed to detrimental environmental conditions when young, although Bunnell (1978) found that growth of later horn increments was inversely related to growth of early increments in Dall sheep.

The substantially lower correlation coefficient (\underline{r}) for the weight-horn length relationship in females (0.649) than



Fig. 9. Graphs showing the relationship between hogdressed weight and total horn length of female (top) and male (bottom) Barbary sheep from Palo Duro Canyon, Texas. in males (0.892) supports my field observations that the body size-horn length relationship appears more variable in females than males. Nutritional stress imposed by pregnancy and lactation, particularly upon a segment of the female population that reaches puberty as a juvenile (Blunt, 1963), is an additional source of variation in the relationship under consideration. This greater variability in the weighthorn length association among females diminishes the predictive value of the equation for this sex. Still, the correlation is good considering the multiplicity, magnitude, and possibilities for interaction of the factors contributing to this variability.

The target of keen hunter interest is invariably prodigiously horned males, and males, therefore, provide a greater source of data for the field biologist; thus it is particularly desirable that the equation for males be a good estimator of weight. Considering the vagaries of field data collection over a period of seven hunting seasons, a correlation coefficient (\underline{r}) of 0.892 for males suggests that this objective essentially has been achieved.

The possibility of expanding the application of this technique to other bovids is reinforced by Nievergelt (1966), who suggested a relationship between horn growth and body weight in the alpine ibex (<u>Capra ibex</u>). Bunnell (1978) asserted that no such relationship exists in Dall sheep. A

horn length-body weight relationship may indeed exist for Dall sheep, but may have been masked in that study by apparent peculiarities of data analysis and a confounding element introduced by the behavior of this ungulate. First, the number of animals from which weights were recorded, 10 rams and 15 ewes, may not be large enough to detect such a relationship given the sources of variation enumerated earlier in this discussion. Secondly, total horn growth from two to six years was regressed against body weight at age six to seven years; that is, data were examined for only what amounts to one year class. But even perfect correlation (r = 1), should it exist, could not be demonstrated for only one given year class of either sex because such correlation would approximate a single point plot. Measurements either from a sample of animals representing several year classes or from a cohort as it passes through several year classes would be necessary as a basis for inferring the extent to which the parameters are correlated. Thirdly, horn brooming in North American mountain sheep removes a variable and indeterminate amount of material from the horn point (which necessitates measuring from the first annulus), but it is during the first year of life -- at least part of which occurs before appearance of the first horn annulus -that the largest relative proportion of both horn and body growth takes place. So a proper regression analysis of

body weights against horn lengths measured from the first annulus is unlikely to produce correlation coefficients as high as those recorded here.

The equations developed here indicate that horn length can be a useful weight estimator and suggest investigating the applicability of this methodology to other bovids for which research and management needs are frustrated by comparable obstacles.

CHAPTER VI

POPULATION CHARACTERISTICS

There are three fundamental problems of population management--the conservation of a small or declining population, the removal of sustained yield harvests from a robust population, and the control of a population judged to be too dense or to have an unacceptably high rate of increase (Caughley, 1977:168). Thus, the goal of population analysis is the determination of essential population attributes so that the dynamics of the population can be delineated for these evaluative or management purposes.

The logistic and financial limitations of marking and monitoring an adequate number of elusive, cryptic, and highly mobile Barbary sheep presented formidable obstacles and were precluded by the scope of this study. It was, however, possible to estimate some parameters that reflect the current status of this population. Because the population has been subjected to yearly hunting since 1963, these statistics are not likely to be representative of conditions in an unexploited population. They should, however, provide a basis for comparison with hunted Barbary sheep populations elsewhere.

Methods

A consistent field procedure, intended to maximize sightings of free-ranging Barbary sheep in rugged terrain, was developed during a preliminary reconnaissance of the study area from 22 July to 23 August 1976. This was adopted for the detailed part of the study to permit comparisons of data organized on a monthly basis.

A field and adjacent pasture, which abut the canyon rim, were observed from a vehicular blind for one hour beginning at sunrise each field day, after which a standard observation route (SOR) was hiked following the northern canyon rim along an east to west arc. Search observations were made using 8X, 40 mm binoculars from fixed points on the rim and ridge fingers chosen for the visibility they afforded of adjacent ridge fingers, bluff faces, and the canyon floor. Direct observations from the blind and SOR occupied 1,246 hours on 271 field days from February 1977 through January 1979, except November 1978 when landowners felt that my presence would interfere with hunter activities. Observations from the blind and SOR averaged one and 3.6 hours each field day, respectively.

Supplementary data were collected during seven aerial censuses of the Dry Creek branch of Palo Duro Canyon (see Fig. 4), which comprises a map-projected area of approximately 65 km² (25.1 miles²). All flights were made in a

Bell 300-C helicopter, and the duration of each was about three hours.

Frequency of sightings, expressed as sightings per observation hour, was calculated for the study area based on ground surveys. Population density estimates and some composition data were derived from the aerial censuses.

Estimates of population structure were made at monthly intervals based upon a minimum number known to be alive (MNKA) concept (Krebs, 1966). This methodology involves direct enumeration and was used by Krebs to estimate population sizes of the California vole (<u>Microtus californicus</u>). The technique was used in the Palo Duro study although it is limited by an ecological uncertainty principle: the accuracy of the enumeration cannot be known without killing the entire population being studied.

The MNKA concept was adapted to my study in the following way. The largest number of animals in any age-sex category seen in one group during a field day was considered to be the number of that category present. Numbers within any given class were summed for each day only when animal location and activity made duplication unlikely. This procedure may have resulted in an underestimation of the number of animals present at one time, especially in those months where group sizes were small and sightings less frequent. Estimates produced by this method were, therefore, conservative.

Each month was treated as a single unit, and the largest daily total in each category for the month was recorded as the MNKA estimate for that segment of the population. The age structure and sex ratio estimates were determined from monthly MNKA population composition estimates.

Natality was expressed as the ratio of juveniles:100 adult females, and the distribution of birth months was based upon encounters with juveniles estimated to be less than onemonth-old.

Juvenile survival rate was estimated from the difference in the proportion of juveniles seen during successive aerial censuses conducted three months apart. The age distribution of adult males was smoothed by regressing age against population composition percentages (Caughley, 1977:36). This regression curve was then used to estimate the adult male survival rate using a procedure described by Henny et al. (1970). A comparable analysis was not possible for females because only two classes of adult females could be distinguished in the field.

Results and Discussion

Frequency of Sightings

Sighting frequency in this study was highest during the late winter and early spring months (Fig. 10). This undoubtedly reflects winter concentrations of large groups



Fig. 10. Frequency of Barbary sheep sightings from the standard observation route (SOR) (top) and from a blind in a field and pasture adjacent to the rim (bottom) in the Dry Creek branch of Palo Duro Canyon, from February 1977 through January 1979.

near fields of winter wheat along the canyon rim, including the field used for observation in this study. These winter concentrations resulted in a small mean winter home range of 1.71 km² (0.66 miles²) for Barbary sheep in the Dry Creek branch of Palo Duro Canyon (Hampy, 1978). By comparison, the mean winter home range was 9.62 km² (3.71 miles²) in the Three-Forks area of the Guadalupe Mountains in southeastern New Mexico (Dickinson and Simpson, 1980b) where no supplemental wheat was available. The winter home ranges in Palo Duro Canyon (Hampy, 1978) included the wheat field that I observed, and the presence of this supplementary food no doubt contributed to higher sighting frequencies during the winter months.

Subnormal precipitation during the late summer and autumn of 1977 delayed winter wheat growth and also probably reduced its palatability. Barbary sheep apparently dispersed from the study area, so the frequency of sightings from the SOR during much of 1978 was distinctly lower than the previous year. This suggests that the reduced availability of wheat during the winter of 1977-78 may have triggered dispersal, thus reducing population density in aggregation areas.

Dispersal and Movement

Reports by ranchers in the vicinities of the 1957-58 introduction sites suggested that most Barbary sheep remained

within about 16 km (10 miles) of release points for approximately two years following their release in Palo Duro Canyon (Wallace, 1959, 1960). Two sets of sightings, however, were documented by Wallace (1959, 1960) from as far away as 32 km (20 miles). One male and two females dispersed from the Briscoe County site on the Alfred Geisler Ranch immediately after their release, and several animals moved from the Armstrong County site on the Christian and Harrell ranches to an area 19.5 airline km (12.1 miles) south.

Subsequent dispersal to the west and north of animals released in Armstrong County was limited by the canyon head and high levels of human activity in Palo Duro State Park. As a consequence most movement was directed southward down the canyon. Dispersal of Barbary sheep from the more southerly Briscoe County site was toward more precipitous portions of the canyon to the north (Hudgins, 1962), so that the two groups converged.

Reliable reports have recently documented the species along the Caprock escarpment east of Lubbock (S. Edwards, pers. comm. to C. D. Simpson, 1979), an airline distance of about 98 km (60 miles) south of the Briscoe County release area. Barbary sheep have also been sighted along the Red River north of Vernon (J. Standridge, pers. comm., 1978), which is about 178 km (110 miles) east of the Briscoe County site. There is no indication of when Barbary sheep reached these areas or how much farther they may have dispersed.

The dispersal of Barbary sheep following their release in Palo Duro Canyon is similar to the pattern reported by Barrett (1980) for the dispersal of this species on the Hearst Ranch in central California. There, Barbary sheep were sighted 1.5 km (0.9 miles) east of the zoo enclosure soon after their escape in 1953. Within a year some animals had moved 14 km (8.7 miles). By 1964 Barbary sheep had been sighted up to 30 km (18.7 miles) north and 65 km (40.4 miles) south of the Hearst enclosure. Even greater movements may have occurred had no dispersing animals been shot, since Barbary sheep are not protected by a closed season or bag limit in California (Barrett, 1980).

Seasonal movements were documented for Barbary sheep in Palo Duro Canyon (Hampy, 1978). Three adult males and two adult females moved an average of 9.8 airline km (6.1 miles) and 14.3 airline km (8.9 miles), respectively, to locations outside their home ranges in the Dry Creek branch during October 1977. These movements were abrupt and appeared to be synchronous. Both females and one male returned to their Dry Creek home ranges within 10 to 17 days, after which the male moved 15.3 km (9.5 miles) to another location outside of Dry Creek. The other two males were never recorded in the Dry Creek branch during the subsequent six months Hampy was in the field.

Long distance movements by lone animals have been further substantiated by two New Mexico reports. One Barbary sheep was shot illegally 105 km (65 miles) east-northeast of Roswell, and another within 32 km (20 miles) of Hobbs. These records represent movements of about 129 airline km (80 miles) and 113 airline km (70 miles), respectively, from the closest rough terrain considered suitable for Barbary sheep (Simpson et al., 1978).

The reports of sightings collected by Dickinson and Simpson (1980a) from throughout southeastern New Mexico are also indicative of the long distances Barbary sheep traverse and the apparent randomness of dispersal direction. Both randomness and distance are consistent with characterizations of an innate dispersal tendency which is unrelated to population pressure (Caughley, 1977; Howard, 1960).

Population Range Extension

Dickinson and Simpson (1980a) recorded a phasic population range extension pattern for Barbary sheep in southeastern New Mexico. There they reported that intervals of population consolidation or slow dispersal alternated with periods of rapid range extension led by mature males.

Range extensions by Barbary sheep in California were also probably led by male dispersers (Barrett, 1980), but were limited by suitable habitat and continuous hunting pressure. The documentation of population range extensions by Barbary sheep in and from Palo Duro Canyon is not sufficiently complete to be able to determine characteristics for this population.

The range extension of another Caprine, the Himalayan thar, following its release in the high country of South Island, New Zealand, displayed a diffusive rather than a phasic type spread. However, new areas were initially colonized by males as is the case for Barbary sheep, and dispersal again appeared to be unrelated to population pressure (Caughley, 1970).

