RESPONSE OF DESERT MULE DEER TO HABITAT ALTERATIONS IN THE LOWER SONORAN DESERT

by

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My wife Belem and my children

Carlos Alexandro, Daniel Eduardo, Natalí, and Anelí

My father Severo and mother Emelia

My brothers and sister

The families Alcalá Galván and Moreno Martínez

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ABSTRACT

About 1,600,000 ha of desert mule deer range in Mexico are currently altered with vegetation clear-cutting and establishment of buffelgrass pastures. Consequently, the availability of important resources as cover and forage from scrub vegetation has been reduced for desert mule deer. No previous research has been conducted to investigate how desert mule deer respond to those alterations. Therefore, the purpose of this research was to examine movements of desert mule deer, evaluate their home range sizes and determine habitat use, and analyze their diets in areas of central and western Sonora, Mexico. The approach involved the use of radiotelemetry techniques and GIS programs to calculate home range sizes, examine selection of vegetation associations, and identify the specific components of habitat that better distinguished the characteristics of selected sites by desert mule deer. I used the microhistological technique to determine botanical components of desert mule deer diets, and compare diets of desert mule deer and cattle in habitat with buffelgrass pastures. Diet analyses included spatial and temporal comparisons of diversity and similarity indices. Sizes of home ranges were larger in the more arid environments of western Sonora (27.3 km^2) than in central Sonora (14.5 km^2). Desert mule deer used altered habitat differently than use areas without buffelgrass, however, there was no difference in the size of home ranges of mule deer from inside buffelgrass areas and the size of home ranges of deer in native scrub vegetation. Thermal cover, ground cover, and percent of gravel in the ground were the variables that distinguished locations selected by desert mule deer. Desert mule deer selected xeroriparian vegetation and sites closer to water sources. Water sources may have

influenced mule deer to stay in buffelgrass areas despite the lack of cover and forage from shrubs and trees. For diets of mule deer, I identified 96 plant species, 69 of which have not previously been reported as forage for this wild herbivore. Desert mule deer and cattle shared 45 forage species from central Sonora. However, biological overlap of diets occurred only for spring. Results from these studies provide information to understand ecological relationships of desert mule deer on altered habitats.

INTRODUCTION

Explanation of the Problem

Desert mule deer (*Odocoileus hemionus eremicus)* represent one of the most important game species in North America and occur in desert regions of the southwestern United States and northwestern Mexico (Heffelfinger 2000). Population dynamics, biology and habitat relationships of desert mule deer have been well documented in the United States (Kie and Czech 2000). However, there is a lack of information about the productivity of this species and their ecological relationships to habitat resources in Mexico. Habitat conditions for the desert mule deer in northwestern Mexico have natural (Brown 1994) and human-caused differences in comparison to the habitat in the rest of their distribution. Rangelands in Sonora, Mexico have been altered to favor cattle production since the 1960 s (Camou-Healy 1994). Alterations include extensive transformation of desert scrub into pasture for exotic buffelgrass (*Cenchrus ciliaris*), overgrazing, and an increasing number of artificial sources of water. About 1,600,000 ha of desert mule deer range in Mexico is currently altered with vegetation clear-cutting and establishment of buffelgrass pastures (Búrquez-Montijo et al. 2002). Consequently, the availability of important resources as cover and forage from scrub vegetation have been reduced for desert mule deer. No previous research has been conducted to investigate how desert mule deer respond to those alterations. Therefore, the present research was on examination of movements of desert mule deer, their home range sizes and habitat use, and the analyses of diets throughout different areas in central and western Sonora, Mexico to understand ecological relationships of desert mule deer on these altered habitats.

Literature Review

Home range and habitat use by desert mule deer in altered habitats. – Daily activities of desert mule deer that reflect home range size and movement patterns are influenced by season, habitat conditions, and other factors inherent to the species (Mackie et al. 1982, Anderson and Wallmo 1984). Deer home range size increases as the distance between necessary resources increases. Mackie et al. (1982) reported home ranges in semi-desert ranges as large as 21 km^2. However in arid environments, home ranges are 8 times than those reported by Mackie et al. (1982). Home ranges for desert mule deer in southern Arizona are 121-172 km^2 (Krausman 1985, Rautenstrauch and Krausman 1989). During summer female desert mule deer commonly exhibit smaller home ranges than during any other season (Fox and Krausman 1994, Krausman and Etchberger 1995). These animals select areas with vegetation that provides good cover to minimize temperature stress and protect their fawns (Fox and Krausman 1994). Another important resource that influences desert mule deer movements is water. Water has been considered as an important limiting factor for desert mule deer (Leopold and Krausman 1991). Amount and distribution of water sources affect the distribution of mule deer in arid environments. In the southwestern United States mule deer are usually found within 2.4 km of free water (Hanson and McCulloch 1955, Swank 1958, Boroski and Mossman 1996). Some studies in the desert areas of southwestern Arizona reported observations where mule deer were found significantly closer to water sources during summer

(Ordway and Krausman 1986, Hervert and Krausman 1986, Krausman et al. 1989, Rautenstrauch and Krausman 1989, Krausman and Etchberger 1995). Conversely, the effect of extensive alterations such as buffelgrass plantations on desert mule deer has not been evaluated. However, tentative suggestions have been made that this exotic grass is not favorable to native wildlife (Bock and Bock 1988; Martin et al. 1998).