Population Density

Barbary sheep densities could not be determined from data collected on the SOR counts. Seven aerial censuses of the Dry Creek branch of Palo Duro Canyon gave minimum population density estimates ranging from 0.35 Barbary sheep per km^2 (0.92 per mile²) to 1.57 per km^2 (4.06 per mile²) (Table 3). By comparison Ogren (1965) estimated a mean population density of 2.37 per km^2 (6.15 per mile²) in the Canadian River gorge of northeastern New Mexico, based on fecal pellet count transects. More recent data, from New Mexico Department of Fish and Game (NMDF&G) aerial surveys of this area, suggest a density of 2.15 per km^2 (5.56 per mile²) (B. Morrison, pers. comm., 1980). Aerial censuses of Largo Canyon in northwestern New Mexico and the Hondo Valley of

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Aerial				Minimum	density ^a		Estimated	density
census			Number	No.	No.	Number	No.	No.
date		seen	per km ²	per 2 mile	estimate	d km ²	mile ²	
29	Jun	1977	97	1.49	3.86	223	3.43	8.88
23	Sep	1977	96	1.48	3.82	221	3.40	8.80
20	Dec	1977	30	0.46	1.19	69	1.06	2.75
28	Jan	1978	50	0.77	1.99	115	1.77	4.58
3	Apr	1978	23	0.35	0.92	53	0.81	2.11
7	Jul	1978	102	1.57	4.06	234	3.60	9.32
3	Oct	1978	44	0.68	1.75	101	1.55	4.02
Means		63	0.97	2.51	145	2.23	5.78	

TABLE 3.--Minimum and estimated densities of Barbary sheep in the Dry Creek branch of Palo Duro Canyon, Texas, as determined by helicopter surveys

^aDensity is based on the number of Barbary sheep seen in the Dry Creek branch which comprises about 65 $\rm km^2$ (25.1 miles²).

^bEstimated density assumes that 43.5% of the animals present are seen (McQuivey, 1978), and corrects actual observations to reflect this percentage. southern New Mexico by the NMDF&G produced estimates of 1.54 per km^2 (4.0 per mile²) and 1.49 per km^2 (3.85 per mile²), respectively (B. Morrison, pers. comm., 1980). The density of the Red Rock herd on the Hearst Ranch in California declined from 0.84 per km^2 (2.17 per mile²) to 0.5 per km^2 (1.29 per mile²) from 1965 to 1977 (Barrett, 1980). This decline appeared to be associated with deteriorating range conditions.

McQuivey (1978) found that 39.6 to 51.5 percent of 82 individually marked desert bighorn sheep (<u>Ovis canadensis</u> <u>nelsoni</u>) were counted by experienced personnel during five helicopter surveys in Nevada. Morgart and Omart (1979) found a similar low recount of marked feral burros present on open desert flats. Because it is likely that Barbary sheep are as difficult to spot as desert bighorns, and more so than burros on open flats, the Palo Duro densities reported here may also underestimate actual densities. This supposition is supported by helicopter censuses in the Dry Creek branch of Palo Duro Canyon that consistently counted approximately 50 percent of the marked and radio-collared Barbary sheep present (Simpson et al., 1978). It was impossible to precisely evaluate the differences between animals counted and those present however, since the number of marked animals was small.

In the absence of a precise estimate of this discrepancy, I applied McQuivey's (1978:44) mean of 43.5 percent to my data. The corrected data yielded density estimates for Barbary sheep of 0.81 per km² (2.1 per mile²) to 3.6 per km² (9.3 per mile²), with a mean of 2.2 per km² (5.8 per mile²) (Table 3). This range encompasses Barbary sheep densities enumerated above, but is considerably higher than desert bighorn sheep densities averaging 0.73 per km² (1.9 per mile²) for 25 occupied ranges in Nevada (McQuivey, 1978).

Natality and Productivity

The distribution of birth months for 25 neonates seen from February 1977 through January 1978 suggests that about 70 percent of all births took place in March and April (Table 4). Some parturition was recorded for other months except for December and the May through August interval. The actual month of parturition could be determined for only eight births from February 1978 through January 1979, of which three were assigned to March, five to May, and one to November. Although these sample sizes are small, no other record of birth month distribution for free-ranging Barbary sheep has been published to date.

Conception rates for the second year of this study may have been depressed by subnormal precipitation the previous summer and autumn. In addition, dispersal left fewer females on the study area for which offspring parturition months could be established.

Inferred birth month	No. of —MNKA births	% of −MNKA births
Feb.	1	3.8
Mar.	8	30.8
Apr.	10	38.5
May	0	0.0
June	0	0.0
July	0	0.0
Aug.	0	0.0
Sep.	3	11.6
Oct.	2 ,	7.7
Nov.	1	3.8
Dec.	0	0.0
Jan.	1	3.8
Sum	26	100.0

TABLE 4.--The distribution of calculated birth months for free-ranging Barbary sheep neonates in Palo Duro Canyon, Texas, from February 1977 through January 1978.

Asdell (1964) commented that Barbary sheep births usually occur at the beginning of the spring season, which is consistent with my field data from Palo Duro Canyon. In the region of Tigueddi, North Africa (exact location unknown), most births take place early in March (Rode, 1943). Panouse (1957) mentioned that parturition in southern Morocco is concentrated in December, but did not elaborate on influencing factors. The spring birth pattern is consistent with the distribution of births noted for this species at the London Zoological Garden, where most of 190 births recorded between 1862 and 1937 were in the months of March, April, and May (Zuckerman, 1953). At the Giza Zoological Garden, 81 percent occurred in March and April (Flower, 1932).

In North America, records from the San Antonio Zoological Gardens show that 311 Barbary sheep were born there between June 1969 and April 1980 (R. Smith, pers. comm., 1980). Most births were registered for March (33.4 percent), February (17.4 percent), and April (13.8 percent). Some parturition was documented for all months during this 11-year period, but not all months were represented by Barbary sheep births in each year. The smallest incidence of births took place during December (1.6 percent), January (2.3 percent), and November (2.9 percent).

Lenarz (1979) cites V. Geist as referring to the Barbary sheep reproductive strategy as a "gambling" one. The concentration of births in the early spring, which synchronizes initiation of lactation with the availability of nutritious spring forage, suggests that the term "modified gambling strategy" may better describe the reproductive adaptation of Barbary sheep.

It was not possible to determine the extent of twinning in the Palo Duro Canyon population. Records from the London

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Zoological Gardens show that twins occur once in every six parturitions (Zuckerman, 1953). At the San Antonio Zoological Gardens, twins comprised about 12 percent of 311 births (R. Smith, pers. comm., 1980).

Fourteen mature females collected in New Mexico during the late autumn of 1957 contained an average of 1.2 embryos per female, and the ratio was 1.6 embryos per female for seven taken in the late winter of 1959 (Ogren, 1965:60). Barrett (1980) found an average of 1.2 corpora lutea in 10 females from California in 1966. During the first eight hunts in Palo Duro Canyon, 67 females were found to contain a total of 57 fetuses (0.85 per female) (DeArment, 1971). Fertility of Barbary sheep in Palo Duro Canyon therefore appears to be appreciably lower than in some other free-ranging populations in the western United States.

Because parturition occurs virtually year-round, but has a period of concentration in March and April, Barbary sheep of appear to occupy an intermediate position between birth-flow and birth-pulse breeding system models (Caughley, 1977:72). Consequently, natality rates were calculated both for flow and for pulse regimes. Juvenile:100 female ratios from all months were averaged to arrive at a birth-flow natality rate, whereas juvenile:100 female ratios for the spring months only were averaged to produce a natality estimate under the birth-pulse model.

Juvenile:100 female ratios derived from four aerial censuses conducted from February 1977 through January 1978 were not significantly different than those produced by the three helicopter counts from February 1978 through January 1979 (Mann-Whitney test, T = 4, 2-tailed $\alpha = 0.63$). For this reason, juvenile:100 female ratios calculated from sightings on all aerial surveys were combined and averaged. This statistic is 46.8 + 6.8 (SE) juveniles:100 females.

Juvenile:100 female ratios based upon monthly ground MNKA observations were significantly different for the two years (χ^2 test, T = 1,097.85 > χ^2 = 18.31, 10 df, $\alpha << 0.005$), so these data are reported separately (Table 5). The results of the combined aerial censuses and findings from the first year's monthly ground MNKA surveys are fairly comparable under either birth distribution model (see Table 5). Taken together, they suggest a natality rate of about 48 juveniles: 100 females. However, the second year's monthly ground MNKA surveys indicate a much higher natality rate of 73 juveniles: 100 males.

Comparable data on juvenile:female ratios are available from several other free-ranging Barbary sheep populations. Barrett (1980) reported 30 juveniles:100 females for the Red Rock herd on the Hearst Ranch, California, in November 1966. In southeastern New Mexico, Dickinson and Simpson (1979) recorded an overall juvenile:100 female ratio of 167:100,

but the deletion of marked female sightings from these data showed a ratio of 132 juveniles:100 females which they felt was more accurate.

TABLE 5.--Natality rates of Barbary sheep in the Dry Creek branch of Palo Duro Canyon, Texas, based on birth-flow and birth-pulse parturition distribution models

Data	Mean number of juveniles:100 females <u>+</u> SE					
source	Birth-flow model	Birth-pulse model				
Aerial censuses (Both years combined)	46.8 <u>+</u> 6.8	50.2 <u>+</u> 13.1 ^a				
Monthly ground MNKA (First year)	53.5 <u>+</u> 4.8	42.5 ± 4.3^{a}				
Monthly ground MNKA (Second year)	72.6 <u>+</u> 11.3	73.2 <u>+</u> 13.2 ^a				

^aOnly spring data for the peak parturition period were used to compute these statistics.

Data on juvenile : female ratios were also collected by the NMDF&G during aerial surveys conducted before hunting seasons between 1969 and 1977 in three Barbary sheep management areas (Bavin, 1978). Seven yearly flights in the Hondo Valley showed a range of 16:100 to 76:100, with an overall ratio of 37:100. Eight yearly surveys of the Canadian River gorge indicated a range of 16:100 to 71:100, with an overall ratio of 36 juveniles:100 females. Two flights in Large Canyon produced ratios of 25:100 (1970) and 37:100 (1975).

The natality rates recorded during the Palo Duro Canyon study showed close agreement between calculations based on a birth-flow model and those derived from a birth-pulse model. This tends to substantiate my suggestion that Barbary sheep occupy an intermediate position between birth-flow and birthpulse regimes.

The information summarized here documents a high degree of variability in natality rates among free-ranging Barbary sheep populations. It also shows widely varying juvenile: female ratios between some years in populations where several year's data are available. The latter suggests that Barbary sheep natality may be strongly influenced by precipitation or available vegetation. This possibility may be reflected by the fact that natality rates from two areas in New Mexico were both lowest during the same year following a year of abnormally low precipitation. Surveys of the Hondo Valley and Canadian River gorge in 1976 both produced ratios of 16 juveniles:100 females (Bavin, 1978). Artesia, near the Hondo Valley, recorded a 1975 precipitation deficit of 66 mm (2.6 inches) from the long-term average (U.S. Department of Commerce, 1975). Springer and Roy, both of which are close to the Canadian River gorge, also showed precipitation amounts for 1975 of 73 mm (2.9 inches) and 79 mm (3.1 inches) below normal, respectively.

Population Structure

Population structure was estimated separately for each of the two years, based upon monthly ground survey MNKA data. The first year's observations indicated that juveniles and subadults comprised about 30 percent of the population, adult males 20 percent, and adult females 50 percent (Table 6). Data for the second year suggested that juveniles and subadults comprised 42 percent of the population, adult males 9 percent, and adult females 49 percent. Because the frequency of sightings was much higher for the first year (see Fig. 10), I believe the first year's population structure data is the more representative sample.

TABLE 6.--Population structure for Barbary sheep in the Dry Creek branch of Palo Duro Canyon, Texas, based upon monthly ground survey MNKA data

Age-sex	Feb. 77 - Jan. 78				Feb. 78 - Jan. 79						
class	Mean % of population + SE						Mean % of population <u>+</u> SE				
Juvenile		26.4		+	2.2		32.3		+	3.0	
Subadult		3.7		+	0.9		9.8		+	1.8	
Male class	1	6.6					2.8				
Male class	2	7.5)					3.2)			
Male class	3	3.4)	20.0	+	3.0		1.9) 9.2	+	2.4	
Male class	4	2.5)					1.2)			
Female cl.	1	13.4					11.0	N N			
Female cl.	2	36.5)	49.9	+	1.9		37.7	48.7	+	3.2	

The results of 15 aerial censuses conducted by the TP&WD from 1965 through 1977 (Evans, 1965, 1966, 1967a, 1968; Taft, 1970; DeArment, 1971; Dillard, 1972; Dvorak, 1973, 1974, 1976, 1977, 1978) indicated that the juvenile segment represented 21.6 \pm 1.4 percent (mean \pm SE) of the population. My findings from seven aerial censuses during 1977-78 showed that 28.7 \pm 3.0 percent (mean \pm SE) of the population were juveniles. Thus, the results of the helicopter censuses I conducted serve to corroborate the first year's ground survey MNKA population structure. data, and support my selection of the first year's data as the more representative sample. Both sets of helicopter census data--TP&WD's and mine--point to the percentage of juveniles in the second year's population structure as being inflated.