The objectives of our studies were to determine home range sizes and differences among seasons and areas of central and western Sonora, Mexico that have been altered with plantations of buffelgrass; determine the use of natural and altered components of habitat by desert mule deer; and identify differences in the characteristics of selected sites to random sites in altered habitat of desert mule deer. We tested the statistical hypothesis that desert mule deer used habitat that has been altered with buffelgrass no differently than use of areas without buffelgrass.

Diets of desert mule deer. – Diets of desert mule deer have been described in the southwestern United States (Krausman et al.1997) including California (Marshal et al. 2004), Arizona (Urness et al. 1971; McCulloch 1973; Anthony 1976; Anthony and Smith 1977; Short 1977; Krausman et al. 1989), New Mexico (Anderson et al. 1965; Boeker et al. 1972), and Texas (Krausman 1978; Leopold and Krausman 1987). Variation in composition of diets is strongly related to the variation on the availability of resources in the habitat (Krausman et al. 1989). This variation may be observed in temporal and spatial scales. Seasonal variation in diets of mule deer has been reported throughout desert mule deer range (Krausman et al. 1997; Marshal et al. 2004). Studies from the southwestern United States have demonstrated that browse is the dominant forage consumed by desert mule deer (McCulloch 1973; Krausman et al. 1997; Marshal et al. 2004). There is no previous documentation of diets of desert mule deer from the Sonoran Desert, Sonora, Mexico. The Plains of Sonora and the Central Gulf Coast subdivisions in Sonora have distinctive biotic characteristics (Brown 1994). Furthermore, these regions have been overgrazed by cattle (Camou-Healy 1994) and transformed into pasture lands with the exotic buffelgrass. This exotic, was introduced to solve erosion problems and boost feed production on cattle pastures. However, no consideration as to how this introduction influenced wildlife. Obviously, extensive buffelgrass stands likely influence forage for desert mule deer, therefore we wanted to know, if, and how they did. Our objectives were to determine diets of desert mule deer from central and western Sonora, Mexico, and compare diets of desert mule deer and cattle in altered habitat with buffelgrass pastures.

Explanation of Dissertation Format

The papers that comprise the appendices of this dissertation communicate the results of work pertaining to the study of responses of desert mule deer to habitat alterations in the Lower Sonoran Desert, Sonora, Mexico. These studies investigated aspects related to ecology of desert mule deer with respect to home range sizes, habitat use, characteristics of selected sites, and seasonal diets in relation to habitat alterations such as the conversion of native scrublands into buffelgrass pastures and the presence of artificial water sources.

All papers in this dissertation are the result of work I conducted as a Ph.D. student while enrolled at The University of Arizona. My major professor and committee members advised me, but I was responsible for collecting and analyzing data, and presenting the results as a dissertation. I will be the senior author on publications that result from my dissertation project, and coauthors may include others, including committee members, who contributed to different aspects of the research.

PRESENT STUDY

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

Study Areas

The fieldwork for the present research occurred in 4 areas of central and western Sonora, Mexico. Area 1 was on Rancho San Luis-CIPES, 54 km north of Hermosillo in the central region of Sonora, Mexico (29° 32’ and 29° 35’N, 111° 01’ and 111° 08’W) (CETENAL 1974). This area encompasses 20,500 ha of the Plains of Sonora Subdivision of the Sonoran Desert (Brown 1994). Approximately 5,600 ha (27%) were converted from native vegetation to buffelgrass. Elevations ranged from 450 m to 550 m on flats and plains to 551 to 750 m of rough terrain (e. g., Sierra La Cobriza). Soils were recent alluvium, weathered from granitic rocks 2 to 6 m deep (Hendricks 1975). Average annual precipitation was 320 mm (Centro de Investigaciones Pecuarias del Estado de Sonora 1989). Precipitation was bimodal: approximately 60% occurred between July and September, and 40% occurred between November and March. The remaining months were usually dry. Summer rainfall occurred as thunderstorms of high intensity. Annual mean temperature was 23°C. Daytime temperatures averaged 34° C, but frequently exceed 40° C in June through August. Night-time temperatures averaged 8° C in winter, and approached 0° C in December, January, and February. Vegetation in Rancho San Luis was representative of the arbosuffrutescent desert-scrub in the Plains of Sonora Subdivision of the Sonoran Desert (Shreve and Wiggins 1964; Brown 1994). Shrubs and small to medium sized trees dominated overstory vegetation. Common species were ironwood (*Olneya tesota* A. Gray), mesquite (*Prosopis juliflora* (Sw.) D.C.), paloverde (*Cercidium microphyllum* (Torr.) Rose & Johnston), bird-of-paradise (*Caesalpinia pumila* (Britt & Rose) Hermann), brittle bush (*Encelia farinosa* A. Gray), and snakewood (*Condalia* spp. Cav). Understory vegetation was represented by perennials including woolly tidestromia (*Tidestromia lanuginosa* (Nutt.) Standl.), milkweeds (*Euphorbia* spp.), and ambrosia (*Ambrosia* spp.), and grasses including false grama (*Cathestecum brevifolium* Vasey & Hack.), spidergrass (*Aristida ternipes* Cav.), sixweeks threeawn (*Aristida adscencionis* L), false sideoats (*Bouteloua reflexa* Swallen) and bristlegrass (*Setaria macrostachia* H.B.K.). Cacti were present but sparse. Common cacti were organ pipe cactus (*Lemaireocereus thurberi* [Engelm.] Britt. & Rose), and chainfruit cholla (*Opuntia fulgida* Engelm). This area was used for cattle production and the condition of rangeland was considered good to excellent.

Area 2 was on Rancho La Jubaivena and adjacent lands. This area was located 54 km north of Hermosillo and 14 km west of area 1 in the central region of Sonora, Mexico (29° 34’ and 29° 41’ N, 111° 12’ and 111° 18’ W) (CETENAL 1974). Elevations ranged from 500 to 650 m. Climate, soil, and vegetation were similar to area San Luis. The core of the study area comprised 10,500 ha of native arbosuffrutescent scrub surrounded by buffelgrass pastures. Cattle have overgrazed this area. Understory vegetation was scarce and bare ground was common and eolic and hydric erosion were evident.

Area 3 was on Rancho La Pintada located 52 km south of Hermosillo, at the northwest base-plains of Sierra Libre, central Sonora, Mexico (28° 38’ and 28° 42’N, 110° 57’ and 111° 01’W). This area was located in the southern portion of the Plains of Sonora Subdivision of the Sonoran Desert. Native desert scrub has also been converted to buffelgrass pastures in > 50% of the land. Average annual precipitation was 260 mm. Temperature regimes were 1 to 2° C warmer than San Luis and La Jubaivena. Common shrubs and tree species included ironwood, mesquite, paloverde, bird-of-paradise, brittlebush, sanjuanico (*Jacquinia pungens* A. Gray), and catclaw mimosa (*Mimosa laxiflora* Benth). The cacti present were organpipe cactus, chainfruit cholla, teddybear cholla (*Opuntia bigelovii* Engelm), and barrel cactus (*Ferocactus* spp. Britt. and Rose). Herbaceous vegetation was scarce were native vegetation occurred.

Area 4 was on Rancho El Americano and its surrounding lands, 25 km north of Puerto Libertad, in Pitiquito, Sonora, (30° 00’ and 30°17’N, 112°17’ and 112°43’W). This area encompassed 83,000 ha where physiognomic and vegetational characteristics represented 2 of the Subdivisions of the Sonoran Desert: Central Golf Coast and Lower Colorado River Valley. The southern and western portions of the area of study were plains inclined to the sea that were part of the Central Gulf Coast Subdivision of the Sonoran Desert. The central and northern portions of area El Americano coastal plains merged into rough terrain and northern plains with characteristics of the Lower Colorado River Valley Subdivision (Shreve and Wiggins 1964; Brown 1994). Elevations ranged from 150 to 500 m in coastal plains and from 500 to 750 m in desert mountains (i.e., Sierra Aguirre and Sierra Picu). Precipitation was also bimodal; 70 % occurred in summer. Average annual precipitation was 180 mm. Annual mean temperature was 23 °C. Vegetation in coastal plains was characteristic of the sarcocaulescent desert-scrub and vegetation in foothills and northern plains was microphyllous desert-scrub (Shreve and Wiggins 1964; Brown 1994). Common plants in the sarcocaulescent area were elephant tree (*Bursera microphylla* A. Gray), lomboy bushes (*Jatropha cuneata* Wigg. And Roll., and jatropha (*Jatropha cinerea* [C. G Ortega] Muell). Creosote bush (*Larrea tridentata* [Sessé and Moc. ex DC.] Coville), burrobush (*Ambrosia dumosa* A. Gray), brittlebush with the cacti cardon (*Pachycereus pringlei* [S. Wats] Britt. and Rose) and teddy bear cholla were also present. Microphyllous desert in foothills and northern plains included creosote bush, ocotillo (*Fouquieria splendens* Engelm), blue paloverde (*Cercidium floridum* Benth), paloverde, burrobush, brittlebush, and lomboy bush. Common cacti were organpipe cactus, saguaro (*Carnegia gigantea* [Engelm ex Emory] Britt and Rose), barrelcactus, and pencil cholla (*Opuntia arbuscula* Engelm). Riparian associations contained ironwood, mesquite, paloverde, and catclaw acacia (*Acacia occidentalis* Rose). Because of lower precipitation, buffelgrass was present in lower proportions than in the other three areas. Small and localized areas converted to buffelgrass represented < 2% of area El Americano. I followed Shreve and Wiggins (1964) for scientific nomenclature and the United States Department of Agriculture – Natural Resources Conservation Service (USDA-NRCS 2005) for common names of plants.