The subnormal precipitation in late 1977 that suppressed winter wheat growth may have caused many Barbary sheep to disperse from the study area. This probability is supported by a sharply reduced frequency for sightings from the SOR during much of 1978 (see Fig. 10). I further suggest that reduced availability of supplemental food may have acted as a dispersal trigger. The smaller percentage of males in the Dry Creek branch in the second year may have been influenced by food availability but is also consistent with the phasic population range extension pattern documented by Dickinson and Simpson (1980a), and with evidence that male dispersers precede females and juveniles (Barrett, 1980; Dickinson and Simpson, 1980a).

The only other population structure data available for Barbary sheep were reported for the Red Rock herd on the Hearst Ranch in California by Barrett (1980). He found that juveniles comprised 14.7 percent of the population, males 11.2 percent, and females 74.0 percent in August 1965. The comparable data for this herd in November 1966 were 20.5 percent, 8.0 percent, and 69.1 percent, respectively. The small juvenile segment in the Red Rock herd suggests a declining population and, in fact, numbers did decline from 258 in 1965 to 154 in 1977. The low percentage of males at Red Rock may be a consequence of the Hearst Ranch hunting concession (Barrett, 1980) combined with male dispersal. As dispersing males are usually shot before they can colonize new areas, female dispersal is minimal accounting for the very high percentages of females in the Red Rock population.

Sex Ratios

Sex ratios of 40 males:100 females and 19 males:100 females were registered for the two years of the Palo Duro Canyon study. These ratios are higher than ratios of 15:100 (August 1965) and 11:100 (November 1966) that Barrett (1980) found in California, but lower than Dickinson and Simpson's

(1979) estimate of 58 males:100 females in the Hondo Valley of southern New Mexico.

The sex ratio of Barbary sheep at parturition was one: one at the Wyoming Game and Fish Department's Wildlife Experiment Unit (Blunt, 1963), but 301 births at the San Antonio Zoological Garden from 1970 to 1980 showed a disparity in favor of females (86 males:100 females) (R. Smith, pers. comm., 1980). The degree to which there is differential mortality between the sexes in juveniles is unknown. Sex ratios in free-ranging populations probably reflect differentially greater mortality in adult males due to dispersal into unsuitable habitats, and to hunter selection.

Mortality and Survival

Neonatal mortality in Barbary sheep is apparently rather high, even under circumstances providing protection from natural hazzards. Of 311 Barbary sheep born at the San Antonio Zoological Garden from 1969 to 1980, 30 died on the day of birth or the day following birth. Another 23 young died within 10 days of birth, and an additional 12 animals died within a month of birth (R. Smith, pers. comm., 1980). Thus, under zoo conditions 68 of 311 died, and 78.1 percent of the young survived more than one month.

The difference in proportion of juveniles (excluding subadults) seen in Palo Duro Canyon between two aerial

censuses conducted on 29 June and 23 September 1977 suggested that the field survival rate of juveniles for this interval was 77 percent. However, young born during the spring birth-pulse were already two to three months old at the time of the first census. Thus, the survival rate for the first three months after birth is probably much lower. On the other hand, juvenile survival from six months to one year is likely greater than 77 percent for each three-month period.

In the absence of other data, the juvenile survival rate from birth to one-year of age was taken to be 77 percent for each three-month interval, (0.77)⁴, or about 35 percent per annum. This is slightly higher than the survival rate of 25 percent in the first year of life that Barrett (1980) found for the Red Rock Barbary sheep herd on the Hearst Ranch in California.

A direct estimate of age-specific mortality (or, conversely, survival) was not possible for adult Barbary sheep in the Palo Duro Canyon population, so an estimate of survival rates was derived indirectly from population structure data (see Table 6).

The juvenile and subadult classes were combined and thus comprised 30.1 and 42.1 percent of the population for the two field years, respectively, of which half (15.05 and 21.05 percent) were presumed to be males. Because population composition percentages had been determined for male age classes rather than year classes, the mid-point of each age class was taken to be the year class represented by the corresponding population composition percentage. The mid-point of the combined juvenile-subadult age range (0 -1.25 years) is 0.625 years, the mid-point of the male class 1 range (1.25 - 2.5 years) is 1.875 years, whereas the midpoints of male class 2 (2.5 - 3.5 years), class 3 (3.5 - 6.5 years), and class 4 (6.5 - 9.5 years) are 3, 5, and 8 years, respectively.

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Age frequencies were smoothed by regressing the independent variable of age in years against population composition percentages (Caughley, 1977:96). Several models were examined and the best least-squares fit was obtained from a loglinear model.

The equation derived from the 1977-78 population structure data, $\ln \hat{\underline{P}} = 2.5986 - 0.2291 \underline{A}$, where \underline{P} is the percentage of the population and \underline{A} is age in years, has a significant slope ($\alpha = 0.0013$) and linear component ($\alpha = 0.0175$), and accounts for 88.3 percent of the variability (\underline{R}^2). The best fit for the second year's population structure data was produced by the equation $\ln \hat{\underline{P}} = 2.3678 - 0.31217 \underline{A}$, in which the slope is significant ($\alpha = 0.024$) and the linear component approaches significance ($\alpha = 0.085$), but for which \underline{R}^2 is only 0.68. Because climatic and vegetation conditions for the two years varied considerably, equations based upon both years were used to smooth age frequencies (Fig. 11). When population structure data for both years were combined, they yielded the equation $\ln \hat{\underline{P}} = 2.5411 - 0.26544 \underline{A}$, with a significant slope ($\alpha = 0.0052$) and linear component ($\alpha = 0.0404$), which explained 80.1 percent of the variability (\mathbb{R}^2).

Age-specific survival rates for males were estimated using time-specific life table procedures (Henny et al., 1970), and calculated from the formula

$$\bar{s}_{x} = \frac{P_{x+1}}{P_{x}}$$

where \bar{s}_{x} is age-specific annual survival rate, P_{x} corresponds to the percentage of males of age x in the population, and P_{x+1} equals the percentage of males of age x + 1 in the population. This produced a constant annual survival rate estimate of 0.795 for males using the 1977-78 data. By comparison, population structure data for the 1978-79 field year suggest a constant annual male survival rate of 0.732, whereas data for the two years combined yielded a rate of 0.767. It was impossible to estimate female survival rates by this method because only two age classes of adult females could be distinguished in the field.

Life tables for males were constructed based upon a survival rate of 35 percent from birth to one year, and constant



Fig. 11. Regression of the percentage of the male Barbary sheep population on the mid-points of each age class as a basis for estimating survival rates.
yearly survival rates of 73.2, 76.7, and 79.5 percent for males over one year. These showed male Barbary sheep surviving to an age of about 20 years. Such ages have been reported from zoo herds (Ogren, 1965:5), but are grossly optimistic for free-ranging animals and ecological longevity probably does not exceed 15 years. The oldest animals and skulls that I examined from Palo Duro Canyon indicated maximum ages of about 10.5 years.

An annual adult survival rate for males of over 70 percent may be correct for younger adult male classes 1 (1.25 -2.5 years old) and 2 (2.5 - 3.5 years old). Survival rates for the older class 3 (3.5 - 6.5-year-old) and 4 (6.5 - 9.5year-old) males are almost certainly much lower, however. Caughley (1966) has shown that mortality rates are high for mammals in young and old year classes, and relatively low for animals in intermediate ear classes.

As a result, life table calculations for the Palo Duro Canyon population were based upon a juvenile survival rate of 35 percent from birth to one year, and an average yearly survival rate of 76.7 percent from one to 3.5 years of age. Cohort mortality was assumed to be total by age 10.5 years, resulting in a calculated average yearly survival rate of about 55 percent for males from 3.5 to 10.5 years of age. This average yearly survival rate probably represents an agespecific rate ranging from about 70 percent for four-year-old males to nearly 0.0 percent by the age of 10.5 years.

CHAPTER VII

TOPOGRAPHIC DISTRIBUTION AND SPATIAL UTILIZATION

The topographic distribution of sightings was recorded in order to clarify Barbary sheep topographic preference, and define spatial utilization as one component dimension of the ecological niche of this species.

Methods

Field procedures were specified in Chapter VI, so this section is limited to a description of data collection and analysis methods.

The five range sites on the study area (Jacquot et al., 1965) constitute four altitudinal levels (Fig. 12), defined as follows: 1) the Deep Hardland of the High Plain above the canyon and the Mixed Land Slope abutting the rim comprise an upper level called the "Canyon Rim"; 2) high ledges on the Rough Breaks of the canyon walls, approximately 30.5 to 46 m (100 to 150.9 feet) below the rim, were termed "High Benches"; 3) lower ledges on the canyon walls, generally 30.5 to 46 m (100 to 150.9 feet) above the canyon floor, were designated "Low Benches"; and 4) the gently rolling Shallow Redland and Bottomland of the floor collectively form the "Canyon Floor."

For each sighting, defined as one or more Barbary sheep, the topographic level was recorded. Sightings were tabulated

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Fig. 12. Vertical profile of the Dry Creek study area in Palo Duro Canyon showing the relationship of USDA Soil Conservation Service range site classifications to the topographic levels defined in this study. by topographic level and examined for monthly, seasonal, and annual differences. The Kolmogorov-Smirnov test (Siegel, 1956; Daniel, 1978) was employed to evaluate null hypotheses (H_0) of no significant differences among topographic levels for Barbary sheep sightings. This test is exact, even for small sample sizes (Conover, 1971:295), sensitive to all types of differences that can exist between two distributions (means or medians, variances, skewness) (Conover, 1971:309), and more powerful than the chi-square test (Siegel, 1956:136). Although the test assumes a continuously distributed variable, it is conservative when applied to discrete distributions (Daniel, 1978:274) and the probability of a type I error is no greater than that assumed by using the Kolmogorov-Smirnov table (Sokal and Rohlf, 1969:574). The null hypothesis (H_0) was rejected for values of $\hat{a} \leq 0.05$.

Results

Barbary sheep were sighted 529 times during 271 field days over the course of 24 months. The distribution of sightings by topographic level did not differ between corresponding months of each year (Kolmogorov-Smirnov Two-sample test, T = 4.83 to $0.518 < \chi^2_{.05, 2} = 5.99$, $\hat{\alpha} = 0.09$ to 0.77), so data for the two years were combined.

The relative proportion of sightings was generally highest for the Low Bench level and lowest for the Canyon Floor, although sightings on the Canyon Rim were frequent during the February to March interval (Table 7). Although this monthly distribution of sightings was consistent, significant differences in sighting frequency among the topographic levels were apparent only for months in which the total number of sightings was fairly large (exceeding 40). When the distribution of sightings among topographic levels was examined on a seasonal and annual basis, significant differences were apparent (Table 8).

Discussion

DeArment (1971:3) observed that aoudads "show a pronounced preference for the roughest and most precipitous terrain of the canyon and caprock where it is almost inaccessible to humans, . . . easily negotiate sheer naked cliffs which are usually the break between upper and lower canyon terraces, . . . (and) have wallows in the bottoms and range up to the top flats of mesas and out into fields of winter wheat which border canyon rims." During helicopter surveys they were usually seen ". . . in the most rugged and impassable parts of the canyon."