Cattle grazing was common all year in all areas, however stocking rates were lower in El Americano, where rangeland offered a comparatively reduced amount of forage for cattle. Large and medium-sized mammals other than mule deer and cattle present in all 4 areas included white-tailed deer (*Odocoileus virginianus*), collared peccary (*Pecari tajacu*), mountain lion (*Puma concolor*), coyote (*Canis latrans*), antelope jackrabbit (*Lepus alleni*), and desert cottontail (*Sylvilagus audubonii*). Feral burros (*Equus asinus*) and black-tailed jackrabbitt (*Lepus californicus*) were also present in area El Americano. I examined home ranges and habitat use in La Jubaivena and El Americano; and analyzed diets of desert mule deer in all areas.

Home Ranges and Habitat Use by Desert Mule Deer in Altered Habitats

I studied radiocollared mule deer to evaluate home range sizes and habitat use on altered habitats in central and western Sonora, Mexico. Sizes of home ranges were larger in the more arid environments of western Sonora (27.3 $km^2 \pm 2.6$ [SE]) than in central Sonora (14.5 $km^2 \pm 2.0$ [SE]) (Kruskal-Wallis $X^2_6 = 17.98$, $P = 0.006$). During summer, mule deer home ranges were smaller ($P < 0.05$) than any other season in both areas. There was no difference (Kruskal-Wallis, $X^2_1 = 0.28$, $P = 0.60$) in the size of home ranges of mule deer from inside buffelgrass areas (5.16 $km^2 \pm 0.95$ [SE]) and the size of home ranges of deer in native scrub vegetation (6.16 $km^2 \pm 0.51$ [SE]). Desert mule deer did not use the vegetation associations in proportion to their availability in either study area ($P < 0.001$). Thermal cover (i.e., vegetation $\geq$ 75 cm high that provided shade for a deer), ground cover, and percent of gravel in the ground were the variables that distinguished ($P < 0.10$) locations selected by desert mule deer versus random locations. In general, desert mule deer selected xeroriparian vegetation and sites closer to water sources in both areas throughout the study. Desert mule deer used altered habitat differently than use areas without buffelgrass. Water sources may have influenced mule deer to stay in buffelgrass areas despite the lack of cover and forage from shrubs and trees.

Diets of Desert Mule Deer in central and western Sonora, Mexico

I conducted microhistological analyses of feces to identify diets of desert mule deer in 4 areas of central and western Sonora, Mexico, to determine seasonal variation in forage classes, and compare diets of mule deer and cattle in altered habitat with buffelgrass. For diet of mule deer, I identified 96 plant species, 69 of which have not previously been reported as forage for this wild herbivore. Of these species, 44 occurred in the mule deer diet $\geq$ 1%. Browse was the most important forage class consumed by mule deer at all study areas (77 - 88%). Forbs comprised 5 to 10% of the diet of mule deer on average among all areas. Use of succulents was highly variable among areas. Grass species were the lowest forage class for desert mule deer throughout the areas and seasons, however, important consumption of native grasses occurred in 1 area of central Sonora. Buffelgrass was not important in diets of desert mule deer. Conversely, buffelgrass was the most important forage species for cattle. Desert mule deer and cattle shared 45 forage species from central Sonora. However, biological overlap of diets occurred only for spring (Morisita coefficient = 0.67). Plant diversity in diets of mule deer was slightly different among areas and seasons. Shannon-Wiener (H') index was different ($P < 0.05$) only between the area with higher precipitation and the area with lowest precipitation. Data from this study contribute to understanding the primary resources for desert mule deer in altered habitat of Lower Sonoran Desert.

CONCLUSION

Availability of resources for wildlife is strongly related to climate fluctuations and management activities. The climate is predictable but not controllable. Management and its effects are measurable and controllable.

Important consequences on the performance of wildlife result from extensive rangeland management that focuses primarily on exclusive production of livestock, with minimal or no concerns for native fauna. Clear examples of this situation are the altered conditions of habitat for mule deer in northwestern Mexico. Adaptations of desert mule deer include a shift of their selection behavior in response to availability of resources. This behavior modification may impact performance and long-term productivity when mule deer use altered habitats regardless of the reduction in browse and cover. There is a high variability among individuals of mule deer in the selection of vegetation associations and altered areas. However, mule deer use areas with a larger amount of trees and shrubs even in those areas treated for buffelgrass pastures. Researchers and managers should focus conservation efforts on identifying threshold limits of altered habitats, determining differences in mule deer densities, evaluating the survival rates and productivity of desert mule deer in relation to those alterations, and recovering the conditions of the native scrub to enhance habitat and satisfy desert mule deer requirements.

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APPENDIX A. DRAFT MANUSCRIPT TO BE SUBMITTED TO THE JOURNAL OF WILDLIFE MANAGEMENT: ALCALÁ-GALVÁN, C. H., AND P. R. KRAUSMAN. HOME RANGE AND HABITAT USE BY DESERT MULE DEER IN ALTERED HABITATS.

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RH: Home range and habitat use • *Alcalá-Galván and Krausman*

HOME RANGE AND HABITAT USE BY DESERT MULE DEER IN ALTERED HABITATS

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Abstract: Alterations of desert mule deer (*Odocoileus hemionus eremicus*) habitat in Sonora, Mexico include overgrazing, additions of water sources, and transformation of desert scrub into pastures of exotic buffelgrass (*Cenchrus ciliaris*). No previous research has been conducted to understand how mule deer respond to these alterations. We studied radiocollared mule deer from April 2002 to June 2004 to evaluate home range sizes and habitat use on altered habitats in central and western Sonora, Mexico. Sizes of home ranges were larger in more arid environment of western Sonora (27.3 $km^2 \pm 2.6$ [SE]) than in central Sonora (14.5 $km^2 \pm 2.0$ [SE]) (Kruskal-Wallis $X^2_6 = 17.98$, $P = 0.006$). During summer, mule deer home ranges were smaller ($P < 0.05$) than any other season in both areas. There was no difference (Kruskal-Wallis, $X^2_1 = 0.28$, $P = 0.60$) in

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the size of home ranges of mule deer in buffelgrass areas (5.16 $km^2 \pm 0.95$ [SE]) versus the size of home ranges of deer in native scrub vegetation (6.16 $km^2 \pm 0.51$[SE]). Desert mule deer did not use the vegetation associations in proportion to their availability in either study areas ($P < 0.001$). Thermal cover, ground cover, and percent of gravel on the ground distinguished ($P < 0.10$) locations selected by desert mule deer versus random locations. In general, desert mule deer selected xeroriparian vegetation and sites closer to water sources in both areas. Desert mule deer used altered areas with buffelgrass, however, they selected sites with larger amount of shrubs or trees that supplied thermal cover. Researchers and managers should focus conservation effort to identify threshold limits of altered habitats, determine differences in mule deer densities, and evaluate the survival rates and productivity of desert mule deer in relation to those alterations.

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Key words: buffelgrass, *Cenchrus ciliaris*, habitat, Mexico, mule deer, *Odocoileus hemionus*, Sonora, water sources.

Desert mule deer are an important big game species in North America and inhabit part of the Sonoran and Chihuahuan deserts in the southwestern United States and northwestern Mexico (Heffelfinger 2000). Population trends, productivity and performance of mule deer have been well documented in the United States (Kie and Czech 2000). On the contrary, there is a lack of literature on the status and trend of mule deer populations and on the conditions of habitat in Mexico.

The central and western regions of Sonora, Mexico have distinctive biotic characteristics (Brown 1994). In addition, landscapes in these regions have been altered to enhance cattle management (Camou-Healy 1994). Alterations to the habitat of desert mule deer include transformation of the desert scrub into pasture for exotic buffelgrass, overgrazing, and establishment of artificial sources of water. By the early 1990s, buffelgrass was present in 1,200,000 ha of Sonoran rangeland (Yetman and Búrquez 1994) and there are estimations that buffelgrass occurs on > 1,600,000 ha (Búrquez-Montijo et al. 2002). In fact, the conditions of desert mule deer habitat in Sonora have been modified to favor cattle production since the 1960s. About 20% of the mule deer range in Sonora has been altered by clear-cutting and establishing of buffelgrass pastures. There is no primary literature showing the effect of these habitat alterations on mule deer populations.

The objectives of our study were to determine home range sizes and differences among seasons and areas of central and western Sonora, Mexico that have been altered with plantations of buffelgrass; determine the use of natural and altered components of habitat by desert mule deer; and identify differences in the characteristics of selected sites to random sites in altered habitat of desert mule deer.

STUDY AREAS

This study was conducted in 2 areas of the Lower Sonoran Desert in the central and western Sonora, Mexico (Fig. 1). The first area included Rancho La Jubaivena and adjacent lands. This area is located 54 km north of Hermosillo in the central region of Sonora, Mexico (29° 34' and 29° 41' N, 111° 12' and 111° 18' W) (CETENAL 1974). The area was 24,155 ha in size and elevations ranged from 500 to 650 m. Average annual precipitation was 320 mm (Centro de Investigaciones Pecuarias del Estado de