Hampy (1978:53) found 24.5 percent of the Barbary sheep he sighted from June through October 1976, and April through October 1977, on the Deep Hardland and Mixed Land Slope comprising the Canyon Rim, 71.5 percent on the Rough Breaks

		Number of	Sightings						
Time period	Canyon rim	High benches	Low benches	Canyon floor	Test T	sta < >	tistic ^D .05		α
Jan.	5	8	8	0	.250	<	.294	>	.10
Feb.	16	7	20	3	.185	<	.201	>	.05
Mar.	58	26	26	2	.268	>	.129	<	.01*
Apr.	37	23	24	4	.205	>	.174	<	.01*
May	19	14	23	3	.199	>	.177	<	.05*
June	7	15	19	0	.250	>	.212	<	.05*
July	3	Э	24	2	.197	<	.221	>	.10
Aug.	3	Э	11	1	.170	<	.270	>	.10
Sep.	3	8	13	1	.210	<	.270	>	.10
Oct.	6	7	11	3	.139	<	.240	>	.10
Nov.	l	6	11	2	.200	<	.294	>	.10
Dec.	5	10	11	1	.213	<	.240	>	.10
Winter ^a	79	41	54	5	.222	>	.102	<	.01*
Spring ^a	63	52	66	7	.213	>	.099	<	.01*
Summer ^a	9	26	48	5	.193	>	.145	<	.01*
Autumn ^a	12	23	33	6	.169	>	.158	<	.05*
Annual	163	142	201	23	.207	>	.059	<	.01*

TABLE 7.--Kolmogorov-Smirnov One-sample test of Barbary sheep spatial distribution by topographic level in Palo Duro Canyon, Texas

^a The seasons were separated as follows: winter, January through March; spring, April through June; summer, July through September; and autumn, October through December.

* Differences are statistically significant at the level indicated.

(High and Low Benches), and four percent on the Shallow Redland and Bottomland of the Canyon Floor. The comparable percentages from this study are 30.8, 64.8, and 4.4, respectively. Hampy's (1978:55) data also suggest a selection for westerly (May through August) or southerly (April and September) slope aspects during the spring and summer and months, and easterly exposures in the early autumn (October). Dickinson and Simpson (1980b) reported that "slope" sites were preferred during spring and autumn seasons by three radiocollared animals in southeastern New Mexico, and that "slope" sites were used extensively for bedding whereas "bottom"

The results of the present study indicate that Barbary sheep range over all topographic levels in Palo Duro Canyon, but spatial utilization is concentrated on precipitous bluffs, which comprise the canyon walls, and particularly on Low Bench sites. These findings are generally consistent with the spatial distribution pattern described by DeArment (1971), Hampy (1978), and Dickinson and Simpson (1979). The high proportion of sightings on the Canyon Rim from February through May represents Barbary sheep usage of winter wheat in fields adjacent to the canyon during a period when it is more palatable and nutritious to grazing animals than native vegetation.

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CHAPTER VIII

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DIET STUDIES

Plant species composition of the Barbary sheep diet was investigated on a seasonal and annual basis by microhistological examination of fecal material, supplemented by microhistological inspection of rumen contents from five hunter-shot animals.

Methods

Fecal Analysis

Barbary sheep fecal pellets, which can be differentiated from those of sympatric mule deer by shape (Ogren, 1962:42), were collected while walking the SOR along the canyon rim each field day from February 1977 through January 1979, except November 1979. Composite monthly fecal samples, comprised of fresh pellets collected -- when available -- on each field day during the month, were stored in 95 percent ethanol, after which microscope slides of reference and fecal material were prepared as described by Free et al. (1970). Microhistological examination followed the procedure outlined by Sparks and Malechek (1968), based on a technique described by Baumgartner and Martin (1939) and refined by Dusi (1949).

The samples were analyzed by examining 50 microscope fields for each monthly sample at 100 - 400X magnification.

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Frequence of occurrence was determined and converted to density, and relative density was calculated as an estimate of percent composition by dry weight. A preference index was calculated for the major browse plants consumed by dividing percent utilization by percent availability, using Hampy's (1978) forage availability data based on 58 random step-point transects each of which consisted of 100 sample points. Plant nomenclature follows Correll and Johnston (1970).

Autumn Rumen Content Analysis

A 500 ml aliquot of rumen contents was collected from each of five Barbary sheep harvested during the November 1976 hunting season. Samples were drained and stored in 95 percent ethanol. Microscope slide preparation and examination was identical to the method already described.

These samples were analyzed by examining 10 fields on each of five slides per stomach, or 50 fields per animal and 250 total fields for all rumen material, at 100X magnification. Again, results are expressed as percent composition by dry weight.

Results

Fecal Analysis

Analysis of fecal material revealed that the average annual diet of Barbary sheep in Palo Duro Canyon comprised 49 percent browse, 22.8 percent grasses, and 23.9 percent forbs. Trace amounts from all categories totalled 4.3 percent. Browse was utilized most heavily during the autumn (61 percent) and spring (49 percent) seasons. Sand shinnery oak and mountain mahogany were the primary forage species consumed during all seasons of the year, accounting for 31.1 percent and 12.5 percent, respectively, of the annual diet (Table 8). Preference indexes showed mountain mahogany to be highly preferred (Table 9).

The use of grasses was significant in all seasons except autumn, but only blue grama (10.1 percent) and silver bluestem (9.7 percent) contributed appreciably to the annual diet (Table 10). Forb consumption was highest during autumn (27 percent) and winter (42 percent) periods, and bladderpods (<u>Lesquerella</u> sp.), which are cool season plants, were the forbs predominantly utilized (11 percent) (Table 11).

Autumn Rumen Content Analysis

Rumen content analysis also showed browse (68.2 percent) to be the most important dietary component during the autumn season. Important forage species included sand shinnery oak (49.2 percent), mountain mahogany (15.7 percent), and blue grama (14.4 percent) (Table 12).

aht)	as	
drv wei	Texas.	
8Seasonal and annual relative densities (percent composition by dry we	of browse plants utilized by Barbary sheep in Palo Duro Canyon, Texas	determined by microhistological analysis of fecal samples
TABLE		

				Season		
common name	Scientific name	Winter	Spring	Summer	Autumn	Annuál
Sand shinnery oak	Quercus havardii	20.7	30.8	24.1	48.4	31.1
Moun tain mahogany	Cercocarpus montanus	5.2	10.2	24.6	5.1	12.5
Skunkbush	Rhus aromatica	۲ ^۱ ,	0.0	1.9	T	Ł
Littleleaf sumac	Rhus microphylla	.L	7.6	3.6	1.3	з. з
Juniper	Juniperus spp.	1.0	J,	E.	5.4	2.1
Cactus	Opuntia spp.	1.4	1.	E	Ł	Ę
Algerita	Berberis trifoliata	T	0.0	0.0	0.0	• E-
E phe dra	Ephedra antisyphlitica	Ц	0.0	0.0	0.0	Ŀ
Yucca	Yucca spp.	Т	0.0	Т	0.0	E.
Elbowbush Total	Forestiera pubescens	0.0	Т 48. б	0.0	0.0	L S
a _m				7.00	2.00	49.0

"The seasons were separated as follows: winter, January through March; spring, April through June; Summer, July through September; and autumn, October through December.

 $b_{T} = traces (< 1.08).$

TABLE 9.--Preference index values for the most important browse plants in the annual diet of Barbary sheep from Palo Duro Canyon, Texas, based upon analysis of fecal samples

	the second se		the second s
Browse plant	Percent availability	Percent utilization	Preference index ^a
Cercocarpus montanus	0.50	12.50	20.16
Rhus microphylla	0.62	3.30	5.50
Quercus havardii	5.80	31.10	5.36
Rhus aromatica	2.70	Т	0.19
Juniperus spp.	8.20	1.70	0.21

^aValues < 1.0 indicate avoidance; values > 1.0 indicate preference.

Discussion

Ogren (1962, 1965) found that the Barbary sheep diet in the Canadian River gorge of northeastern New Mexico consisted of 48.4 percent browse, 41.6 percent grasses, and 9.3 percent forbs on an annual basis (plus traces totalling 0.7 percent) as determined by an analysis of rumen samples from 95 animals. Wavy-leaf oak and mountain mahogany were the dominant forage plants, accounting for 27.7 percent and 21.8 percent of the annual diet, respectively. Browse was also the dominant forage category of Barbary sheep in Largo Canyon (Bird and Upham, 1980) and the Guadalupe Mountains (Simpson et al., 1980) of New Mexico, and oaks and mountain mahogany were found to be important dietary components in these studies also.

composition by drv	Palo Duro Canyon, sis of fecal samples
ALE 10Seasonal and annual relative densities (percent	weight) of grasses utilized by Barbary sheep in Texas, as determined by microhistological analys
TA	

	1			Season ^a		
Conmon name	Scientific name	Winter	Spring	Sumer	Autumn	Annual
Silver bluestem	Bothriochloa saccharoides	8.0	18.1	12.1	Т	9.7
Blue grama	Bouteloua gracilis	12.5	5.4	13.9	8.5	10.1
Winter wheat	Triticum aestivum	4.6	1.1	0.0	2.6	2.1
Sideoats grama	Bouteloua curtipendula	2.1	1.7	$^{\mathrm{Tb}}$	L	L
Indiangrass	Sorgastrum nutans	0.0	1.1	Ţ,	0.0	L
Little bluestem	Schizachyrium scoparium	0.0	1.1	E	0.0	L
Big bluestem	Andropogon gerardii	0.0	0.0	0.0	0.0	- L
Sand dropseed	Sporobolus cryptandrus	0.0	0.0	L	Т	Ŀ
Hairy grama	Bouteloua hirsuta	0.0	0.0	T	0.0	E-
Wolftail	Lycurus phleoides	0.0	0.0	Ţ	0.0	· E
Rescuegrass	Bromus unioloides	0.0	0.0	0.0	L	L
Wright's threeawn	Aristida wrightii	0.0	0.0	0.0	Ţ	T
TOTAL		29.6	27.4	26.6	11.7	22.8
٢						

^aThe seasons were separated as follows: winter, January through March; spring, April through June; summer, July through September; and autumn, October through December.

 $b_{T} = traces (< 1.0%).$

TABLE 11.--Seasonal and annual relative densities (percent composition by dry

Texas, as determined by microhistological analysis of fecal samples weight) of forbs utilized by Barbary sheep in Palo Duro Canyon,

Common name				Season ^d		
	scientific name	Winter	Spring	Summer	Autum	Annual
Bladderpod	Lesquerrella spp.	27.0	0.6	c -	0	
Silverleaf nightshade	Solanum elacagnifolium	2.0			α. 2	0.11
Globemallow	Sphaeralced spp.	10.4	 -	0.0	5.6	4.8
Common ragweed	Ambrosia psilostachu.			0.0	L	3.7
Groundcherry		5. L	1.3	1.8	1.8	2.0
	Physalls VISCOSA	, I,	Л,	Т	Т	Ŀ
Spectaclepod	Dithyrea wislizenii	0.0	5.5	0.0	0	•
Penstemon	Penstemon spp.	0.0	ιĿ	0 0		1.4
Buffalobur	Solanum rostratum	Ē	- 6	0.0	0.0	L
			H	Т	Т	Т
COMMON SUIT LOWER	Helianthus annuus	0.0	0.0	1.4	£	E
Horsetail	Conyza canadensis	0.0	0.0	E		- 1
Sandlily	Mentzelia stricta	0	0	+ _	0.0	H
White sage	Artemesia ludominici		0.0	L.3	0.0	I.
	THURSDAY THUN TUTANA	0.0	0.0	0.0	Т	Т
Erect dayflower	Commelina erecta	0.0	0.0	E		E
Groundsel	Senecio longilobus	0.0	0.0	E		H 6
Sanbur	Cenchrus incertus	E		, (0.0	H
TOTAL		0 67		0.0	0.0	Т
G		0.24	23.4	10.1	20.1	23.9
^a The seasons were s	ebarated as follows:	۲				

winter, January through March; spring, April through June; summer, July through September; and autumn, October through December. area as IOLLOWS: bT = traces (< 1.0%).

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TABLE 12.--Relative densities (percent composition by dry weight) of food plants found in rumens of five Barbary sheep from Palo Duro Canyon, Texas, November 1976

Common name	Scientific name	Relative density %
Grasses		16.2
Sideoats grama	Bouteloua curtipendula	1.4
Blue grama	Bouteloua gracilis	4.2
Panicum	Panicum spp.	0.5
Winter wheat	Triticum aestivum	10.2
Forbs		15.3
Western ragweed	Ambrosia psilostachya	1.2
Illinois bundleflower	Desmanthus illinoensis	1.1
Common sunflower	Helianthus annuus	0.6
Beach groundcherry	Physalis viscosa	4.1
Waferash	Ptelea trifoliata	0.3
Silverleaf nightshade	Solanum elaeagnifolium	0.8
Buffalobur	Solanum rostratum	6.5
Unknown forb		0.8
Woody plants		68.5
Mountain mahogany	Cercocarpus montanus	15.7
Feather dalea	Dalea formosa	0.3
Cactus	Opuntia spp.	1.8
Honey mesquite	Prosopis glandulosa	1.8
Sand shinnery oak	Quercus havardii	49.2
Mohr's shin oak	Quercus mohriana	0.5
Littleleaf sumac	Rhus microphylla	0.3

Forbs were the preferred forage of a tame aoudad, the food habits of which were studied on the Edwards Plateau of central Texas (Ramsey and Anderegg, 1972), but grasses constituted the highest percentage of the diet. Grasses likewise comprised most of the diet of Barbary sheep on the Hearst Ranch near San Luis Obispo, California, where more than 95 percent of stomach contents were grasses (California Department of Fish and Game, 1967), although Barrett (1967a) reported some stomachs of Barbary sheep from this area filled with live oak (Quercus agrifolia) leaves.

The stomach contents collected in late autumn or early winter hunting seasons in Palo Duro Canyon from 1963 to 1970 (DeArment, 1971) revealed sand shinnery oak in 73 of 109 stomachs (67 percent); and 91.5 percent by volume of the browse in 32 rumens collected in 1970 was shinnery oak (DeArment, 1971). Thus, the results of this research are consistent with findings of previous studies from this area.

Smith and Shandruk (1979) found that fecal analysis of pronghorn diets was less accurate than rumen data, and fecalmethod validation tests conducted with mule deer fed known diets showed substantial differences. Rumen contents examined in this study were taken before fecal pellet collection was initiated so no direct comparison is possible, but both methods indicate that Barbary sheep in Palo Duro Canyon are primarily browsers. Forbs and grasses make a substantial dietary contribution, particularly during the winter.

Several examples indicate that aoudad dietary utilization patterns parallel palatable and nutritious stages in the phenology of important forage plants. Sand shinnery oak is heavily utilized in all seasons, probably because of high nutritional levels maintained by oak throughout the year (Snyder, 1961). The highest level of mountain mahogany usage occurred during the summer, which coincides with this plant's peak leader production. Grasses comprised the smallest proportion of the diet during the autumn, after they had cured. And consumption of bladderpods, a cool season forb, was greatest during the winter months.

Barbary sheep are predominantly browsers in Palo Duro Canyon and other areas of the southwestern United States where palatable woody vegetation is abundant, but consume appreciable amounts of plants from the other forage categories in all seasons. Utilization of forbs and grasses is particularly heavy during the winter months in Palo Duro Canyon, when browse comprises less than one-third of the diet, and in other regions where browse availability is severely restricted. Thus this species exhibits behavioral, and perhaps physiological, plasticity that permits dietary shifts to accommodate available forage resources.

CHAPTER IX

PARASITISM AND PATHOLOGY

Parasitism and the gross pathological changes caused by one parasitic helminth species were examined in an attempt to assess the potential impact of these factors on the Barbary sheep population in Palo Duro Canyon, and, conversely, to examine the role of Barbary sheep as a reservoir and dispersal mechanism for various disease organisms. The collateral examination of sympatric mule deer permitted a fuller inventory of the parasites of wild ungulates in this area and a tentative appraisal of host-parasite associations.

Methods

Gastrointestinal Helminth Parasitism

Viscera were collected from five Barbary sheep and five mule deer harvested during the November 1976 hunting seasons. This sample size is consistent with that reported for similar studies (Prestwood et al., 1975, 1976). Necropsy and parasitologic techniques were similar to those described by Prestwood et al. (1973). Simpson's diversity index (Holmes and Podesta, 1968) was calculated to quantify the degree to which helminth species were equitably concentrated within each ungulate host species, and an index of similarity (Holmes and Podesta, 1968) indicated the extent to which the helminth fauna differed between Barbary sheep and mule deer.

Ectoparasitism

Ectoparasites were collected from 11 Barbary sheep and 12 mule deer harvested during the November 1977 hunting seasons. External surfaces of host animals were examined as soon as possible following death. The head, ears, neck, axilla, umbilical area, groin, perianal area, and tail were brushed for ectoparasites. Ears and nasal passages were swabbed with cotton-tipped applicators. Skin snips were taken from the concave pinnae, coronary band of the hooves, tail dorsum, eyelids, lips, nostrils, and umbilicus of each host. These were preserved in 10 percent formalin for later examination as histological preparations. The trachea and retropharyngeal pouches were examined for nasal bots. Representative portions of crusty dermal lesions were removed and preserved in 10 percent formalin. All brushings and ectoparasites removed in the field were preserved and stored in 70 percent ethanol. Ticks were stored in 70 percent ethanol, while nasal bots and lice were cleared in 10 percent KOH, dehydrated in a graded series of alcohols, cleared in methyl salicylate and mounted in Canada balsam. Histological sections of skin snips were stained with hematoxylin and eosin.

Elaeophorosis

The presence of small to sometimes extensive encrusted scabby lesions on the muzzle, face, ears, and crown of several Barbary sheep was noted during the November 1976 hunting season. These areas were generally considered to be fighting scars by local hunters and guides. In November 1977 a mature hunter-killed female was examined in the field. She exhibited severe proliferative lesions on the muzzle, tongue, gums, and face extending to the base of the horn and involving the ear. A viral etiology was initially suspected since the lesions clinically resembled contagious ecthyma (sheep pox). Histological examination at the light and electron microscopic levels failed to reveal evidence of inclusion bodies or isolate virus particles. A moderate inflammatory response in certain areas and presence of a yeast indicated a possible fungal dermatophycosis, and cultures of material obtained from a second animal exhibiting extensive lesions, and two less severely affected animals examined in November 1978, revealed Trichophyton sp. and Candida albicans as well as Staphylococcus albus; these were later found to be secondary infections.

The entire head and neck of six Barbary sheep and 14 mule deer were transported to the laboratory for necropsy, and the carotid arteries and secondary branches were excised and examined for nematodes. Nematodes were fixed in glacial acetic acid and stored in 70 percent ethanol with five percent glycerine added. Sections of skin lesions were cut at 4 - 6 mµ and stained with hematoxylin and eosin Gram's stain, and Giemsa. Sections of infected arteries were stained with hematoxylin and eosin or Verhoff's iron hematoxylin and Von Gieson's stains. Thin sections of eponembedded material were cut from the formalized material for electron microscopy. Suspensions of minsed formalized tissue were also negatively stained with phosphotungstinate for examination for virus particles from the same preparation.

Results

Gastrointestinal Helminth Parasitism

Two nematodes and one cestode, and two nematodes were recovered from Barbary sheep and mule deer, respectively, but worm burdens were very light (Table 13). Two Barbary sheep and two mule deer were free of helminth infections. Simpson's index was 0.36 for Barbary sheep and 0.63 for mule deer; the similarity index was 40.0. Representative specimens of helminth species recovered were deposited in the U.S. National Museum Helminth Collection (Nos. 74538 -74542).

Ectoparasitism

Two species of ticks and two of lice were recovered from Barbary sheep, including one species of louse that had not previously been described in the scientific literature (K. C. Emerson, pers. comm. to D. B. Pence, 1978). Mule deer were infested with one tick and one nasal bot species (Table 14). One animal of each host species was free of ectoparasites.

TABLE 13.--Gastrointestinal helminth parasites of Barbary sheep and mule deer from Palo Duro Canyon, Texas, 1976

Host Parasite	No. of hosts infected	No. of parasites recovered (range)
Barbary sheep $(N = 5)$		
Tapeworm (Monezia expansa)	1	l
Pinworm (Skrjabinema caprae)	2	1-88
Abomasal worm (<u>Haemonchus contortus</u>)	2	2-16
Mule deer $(N = 5)$		
Lungworm (Dictyocalus viviparous)	1	1
Abomasal worm (Haemonchus contortus)	3	2-24

Elaeophorosis

Gross lesions on Barbary sheep varied from small circumscribed slate-gray scars 1 - 5 cm in diameter on the temporal or orbital region of the head to extensive proliferative irregular encrustations on the frontal, temporal, and/or orbital regions, sometimes extending to the ears and muzzle (Fig. 13). The most severely affected animals examined had slate-gray to brown crusty lesions involving various combinations of temporal, frontal, and orbital regions and muzzle, lips, or ears. There was general hair loss over much of the affected areas and certain portions were edematous with serous fluid oozing from beneath the infected epithelium. Lesions on most animals were unilateral; eyes were not involved and corneas appeared normal on animals with orbital lesions. In some animals displaying lesions on the poll there was evidence of horn sheath deterioration extending as much as 1.5 cm from the base.

TABLE 14.--Ectoparasites of Barbary sheep and mule deer from Palo Duro Canyon, Texas, 1977

		No. of pa recove	arasites ered
Host Parasite	No. of hosts infested	Range	Mean
Barbary sheep (N = 11)			
Winter tick (Dermacentor albipictus)	6	1-20	5
Spinose ear tick (Otobius megnini)	3	1-4	2
Louse (Bovicola fulva) ^a	6	1-3	2
Louse (Bovicola neglecta)	3	1-87	18
Mule deer $(N = 12)$			
Winter tick (Dermacentor albipictus)	8	1-34	10
Nasal bots (<u>Cephenemyia pratti/</u> apicata)	8	1-27	12

^aHolotype collected by Gary G. Gray, described by Emerson and Price (1979), and deposited in the collection of the U.S. National Museum.



Fig. 13. Elaeophorosis in Barbary sheep from Palo Duro Canyon, Texas. A. Encrusted scaby lesions on the lip, muzzle, and ear. B. Suppurative lesions on the frontal and orbital regions of the head, with horn sheath deterioration. C. Elaeophora schneideri in a dissected

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Four and 13 reproductively mature Elaeophora schneideri were removed from the external carotid arteries of the one Barbary sheep collected in November 1978, and one of the five collected in November 1979, respectively. The nematodes were situated at the bifurcations of the external maxillary and internal carotid arteries with the external carotid (Fig. 13). In the former host, adult worms were unilateral and on the side exhibiting lesions. Extremely small mammalations were noted on the endothelium of affected arteries. Several additional hunter killed aoudads ranging in age from six months to about 9.5 years that were examined in the field displayed dry, slate-gray, scarified areas on the head, in some instances with partial regrowth of hair. These apparently represented previous elaeophorosis infections. All 14 mule deer necropsied in 1977 and 1978 harbored Elaeophora schneideri although there was no evidence of gross pathologic lesions. Small mammalations were also seen in mule deer carotid arteries at the sites of nematode obturation.

Microscopic examination of the lesions revealed severe pyogranulomatous reactions in active suppurating lesions, including 1) epithelieal surfaces characterized by eosinophilic masses of amorphous serous fluid, necrotic cells, and dark brown pigment, 2) hyperkeratosis with folds or spikelike projections of hyperplastic pigmented squamous epithelium, 3) some extensive loss of the surface epithelium, 4) edema-filled spaces in the hyperplastic stratum granulosum, with some infiltration of neutrophils, eosinophils, and lymphocytes, 5) severe vacuolation of the arterial adventitia, and 6) serous fluid infiltration of sebaceous glands and hair. follicles which were surrounded by intensely inflamed areas. Foreign body giant cells were not observed in these lesions, nor were microfilariae. Microscopic changes in the carotid arteries were limited to the intimal surface, with small villous projections produced by hyperplasia of the collagenous tunica media. Healed granulation tissue characterized older scars from less severely affected animals. In these cases there was little or no evidence of inflammatory response and foreign body giant cells and/or microfilariae were absent.