Sonora 1989). Precipitation was bimodally distributed: approximately 60% occurred between July and September, and about 40% occurred between November and March. The remaining months were usually dry but exceptions occur. Summer rainfall occurs as thunderstorms, that are frequently localized, and of high intensity. Annual mean temperature was 23 °C. Daytime temperatures averaged 34° C, but frequently exceed 40° C in June through August. Night-time temperatures averaged 8° C in winter, and approached 0° C in December, January, or February. Vegetation was representative of the arbosuffrutescent desert-scrub in the Plains of Sonora Subdivision of the Sonoran Desert (Shreve and Wiggins 1964, Brown 1994). We followed Shreve and Wiggins (1964) for scientific nomenclature and USDA-NRCS (2005) for common names of plants. Shrubs and small to medium sized trees dominate overstory vegetation. Common species were ironwood (*Olneya tesota*), mesquite (*Prosopis juliflora*), paloverde (*Cercidium* spp.), bird-of-paradise (*Caesalpinia pumila*), brittle bush (*Encelia farinosa*), snakewood (*Condalia* spp.), and catclaw mimosa (*Mimosa laxiflora*). Understory vegetation was represented by perennial herbaceous like tidestromia (*Tidestromia lanuginosa*), and milkweeds (*Euphorbia* spp.), and grasses like false grama (*Cathestecum brevifolium*), spidergrass (*Aristida ternipes*), sixweeks threeawn (*Aristida adscencionis*), false sideoats (*Bouteloa reflexa*) and bristlegrass (*Setaria macrostacya*). Cacti were present but sparse. Common cacti were organ pipe cactus (*Lemaireocereus thurberi*), and chainfruit cholla (*Opuntia fulgida*). The core of the study area comprised 10,500 ha of native arbosuffrutescent scrub surrounded by buffelgrass pastures. Native vegetation has been overgrazed by cattle. Understory vegetation was scarce and bare ground appeared on extensive areas where eolic and hydric erosion was evident. We identified 4 major vegetation associations: *mesquite– bird-of-paradise* – xeroriparian, *ironwood* – brittle bush – plains, elephant tree – catclaw mimosa – foothills, and buffelgrass pastures in the area (Fig. 2).

The second area included Rancho El Americano and adjacent lands. This ranch was located 25 km north of Puerto Libertad in Pitiquito, Sonora, (30° 00’ and 30°17’ N, 112°17’ and 112°43’ W). This area encompassed 83,000 ha where physiognomic and vegetational characteristics represent 2 of the subdivisions of the Sonoran Desert. The southern and western portions of the area of study were plains inclined to the sea that were part of the Central Gulf Coast Subdivision of the Sonoran Desert. The central and northern portions of Rancho El Americano were coastal plains that merged into rough terrain and northern plains characteristic of the Lower Colorado River Valley Subdivision (Shreve and Wiggins 1964, Brown 1994). Elevation ranged from 150 to 500 m in coastal plains and from 500 to 750 m in desert mountains (i.e., Sierra Aguirre and Sierra Picu). Precipitation was bimodal with 70 % in summer months. Average annual precipitation was 180 mm. Annual mean temperature was 23 °C. Vegetation in coastal plains was characteristic of the sarcocaulescent desert-scrub and vegetation in foothills and northern plains is microphyllous desert-scrub (Shreve and Wiggins 1964; Brown 1994). Common plants in the sarcocaulescent area included elephant tree, bursera (*Bursera hindsiana*), limberbush (*Jatropha cuneata*, *J. cinerea*), and creosote bush (*Larrea tridentata*), burrobush, brittle bush with the cacti etcho (*Pachycereus pringlei*), chainfruit cholla and teddy bear cholla (*Opuntia bigelovii*). Microphyllous desert in foothills and northern plains included creosote bush, ocotillo (*Fouquieria splendens*), paloverde (*Cercidium floridum*, and *C. microphyllum*), triangleleaf bursage (*Ambrosia deltoidea*), burrobush (*Ambrosia dumosa*), brittle bush, and limber bush. Common cacti were organ pipe cactus, saguaro (*Carnegia gigantea*), barrel cactus (*Ferocactus acanthodes*) and teddy bear cholla. Small and localized areas converted to buffelgrass represent 1% of the study area. Performance and natural dispersion of buffelgrass was limited in the area because of lower precipitation. We identified 6 major vegetation associations in this area: mesquite – ironwood – xeroriparian, elephant tree – limber bush – northern foothills, creosote bush – paloverde – hills, creosote bush – bursage – plains, creosote bush – etcho – coastal plains, and buffelgrass pastures (Fig. 3).

Cattle grazing was common year-round in both areas, however stocking rates are lower in El Americano, where rangeland offered a comparatively reduced amount of forage for cattle. Free standing water (i.e., 15 sources in each area) was available for desert mule deer. Large- and medium-sized mammals other than mule deer and cattle present in both areas included white-tailed deer (*Odocoileus virginianus couesi*), collared peccary (*Pecari tajacu*), mountain lion (*Puma concolor*), coyote (*Canis latrans*), antelope jackrabbit (*Lepus alleni*), and desert cottontail (*Sylvilagus audubonii*). Feral burros (*Equus asinus*) and black-tailed jackrabbitt (*Lepus californicus*) are also present in El Americano.

We determined seasons for our study areas from bimodal precipitation and temperature regimes (Krausman 1985). The seasons were cold-wet (winter: January-

March), hot-dry (spring: April-June), hot-wet (summer: July-September), and cold-dry (autumn: October-December).