Dicussion

Gastrointestinal Helminth Parasitism

Thirteen helminth parasite species were reported from two Barbary sheep (Allen et al., 1956), and 17 helminth species were recovered from seven host animals (Allen, 1960), all collected in New Mexico. The species reported here were also recovered in those studies. Although <u>Haemonchus contortus</u> has been reported in Texas white-tailed deer (Robinson et al., 1967; Emerson, 1969), this study produced the first record of this species in Texas mule deer and apparently the first record of <u>Dictyocalus viviparous</u> in mule deer from the Southwest. As Levine (1968) indicated, the critical phase of the nematode life cycle is transmission from host to host. The range of environmental conditions that tend to promote optimum pasture transmission of several common ruminant trichostrongyles (Levine 1968:31) ordinarily limits the possibility of transmission to spring and summer months (May through September) in the Texas Panhandle. High evapotranspiration potentials reduce soil moisture during much of this period (June through August) further limiting possibilities for trichostrongyle larval development and survival. These factors probably account for low <u>Haemonchus contortus</u> infection levels and the absence of other trichostrongylids, such as Ostertagia and Trichostrongylus sp., in this area.

Ectoparasitism

Allen et al. (1956) and Allen (1960) recorded the winter tick (<u>Dermacentor albipictus</u>) among parasites found on wild Barbary sheep in New Mexico; this species had not been previously reported from free-ranging aoudads in Texas. The recovery of the spinose ear tick (<u>Otobius megnini</u>) from Barbary sheep represents a new host record. Both <u>D</u>. <u>albipictus</u> and <u>O</u>. <u>megnini</u> were previously reported from Texas mule deer by Eads et al. (1956).

Nasal bots, <u>Cephenemyia</u> sp., have been widely reported from both mule deer and white-tailed deer in the western United States (Walker and Becklund, 1970). Nasal bots recovered from mule deer in this study were readily identified to the <u>Cephenemyia pratti/apicata</u> group as defined by Bennett and Sabrosky (1962), but could not be distinguished to species because the key character -- the number of spines on the posterior dorsal margin of segment 11 of the third instar larvae -- was probably confounded by the loss of spines during recovery from the host, or during preservation and mounting procedures, and no attempt was made to rear larvae to adults. Both <u>C. apicata</u> (Glazner and Knowlton, 1967) and <u>C. pratti</u> (Hunter, 1915; Bennett and Sabrosky, 1962) have been reported from white-tailed deer in Texas.

One louse collected from Barbary sheep was found to represent a new species, which was described and named by Emerson and Price (1979). A second louse recovered, <u>Bovicola</u> <u>neglecta</u>, is apparently host-specific for Barbary sheep but was previously known only from zoo animals (Kéler, 1942:77; Werneck, 1950:81).

Although lice commonly occur on Texas deer (Walker and Becklund, 1970; Samuel and Trainer, 1971) none was recovered in this study. Also, deer keds (<u>Lipoptena mazamae</u>), which frequently parasitize East Texas deer, were not recovered. Finally, <u>D</u>. <u>albipictus</u> was the only hard tick collected from mule deer on the study area, whereas many other genera and species are reported from deer in other Texas localities (Walker and Becklund, 1970).

Barbary sheep and mule deer both exhibited winter tick infestations, but the other ectoparasites recovered were associated with one but not both wild ungulates. Thus the ectoparasite faunas of Barbary sheep and mule deer appear to be distinct in this area.

Elaeophorosis

The comparative pathology of elaeophorosis in elk (<u>Cervus elaphus</u>) and deer was reviewed by Hibler and Adcock (1971). This parasite has been documented in wild ungulates from Arizona, British Columbia, California, Colorado, New Mexico, Utah, and Wyoming, and seems to be common in mule deer throughout the Southwest.

It is highly pathogenic for elk, causing blindness, gangrene of the muzzle and ears, and antler deformities in older animals. Elaeophorosis probably accounts for elk calf mortality rates as high as 50 percent in some herds during certain years (C. P. Hibler, pers. comm. to D. B. Pence, 1979). In this ungulate, the disease primarily affects the cephalic arterial system causing circulatory impairment and producing secondary ischemic damage to the brain, eyes, optic nerves, muzzle, and other tissues of the head. This infection is also common in domestic sheep that graze summer pastures above 1,828 m (6,000 feet) in the western United States (Soulsby, 1965). The major clinical symptom produced by <u>Elaeophora schneideri</u> in sheep is the presence of filarial dermatosis, particularly about the head (Kemper, 1957), and secondary mechanical tissue damage caused by rubbing affected areas to relieve the itching sensation. Sheep exhibiting this condition are commonly referred to as having "sore head." Elaeophorosis has been found in sika deer (<u>Cervus nippon</u>) from several areas in Texas, and produced unilateral tumorous masses on the heads and/or feet of affected animals (Robinson et al., 1978).

Chronic graulomatous dermatitis associated with the presence of dead <u>E</u>. <u>schneideri</u> microfilariae have been observed microscopically in tissue from the foreheads of deer (Hibler and Adcock, 1971), but there is apparently no reported evidence of gross pathologic lesions in endemic white-tailed or mule deer of the type seen in elk or sika deer, or in Barbary sheep during this study. This factor, and the broad geographic distribution of <u>E</u>. <u>schneideri</u> in mule deer throughout the western United States, supports the speculation of Hibler and Adcock (1971:266) that deer are the normal definitive hosts.

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CHAPTER X

SOCIOBIOLOGY

Behavior is the means by which much of the ecology of vertebrate species is revealed, and is implicit in such facets of their biology as population structure and density, habitat selection, food habits, home range, dispersal or seasonal movements, and interspecific relations. The ontogeny and variability of the social behavior repertoire indicate the range of behavioral plasticity and probable adaptive strategy of a species.

Much social behavior can be discerned by intensive studies of captive animals. Still, the relatively depauperate environments of zoos and game farms demand that such studies be complemented by observations of free-ranging animals in order to fully delineate social behavior. This chapter provides qualitative and quantitative information on group dynamics and social organization of free-ranging Barbary sheep.

Methods

A detailed description of field procedures is provided in Chapter VI. Qualitative and quantitative descriptions of social behavior were recorded in field notebooks and later transcribed to daily record sheets. Definition of observed groups based upon group composition relied upon the

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differentiation of individuals into age-sex classes as described in Chapter IV.

Appropriate nonparametric statistical tests (Siegel, 1956; Conover, 1971; Daniel, 1978) were used to evaluate null hypotheses (H_0) of no significant difference between age-sex categories for several behavioral characteristics examined. Null hypotheses were rejected for values of $\alpha \leq 0.05$.

Results and Discussion

Group Size

During the first year of fieldwork, mean group size (N = 307 groups observed), as determined from ground surveys, declined steadily from about 25 animals in February to five in July, then gradually increased during the autumn and winter months (Fig. 14). Group sizes noted during six of seven aerial censuses throughout the study (Table 15) were not significantly different from those recorded during ground surveys for the corresponding months (six Mann-Whitney U tests, U = 27 to 136, z = 1.24 to 0.21, 2-tailed $\alpha = 0.22$ to 0.84, as compared with one Mann-Whitney U test (December 1977), U = 0.5, z = -7.06, 2-tailed $\alpha < 0.001$). This constitutes independent corroboration of ground survey data, and indicates that group sizes seen from the vehicular blind and SOR fairly represented sizes of groups throughout the Dry Creek study area.

		No. of	Gr	oup size		
Date		sightings	Mean	<u>+</u> SE	Range	C.V. (%)
29 Jun 19	977	14	6.9	1.7	1-22	93.9
23 Sep 19	977	16	6.0	1.5	1-19	97.8
20 Dec 1	977	2	15.0	2.7	12-18	28.3
28 Jan 1	978	4	12.5	4.5	3-22	71.7
3 Apr 1	978	2	11.5	8.5	3-20	104.5
7 Jul 19	978	10	10.0	3.2	1-33	101.1
3 Oct 1	978	9	10.0	3.0	1-20	90.8

TABLE 15.--Sizes of Barbary sheep groups observed during aerial censuses of the Dry Creek study area in Palo Duro Canyon, Texas

There was no consistent pattern the second year. Group sizes (N = 184 groups) were generally larger, but monthly means fluctuated erratically (Fig. 14).

In southeastern New Mexico, Dickinson and Simpson (1979) found that group sizes (N = 270 groups) averaged 2.8 animals. Group sizes there were largest during the autumn (4.2 animals) and smallest in the winter (1.5 animals). Spring and summer group sizes averaged 2.9 and 3.0 animals, respectively. These differences in group size were attributed to changes in behavior associated with the reproductive cycle of Barbary sheep.

Seasonal changes in the size of Barbary sheep groups in Palo Duro Canyon are probably also related to behavior



Sizes of Barbary sheep groups observed from the vehicular blind and standard observation route (SOR) during ground surveys of the Dry Creek study area in Palo Duro Canyon. Horizontal lines indicate means, enclosed rectangles show mean standard errors, and vertical lines show ranges for monthly group sizes. Fig. 14.

associated with reproductive phenology, with one notable exception. Large group sizes in the Dry Creek branch during the winter were almost certainly related to the presence of supplemental food sources provided by winter wheat fields near the canyon rim.

Dzieciolowski (1979) found that the size of red deer aggregations in Poland exhibited seasonal variations; and Rodgers (1977) documented a correlation of seasonal fluctuations in group size with changes in social and reproductive behavior of Nyassa wildebeest (<u>Connochaetes taurinus</u> johnstoni) and southern impala (Aepyceros melampus melampus).

The one consistent feature of Barbary sheep group size is its high degree of variability, which is evident in monthly group size coefficients of variation ranging from 53.6 to 122.7 percent (Fig. 14). This variability in group size is entirely consistent with the variability seen in other aspects of Barbary sheep biology. It does, however, tend to mask or confound the pattern of seasonal differences in group size that are probably related to phenological changes in reproduction and associated social behavior.

Group Composition

Changes in group composition during the first year (Fig. 15, Table 16) generally seemed to be related to changes in group size, and reflected the reproductive phenology of






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12.5		100.0	84.6		42.85	60.0	
75.0	100.0		7.7		42.85	40.0	
12.5		1			1 1 1		
444	1		 				
 		1		Data	14.3	1	
1 1		2	f I f	0 N			
1	L L	-	7.7			1	
i I	*						
						1979	
Jul	Aug	Sep	Oct	NOV	Dec	Jan.	

Barbary sheep. Large mixed groups seen during the winter were probably artifacts of the supplemental food source furnished by winter wheat in fields along the canyon rim. These large mixed groups were supplanted by small nursery groups, solitary males, and male groups (bachelor herds) during the spring parturition period. Nursery groups and solitary animals were frequently seen during the summer lactation stage. In the autumn, intermediate-sized mixed groups were formed for the rut, but nursery groups still accounted for an appreciable percentage of all sightings. During the first year, sightings of mixed groups were common in most months.

There seemed to be no consistent pattern in group composition the second field year. This was particularly evident during the spring parturition period, when more mixed groups than nursery groups were seen.

Solbert (1980) observed the dynamics of group composition in 75 - 85 Barbary sheep confined on the 2.78 km² (1.1 mile²) wildlife preserve of Camp Cooley Ranch in southeastern Texas. He recognized two distinct group types during the summer (June - September), 1) female groups, including juveniles and subadult males, and 2) adult male bachelor groups. Beginning in late August, and continuing into December, Solbert found that group composition changed with the peak of the rut: both large (30 - 40 animals) and small (5 - 10 individuals) mixed groups predominated, and adult male groups were rarely seen. During this period, juveniles and subadult males were most often seen in the larger groups, and they associated with their own age classes.

The three social classes common to all gregarious bovids are nursery herds (females with or without young), bachelor (all-male) herds, and solitary adult males (Estes, 1974). The Palo Duro Canyon study documents a greater diversity of group types for Barbary sheep, including solitary juveniles or subadults, solitary females, and groups comprised entirely of juveniles and/or subadults. Female groups were frequently seen without any juveniles or subadults, even during peak lactation months, so this group type was distinguished from nursery groups (Table 16).

Group Leadership

A study of goats by Stewart and Scott (1944) indicated that group leadership is a behavioral characteristic apparently unrelated to the social dominance hierarchy. The dominance hierarchy of Barbary sheep at the New York Zoological Park was one of linear descent through males, females, and juveniles (Katz, 1949). Group leadership in this Barbary sheep herd of 12 animals was attributed to an adult female however, based upon the results of food box experiments.

Solbert (1980) found that an older adult female with young initiated changes of group activity and occupied the leadership role during movements of Barbary sheep groups in the wildlife preserve of Camp Cooley Ranch, Texas, during the summer months (June to September). During the autumn rut, males in this herd initiated group activities and functioned as leader as often as females with young. Thus, there may be a degree of seasonal plasticity in Barbary sheep group leadership.

Group leadership for free-ranging Barbary sheep in Palo Duro Canyon was ascribed to animals that led when groups flushed upon detecting my presence. A determination of group leadership was made only when adults of both sexes were present in a group, and when the sex of the leader could be reliably ascertained. Under these circumstances, females more frequently led flushing groups (N = 22) than did males (N = 1) (Binomial test, z = -4.17, $\alpha < 0.00003$). For this reason, group leadership was ascribed to females when adults of both sexes were present in a group.

Female leadership also has been documented in such diverse taxa as beavers (<u>Castor canadensis</u>) (Hodgdon and Larson, 1973), nonterritorial plains and mountain zebras (<u>Equus quagga and E. zebra</u>) (Klingel, 1974), and European red deer (Darling, 1937). Female group leadership may have evolved in social mammals to insulate the mother-infant relationship from variable mating strategies. Males may be seasonally absent, or--if present--engaged in dominance displays, territorial contests, or distracted by estrus females.

Vocalizations

Six different types of vocalization could be distinguished for the free-ranging Barbary sheep in Palo Duro Canyon. These types were 1) sheeplike bleats, 2) goatlike bleats, 3) nose snorts, 4) mouth blows, 5) rasping screeches, and 6) guttural growls or grunts.

Females with young used all six vocalization types, whereas females without young utilized all but the rasping screech and guttural growls or grunts. Juveniles emitted only sheeplike bleats and goatlike bleats. Adult male vocalizations were limited to goatlike bleats, mouth blows, and guttural growls or grunts.

A contingency table analysis was conducted of 49 vocalizations for which the age-sex class of the vocalizing animal could be reliably determined. This analysis showed that the observed distribution of vocalizations among age-sex classes was significantly different from the expected distribution $(\chi^2 \text{ test}, T = 40.3 > \chi^2_{.05, 15} = 25.0, \alpha < 0.001)$. This finding indicates that the relationship between the age-sex class of the vocalizing animal and the sound produced is purposeful rather than random. Such an association, between vocalization type and age-sex class of vocalizing animal, suggests the adaptive or survival value of this relationship.

Adult females vocalized significantly more frequently (N = 36) than juveniles and adult males combined (N = 13)

(Binomial test, z = -3.14, $\alpha = 0.0008$). This preponderance of female utterances may be related to the female role as group leader.

Females with young routinely sounded nose snorts, rasping screeches, or guttural growls when they detected me within flushing distance. These vocalizations by females with young (N = 30) were significantly more frequent than the total of all sounds emitted by Barbary sheep in three other general categories (females without young, juveniles and subadults, and adult males) (N = 19) (Binomial test, z = 1.71, $\alpha = 0.044$). These sounds produced by females with young were therefore concluded to have a warning function.

Vocalizations by confined Barbary sheep are apparently uncommon. Solbert (1980) heard a "blowing of air through the nostrils on one occasion," but I was unable to find any other documentation in the literature for sounds emitted by Barbary sheep.

Intraspecific Aggression

Studies of confined Barbary sheep indicated that intraspecific aggressive behavior in this species is typically ritualized and of two major types (Katz, 1949; Haas, 1959; Schaffer and Reed, 1972:12). One, the head-on charge, is ordinarily confined to interactions between males and may feature a closing velocity up to 81 km/hr (50 mph) (Schaffer. 1968), with both animals remaining quadrupedal on impact. The other involves close butting and head shoving, or hooking the horns, neck, flank, or belly of the conspecific from a parallel position, followed by twisting or gouging motions.

Five types of intrapsecific aggressive behavior were distinguished for the free-ranging Barbary sheep in Palo Duro Canyon. These were 1) head-on butting where contact was horn-to-horn, 2) head shoving from a frontal position, 3) horn hooking and pulling from a frontal position, 4) horn or neck hooking from a parallel position with side- and downward pulling, or quick head movements in an attempt to hook the conspecific's flank or side from an offset parallel position, and 5) hooking of the conspecific's neck, back, or hip from a reverse-parallel position. Neck sparring from a parallel position was also sometimes seen, but seemed always to be associated with parallel horn or neck hooking.

Unsexed young juveniles were seen engaging in head-on butting and head shoving during play bouts, and seemed to attempt horn hooking from a frontal position and body hooking from a reverse-parallel position. Subadults were noted engaging in all intraspecific aggressive behaviors except horn hooking from a frontal position.

Adult males exhibited all five types described above. However, class 1 males engaging in body hooking from a reverseparallel position treated it more as a mutual grooming exercise, with a greater degree of rubbing and scratching than found in a truly aggressive encounter. Older males body hooking from a reverse-parallel position sometimes kneeled and stretched with necks near the ground as they hooked, gouged, and pulled at their opponent. I was unable to determine whether this was related to the low-stretch aggressive posture described by Geist (1971) for North American mountain sheep, or merely a response to minimize the discomfort.

Although male head-on butting and head shoving were seen, head-on clashes never reached the intensity noted by Schaffer (1968) or Hamdy and Schmidt (1972). Further, no female was ever seen engaged in an aggressive encounter with another female, except that one female sometimes chased another female a short distance. Katz (1949), however, commented that fighting was almost as common among females as among males until August, and that the usual contest between females consisted of a brief exchange of butts, sometimes accompanied by locking of horns and twisting. I saw anestrus females frequently defend themselves against unwanted male suitors, as was reported by Ogren (1965:67).

I do not know whether the absence of aggressive behavior observations featuring head-on male clashes and female-female aggressive acts in this study was merely due to chance, or these observations of Barbary sheep in Palo Duro Canyon represent the ordinary aggressive behavior repertoire of

free-ranging animals in contrast to higher levels of aggression displayed under confined conditions.

Social Ontogeny

Ogren's (1965:69) description of neonate activity immediately after parturition suggests that Barbary sheep may be among the most precocial of all higher vertebrates. All my observations of females with young estimated to be a few days to 4.5 months old (N = 159 observations) were made in or adjacent to the rugged terrain Barbary sheep typically inhabit in Palo Duro Canyon (see Chapter VII). Of these 159 observations, at least 34 represented different mother-young groups corresponding to the 26 and eight MNKA neonates documented for the two field years, respectively (see Chapter VI). Most of the other sightings were probably multiple observations of these 34 mother-young groups.

Locations of undisturbed mothers with young and escape routes used by flushing mothers indicated that few concessions are made to young animals. Neonatal young scrambled after fleeing mothers, the latter pausing periodically to allow the young to catch up. Young judged to be from one to six weeks old were frequently seen running directly under mothers during flight, whereas juveniles thought bo be eight weeks old or older moved with a flushing group but apparently not in close proximity to a particular female.

Females with neonates that appeared to be less than oneweek-old stayed near the canyon rim or rough breaks while grazing in the wheat field adjacent to the canyon. Young from about one to six weeks of age frequently were left in a nursery area watched by one or two older females while mothers grazed in the field up to 50 m away. Solitary young, or small groups of animals more than eight weeks old, also were seen occasionally. These occurrences imply a rather loose maternal-infant bond, and are consistent with findings reported by Haas (1959), who commented that female Barbary sheep rarely drove away strange infants that approached them. My field observations, therefore tend to support this conclusion. By way of contrast, Lent (1974:38) cited several studies in which ungulate mothers seemed to actively promote strong maternal-infant bonds by chasing away any strange infants which approached.

Play behavior (N = 74 observations, also representing at least 34 different juveniles based upon MNKA calculations) was noted in the youngest animals observed--probably two or three days old--and included all four of the patterns Autenrieth and Fichter (1975:65) described for pronghorn fawns: leaping, running, sparring, and bunting. Because sighting frequency was variable and groups including neonates were not seen every day, it was impossible to discern the exact ontogeny of play behavior. However, both leaping and running were observed in young thought to be less than one-week-old. Juveniles over about eight weeks of age did not exhibit spontaneous leaping and/or running, although they were sometimes lurred into these activities by younger animals engaged in play bouts. Haas (1959:240) also commented that young Barbary sheep appeared to challenge older animals to join their running play by springing past them at close range.

Sparring and bunting behaviors began to emerge as play components at two to three weeks of age, and were often seen among young left in nursery areas. These actions included head pushing, light butting, head twist-shoving (similar to adult males trying to hook or interdigitate horns from a frontal position), and neck sparring from a parallel position. In one instance, two young juveniles were seen assuming a reverse-parallel position, touching each other, then hunching down and jumping away sideways. The actions were similar to the adult male body hooking sequence from a reverseparallel position. Subadults were frequently seen engaged in head pushing or butting with other members of this age class, and subadults occasionally chased and tried to butt young juveniles which disturbed their feeding, but adults appeared to ignore playful young juveniles.

Play behavior is probably an important aspect of learning. Through the actions which comprise this behavioral category the young animal acquires information about its

environment, discovers the range of its own movements (Eibl-Eibesfeldt, 1975:273), and practices important motor patterns (Wallace, 1973:47). Although play is not directed toward an immediate consummatory act (Wallace, 1973:47), the phenomenon is certainly adaptive. Thus it is reasonable that leaping and running are the first playful actions to emerge in Barbary sheep because they have the most immediate survival value.

Eibl-Eibesfeldt (1950) observed that a badger (<u>Meles</u> <u>meles</u>) exhibited a particular play behavior only until it was mastered, then lost interest and tried something new. This may explain the reduction and disappearance of leaping and running in play bouts of Barbary sheep young after about eight weeks of age.

As Berger (1979) indicated, many factors influence the social organization of a species. Studies are just beginning to relate social development to the social organization of a species (see Barash, 1974). In free-ranging Barbary sheep, the high level of precocity and loose mother-infant bond may promote groups comprised entirely of juveniles and/ or subadults, and solitary juveniles. Further, neonatal precocity, loose mother-infant bonds, and juvenile groups may be stages of social development leading to an adult social organization characterized by considerable variability in group size and composition, and ultimately to an innate dispersal tendency.

CHAPTER XI

CONCLUSIONS AND MANAGEMENT CONSIDERATIONS

The information on Barbary sheep assembled by the literature survey, and the findings of this study based upon data collected during two years in the field, indicate several adaptive features that may be important components in the survival strategy of this species. This information and these findings also suggest a number of management considerations that are particularly relevant as Barbary sheep extend their range throughout the southwestern United States.

Adaptive Features of Barbary Sheep Biology

A "modified gambling" reproductive strategy appears to be one major adaptive feature of Barbary sheep biology. This artifice serves to concentrate most parturition into a relatively short time span during the spring when nutritious and palatable forage is available for lactating females and the juveniles they produce. The consolidation of most births into a short period of time also tends to prevent a numerical population response by predator species (Holling, 1959). The production of some young at other times of year seems to be an adaptation to irregular monthly precipitation distribution and extreme variability in precipitation amounts in an arid or semiarid environment. Young produced outside the peak parturition period do not represent a large energy investment

by the population but can benefit the population by contributing to increased numbers during years in which range condition is good throughout the year, and by compensating for some spring juvenile mortality when climatic factors at that time are unfavorable due to extreme cold, snow, or drought.

Another adaptive feature is also related to reproduction, and is exhibited in a relatively low incidence of twinning. Sixty-five females collected during hunts in New Mexico and Texas contained a mean of 1.3 fetuses per female. This compares with 1.77 fetuses per two-year-old doe for mule deer in Utah (Robinette et al., 1955), and 1.76 and 1.96 fetuses per doe from white-tailed deer in Illinois (Roseberry and Klimstra, 1970) and Iowa (Haugen, 1975), respectively. The tendency to concentrate reproductive effort and maternal care in one offspring improves juvenile survial opportunities under hostile arid or semiarid conditions and increases the reproductive output of females in such an environment. When range condition is optimal, natality in this species is increased by production of two single births in a year or three births in two years (Blunt, 1963).