METHODS

We captured mule deer in April 2002 with a net-gun fired from a helicopter (Krausman et al. 1985). We attached VHF standard radiocollars (MOD-500) with mortality sensors (S6A, 4 hr) (Telonics, Mesa, Arizona) to the neck of each animal. We monitored marked deer from April 2002 to June 2004. Ground locations involved visual contact of radiocollared mule deer and were made $\geq$ 4 times each month (i.e., we attempted to locate each deer once a week) using a Model TR-2 receiver and hand-held H-antennas (model RA-1AK, Telonics, Mesa, Arizona). We made aerial locations 1 time/month from a Cessna 182 aircraft equipped with a Model TR-2 receiver, an antenna switch selector, and directional H-antennas (model RA-2AK, Telonics, Mesa, Arizona) mounted on each wing strut. We assumed location error and followed recommendations in aerial tracking according to Krausman et al. (1984). We uploaded geographic position of all locations of mule deer into a Geographic Position System (eTrex, Garmin, Olathe, Kansas, USA) and later downloaded them to a computer, and plotted each one on cartographic images using ArcView 3.2 (Environmental Systems Research Institute 1996). When mule deer were located from the ground, we recorded information on vegetation association used. For $\geq$ 20% of locations in every season we evaluated plant composition, ground cover, thermal cover (i.e., vegetation $\geq$ 75 cm high that provided shade for a deer), and percent of ground covered by organic litter, gravel (i.e., rocks < 25 mm in diameter), and stones (i.e., rocks $\geq$ 25 mm in diameter). Locations for vegetation measurements represented the proportional amount of time deer spent in every vegetation association. We used the point intercept method (Heady et al. 1959) and measured vegetation in a 40-m line centered at mule deer locations. We determined the direction of the line randomly. For comparison, we randomly selected a paired location 100 m from the selected location and collected the data in the same manner. We used logistic regression to compare site characteristics between selected and random locations. We discriminated site characteristics with $P > 0.10$ and conducted comparisons using Wilcoxon tests.

We calculated home range of desert mule deer during each season in both study areas. We used the minimum convex polygon (MCP) through the MCP extension in ArcView 3.2 (Environmental Systems Research Institute 1996). We followed procedures described by Mares et al. (1980) to obtain an adequate number of locations and minimize bias. We compared home range sizes among seasons and study areas using Wilcoxon (Kruskal-Wallis) tests.

The area of every vegetation association was calculated with ArcView 3.2 (Environmental Systems Research Institute 1996). We used chi-square contingency table analysis to test the null hypothesis that mule deer used vegetation associations in proportion to their availability (Neu et al. 1974, Byers et al. 1984) by comparing the total number of observations in every study area with the total area of each vegetation association. When we found a difference ($P < 0.05$) between expected and observed use, we calculated Bonferroni confidence intervals to determine whether percentage use of each vegetation association was significantly ($P \leq 0.05$) greater or less than its percentage availability (Neu et al. 1974, Byers et al. 1984). We plotted individual selection variability (Thomas and Taylor 1990) for each vegetation associations in both study areas.

We used ArcView to calculate distance of every deer location to the nearest source of water. We generated the same number of random locations and determined if deer locations were closer to water sources than random points. We used analysis of variance with Tuckey-Kramer (Honestly Significant Difference) tests ($P < 0.05$) for comparisons between areas and among seasons.

RESULTS

We captured and collared 19 female mule deer in La Jubaivena and 14 female mule deer in El Americano. We obtained 1,175 locations of radiocollared mule deer in La Jubaivena and 829 locations of radiocollared mule deer in El Americano. We calculated home range for each deer that had $\geq$ 14 locations/ season. We had restricted access to both areas during winter due to hunting so we did not have enough data to calculate home ranges in winter for La Jubaivena. Overall, sizes of home ranges were larger in El Americano (27.3 $km^2 \pm 2.6$ [SE]) than La Jubaivena (14.5 $km^2 \pm 2.0$ [SE]) (Kruskal-Wallis $X^2_6 = 17.98$, $P = 0.006$). During summer, mule deer home ranges were smaller ($P < 0.05$) than any other season in both areas (Table 1). There was no difference ($P > 0.05$) in sizes of mule deer home ranges between spring (6.0 km^2) and autumn (7.6 km^2) in La Jubaivena. Conversely, home range sizes in winter (12.3 km^2) and spring (10.1 km^2) were larger ($P < 0.05$) than summer (5.1 km^2) and autumn (6.9 km^2) in El Americano (Table 1).

During capture operations in La Jubaivena, 4 of 19 desert mule deer were captured inside buffelgrass pastures. These animals were subsequently located 235 times. All but 2 locations were inside the perimeters of the buffelgrass plantations. Therefore, we compared the home ranges sizes of the mule deer inside buffelgrass areas to the rest of the collared mule deer in La Jubaivena. There was no difference (Kruskal-Wallis, $X^2_1 = 0.28$, $P = 0.60$) in the size of home ranges of mule deer from inside buffelgrass areas (5.16 $km^2 \pm 0.95$ [SE]) versus the size of home ranges of the rest of collared mule deer (6.16 $km^2 \pm 0.51$[SE]) in La Jubaivena.