A third adaptive aspect combines reproduction, group dynamics, and behavior. Most groups encountered during the autumn rut, from mid-September through mid-November, were "mixed" consisting of animals of both sexes and most age classes (Table 17). These mixed groups included older class

3 and 4 males, which appeared to dominate mating attempts. Thus most juveniles born in March and April are probably sired by older males. During much of the year older males are solitary or members of small bachelor bands, however, so most matings of estrus females at other times of year are probably accomplished by younger class 1 or 2 males associated with predominantly female groups. The tendency of younger males to associate with adult females may be explained by the concept of paedomorphism, in which a younger male favors the company of "equals" -- that is, morphologically similar adult females -- but follows these adult females (Geist, 1966a:144). This behavioral mechanism tends to maintain a higher level of genetic variability in the population than might otherwise prevail, and also operates as an evolutionary mechanism to reduce lag time between major environmental changes and appearance in the population of an increased proportion of individuals better adapted to survive under altered conditions.

The fourth major adaptive feature of Barbary sheep biology is an innate dispersal tendency that is not related to population density. This has been documented in Palo Duro Canyon (see Chapter VI) and in southern New Mexico (Dickinson and Simpson, 1980a), and serves as a mechanism to promote colonization of unoccupied habitats. The phasic pattern of this dispersal, in which periods of rapid dispersal led by adult males alternate with intervals of population consolidation or slow dispersal, may allow males to select among habitats for those most suitable before the female influx allows mating to take place in newly discovered areas.

A fifth adaptive aspect is a high degree of behavioral plasticity. This is exhibited in behavioral variability (see Chapter X), in dietary differences among Barbary sheep in various geographical regions, and in dietary shifts to accomodate available forage within a region (see Chapter VIII). Behavioral plasticity is also evident in the species' ability to tolerate a wide range of population densities (see Chapter VI) and its adaptation to variability in group sizes (see Chapter X). Eibl-Eibesfeldt (1975:251) comments that "the more variable the environment is, the less precisely can the behavior be adjusted in advance. Changing environmental conditions require individual capacities for adjustment." Additionally, Barrett (1967b) reminds us that Barbary sheep were probably subjected to several major environmental changes during their evolutionary development. This environmental variability over an evolutionary time scale likely promoted a behavioral plasticity that has been maintained by the climatic variability along an altitudinal gradient within the endemic North African range of this

species, and by climatic variability in its exotic range in the southwestern United States.

Conclusion

A review of the information on this species collated in the literature survey, and the findings of this study based upon data collected during two years of field research, suggest a general conclusion about the adaptive strategy of Barbary sheep. Although there are monthly or seasonal means for several population statistics, patterns of social organization that apparently reflect phenological changes, distinctive behavioral patterns, well defined dietary and topographic utilization preferences, and definite home range and movement characteristics, there is also a high degree of variability associated with each aspect of Barbary sheep ecology reviewed or studied. This variability is apparent within, as well as between or among, temporal intervals (months, seasons, years) and geographical regions, and suggests that a Barbary sheep population may be able to adapt its survival strategy to population density and environmental conditions.

MacArthur and Wilson (1967) originated the terms \underline{r} selection and \underline{K} -selection to indicate the adaptive strategies available to organisms. In general, \underline{r} -selected species are characterized by a high intrinsic rate of population growth, rapid individual development, relatively small size, early reproduction, and a short life span. These species emphasize a high level of productivity and colonize newly available habitats (ecological vacuums) where there is little competition for available environmental resources, often in regions of variable or unpredictable climate. They are, in a word, colonizers. K-selected species exhibit features that are diametrically opposed to those just described. Pianka (1970, 1972) subsequently refined these concepts and indicated that no organism embraces either extreme; all have evolved a compromise strategy that falls somwhere on the r-K continuum. I contend that the high degree of intrinsic variability in all facets of Barbary sheep ecology reviewed or studied allows this species to change adaptive strategies -- to move back and forth along the r-K continuum -- depending upon population density and environmental conditions. If this is true, Barbary sheep should prove to be an increasingly important, and perhaps troublesome, component of the fauna of the southwestern United States and northern Mexico for the forseeable future.

Management Considerations

The findings from the various aspects of this study have a number of implications for Barbary sheep management. Some of the more important management considerations are indicated here.

Criteria for Age and Sex Determination

1. It is possible to distinguish and recognize several age-sex classes of Barbary sheep without marking animals. This procedure has utility in field investigations of population dynamics, social organization, and behavior where project limitations make it impossible to mark large numbers of animals. Examination and measurement of skulls with horns intact and hunter-shot animals will help field workers learn to separate categories.

2. The number of classes to be differentiated should be determined by project objectives, personnel experience with this or similar species, and available learning time.

3. Where there is not a discrete correspondence between age and animal size, horn length classes can still be justi-fied for management reasons.

4. The exponential pattern of horn growth in relation to age estimates derived from growth check counts, and the high degree of correlation ($\underline{r} = 0.965$) between the two, supports the concept of horn growth checks as true growth annuli that can be used as a valid criterion of age for Barbary sheep.

5. The equations developed here indicate that total horn length measurements offer a simple and reasonably good technique for estimating Barbary sheep age, and suggest investigating the applicability of this method to other bovid species.

6. Age estimates based on horn length measurements can be used a) to supplement horn growth check counts, b) when checks have been obscured by wear, and c) by hunters and inexperienced wildlife management personnel who may find annulus identification confusing.

7. The application of these equations probably should be limited to the Palo Duro Canyon population. Wildlife biologists should calculate predictive equations for Barbary sheep populations in other areas to account for possible variations in age-specific horn growth among various climatic and vegetational zones in the southwestern United States.

Weight Estimation from Horn Length

1. The equations developed in this study indicate that horn length can be a useful weight estimator, and suggest investigating the applicability of this methodology to other bovids for which research and management needs are frustrated by comparable obstacles.

2. Again, the application of these equations should probably be limited to the Palo Duro Canyon population. Predictive equations for populations in other areas should be developed from samples of those populations to account for possible variations in the body weight-horn length relationship among geographical regions. 3. My field data suggest that it may be possible to sex aoudad skulls from a combination of horn measurements. If so, that technique used in conjunction with these equations would permit sex determination and weight estimation of animals from skulls found in the field.

Population Characteristics

 My experience during this study indicates that it is difficult, time consuming, and expensive to collect reliable data on Barbary sheep population characteristics.

2. Because of the innate dispersal tendency of Barbary sheep, population data from some areas may not be useful beyond the period in which it was collected.

3. It might be possible to develop surrogate index values as an indication of population trends in selected areas rather than estimating population size. Such index values could be based on frequency of sightings along a standardized route similar to the method used in this study.

4. Population structure data suggest that the preponderance of females in the population will tend to maximize productivity in this species, with concommitant increases in population size and dispersal.

5. The population structure also shows a small percentage of males in the two oldest age classes. Under the current harvest strategy the percentage of trophy and near-trophy males is likely to decline. Because, unlike deer, this species is not ordinarily hunted for meat, a decline in the percentage of available trophy class males may have unfavorable economic consequences for some ranchers who depend upon hunting revenue.

Topographic Distribution and Spatial Utilization

1. The ubiquitous distribution of Barbary sheep on the study area indicates this species overlaps areas used by mule deer and domestic cattle, and suggests the possibility of competition for preferred forage plants. Such competition could be -- or become -- locally severe and might diminish range condition on some sites.

 Barbary sheep apparently prefer precipitous sites that are inaccessible to cattle and may not be heavily used by mule deer.

Diet Studies

1 Woody browse is the major dietary component of Barbary sheep in Palo Duro Canyon, although substantial amounts of forbs and grasses are consumed in all seasons. A high degree of dietary adaptability permits shifts in food plant utilization in response to available forage on a seasonal basis.

2. The dietary plasticity of Barbary sheep suggests that variations in the availability of particular food

plants or even broad forage classes will not prevent or reduce dispersal in areas of suitable topography throughout the southwestern United States.

3. Diets of Barbary sheep and mule deer are similar where both species occur (Bird and Upham, 1980; Krysl et al., 1980), but mule deer exhibit rather narrow food preferences in the Southwest (Kufeld et al., 1973; Krysl, 1979). Thus mule deer are at a competitive disadvantage where these two species are sympatric.

4. Sand shinnery oak and mountain mahogany are important foods of Barbary sheep in Palo Duro Canyon, and appear to be critical ingredients of mule deer diets in this area as well (Krysl et al., 1980). Competition for these two shrubs could seriously diminish the physical condition of mule deer, with their restricted diet, as they enter the late autumn rut and winter stress period. With these considerations in mind, programs designed to control brush and woody vegetation should be carefully planned to preserve and enhance shinnery oak and mountain mahogany in Palo Duro Canyon and adjacent areas if mule deer populations are to be maintained in this region.

Parasitism and Pathology

1. Gastrointestinal helminth infections of both Barbary sheep and mule deer were limited to a small number of worm

species, the proportion of hosts infected with any of the helminth parasites was small to moderate, and infection levels in all host animals were light, therefore gastrointestinal helminth parasites do not appear to be a factor of major consequence in the ecology of either ungulate species in Palo Duro Canyon at this time.

2. With the possible exception of the abomasal worm (<u>Haemonchus contortus</u>), neither Barbary sheep nor mule deer is a reservoir for helminths found in the other host species.

3. Considering the paucity of helminth species and the low infection levels, neither Barbary sheep nor mule deer can be considered an important helminth reservoir for domestic livestock in this area.

4. The common presence of range cattle, and their locally high densities in some pastures, may constitute a major reservoir for helminth parasite infections in Barbary sheep and mule deer.

5. Infestations of both wild ungulates consisted of a small number of ectoparasite species, the proportion of hosts harboring any one of the parasites was small and infestation levels on all host animals were light, therefore ectoparasites appear to pose no immediate threat to populations of either Barbary sheep or mule deer in this area.

6. Both ticks recovered are important pests of domestic livestock and their presence on Barbary sheep, which have

demonstrated a capacity for pronounced range extensions (Dickinson and Simpson, 1980a) and abrupt long distance movements (Hampy, 1978; Chapter VI), indicates a means by which these arthropods can be broadly dispersed. Considering the inaccessibility of many places in the canyon to domestic livestock, the occurrence of even small numbers of ticks on Barbary sheep emphasizes their potential importance as a reservoir and transport host over much of this rugged terrain. Conversely, the presence of range cattle may be the source of Barbary sheep and mule deer infestations.

7. The discovery of a previously undescribed species of louse on Barbary sheep suggests the desirability of examining other exotic ungulates in Texas for lice.

8. Since the Barbary sheep and mule deer examined were collected only during the autumn, these findings undoubtedly reflect some seasonal bias. Thus it would be desirable to examine additional host animals collected during other seasons in order to more fully define the parasite fauna of wild ungulates in Palo Duro Canyon.

9. Scarified granulation tissue and active suppurating lesions noted on a high proportion of hunter-killed Barbary sheep suggests that most animals of this species from the Palo Duro Canyon population are infected with elaeophorosis at some time in their lives.

10. Lesions on the heads of some animals are so extensive that hunters consider them unsuitable for trophy mounts, so this infection must now be considered in all planning related to Barbary sheep population management and should be an important consideration for stocking or game ranch programs, especially in areas with moderate to high mule deer populations.

11. Little is known at present about the distribution, vectors, epizootiology, or pathogenicity of elaeophorosis in in Barbary sheep, and this would undoubtedly be a promising area for further investigation.

Sociobiology

1. Neonatal precocity, the rather loose mother-infant bond, and the surprisingly high percentage of solitary juveniles or juvenile groups encountered suggest that many young attempt, or are forced into, an independent role before they are fully capable of functioning self-sufficiently. These young may be subjected to heavier predation pressure, which is partially reflected in a high juvenile mortality rate (see Chapter VI); conversely, young animals may be capable of surviving the loss or death of mothers.

2. It is probable that Barbary sheep group dynamics follow a coherent pattern of seasonal variation correlated with species phenology under normal range conditions. For this reason, population control measures, if deemed necessary, would be most cost-effective during the autumn rut -especially October -- when group sizes are moderately large, both sexes occur together, and the animals are preoccupied with mating activities, or during the winter aggregation period. Likewise, if it is intended that hunting have a minimal impact on the population, then seasons should be scheduled to end before 15 September or begin after 15 November in order to reduce interference with rutting behavior and avoid depressing conception rates.

3. It appears that the adaptive strategy when range condition is poor due to low precipitation is a random one, reflected in variable and rapidly changing group sizes and compositions, in response to what is perceived as a stochastic environment. It is also possible that poor range conditions may act as a dispersal trigger.

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