For the examination of habitat use by desert mule deer we determined the boundaries of each study area by connecting all the outermost locations of collared deer and adding a zone of half the mean traveled distance registered between individual locations. Thus, we defined 24,155 ha for La Jubaivena (Fig. 2) and 83,036 ha for El Americano (Fig. 3). Buffelgrass made up 32 and 1% of the study areas in La Jubaivena and El Americano, respectively (Tables 2,3).

Desert mule deer did not use the vegetation associations in proportion to their availability in either study areas ($P < 0.001$; Tables 2,3). In general, desert mule deer selected xeroriparian vegetation in both areas throughout the study (Tables 2,3). Vegetation association in plains next to xeroriparian was also selected in El Americano (Table 3) and used in proportion to availability in La Jubaivena (Table 2). The buffelgrass area was avoided in La Jubaivena and used in proportion to availability in El Americano.

The mesquite – bird-of-paradise – xeroriparian association was selected during all seasons in La Jubaivena (Table 4). The elephant tree – catclaw mimosa – foothills association was consistently avoided. The ironwood – brittlebush – plains association was used in proportion to availability in all seasons. Buffelgrass areas were avoided in most seasons except on summer, when that area was used in proportion to availability (Table 4).

In El Americano the mesquite – ironwood – xeroriparian association was also selected during all seasons (Table 5). The creosote bush – bursage – plains association was selected in spring and summer and used in proportion to availability during autumn and winter. The creosote bush – etcho – coastal plains association was consistently avoided during all seasons. The elephant tree – limber bush – northern foothills association was avoided during spring and summer but used in proportion to availability during autumn and winter. The buffelgrass areas were used in proportion to availability in most seasons, with exception of winter when these areas were avoided (Table 5). Individual mule deer showed a high variation in their preferences for vegetation associations in both study areas (Figs. 4 and 5)

From the logistic regression examinations, we identified thermal cover (estimate = -0.15 $\pm$ 0.049, X^2 = 9.3, P = 0.002) ground cover (estimate = -0.06 $\pm$ 0.036, X^2 = 2.4, P = 0.09), and percent of gravel (estimate = 0.03 $\pm$ 0.018, X^2 = 2.93, P = 0.08) as the variables that distinguished ($P < 0.10$) locations selected by desert mule deer versus random locations. These habitat characteristics varied between areas and among seasons (Table 6).

Consistently, thermal cover was higher (*P* < 0.05) in selected locations by mule deer versus random locations in both areas. Thermal cover was highest in summer in La Jubaivena and highest in autumn in El Americano (Table 6).

With the exception of winter in La Jubaivena, ground cover was higher in selected sites by mule deer than in random locations for all seasons in both areas of study. However, the only significant difference (*P* < 0.05) in ground cover was during winter (26.5%) for El Americano.

The presence of gravel on the ground for La Jubaivena was detected only in random and selected sites during winter. Percent of gravel for that area and season was not significantly different (*P* > 0.05). Gravel was present in all sites of El Americano. Percent of gravel was lower in selected locations than in random locations during all seasons in that area; however, significant difference (*P* < 0.05) was found in selected locations (7.8%) versus random locations (22.7%) during spring.

We obtained 1,175 and 829 locations of desert mule deer in La Jubaivena and El Americano, respectively to examine the relationships of deer to the distance to water sources. The average distance of desert mule deer to the nearest source of water was closer (*P* < 0.05) in every season throughout the study than were random locations.

In La Jubaivena, mean distances of desert mule deer to nearest water were 1.9 $\pm$ 0.07, 1.5 $\pm$ 0.05, 1.7 $\pm$ 0.05, and 2.0 $\pm$ 0.05 km in winter, spring, summer, and autumn, respectively. Distances to a nearest source of water were closer (*P* < 0.05) during spring and summer than during other seasons.

In El Americano, mean distances of desert mule deer to the nearest source of water were 3.5 ± 0.22, 2.4 ± 0.19, 2.1 ± 0.18, and 2.6 ± 0.26 km in winter, spring, summer and autumn, respectively. Mean distance to the nearest water source was closer during summer than during any other season, however not significantly different ($P >$ 0.05) from spring or autumn. During winter, the mean distance to the nearest source of water was larger ($P < 0.05$) than during any other season.

DISCUSSION

Home range size and movements of desert mule deer are influenced by season, habitat, and other factors inherent to the species (Mackie et al. 1982, Anderson and Wallmo 1984). Deer home range size increases as the distance between necessary resources increases. Mackie et al. (1982) reported home ranges in semi-desert ranges as large as 21 km^2. However, in arid environments home ranges are as larger as 8 times the reported by Mackie et al. (1982). Studies in southern Arizona have reported home ranges for desert mule deer as large as 121- 172 km^2 (Krausman 1985, Rautenstrauch and Krausman 1989).

Overall in our study, sizes of home ranges were larger in El Americano than in La Jubaivena. El Americano in western Sonora receives lower precipitation and has more scarce vegetation than La Jubaivena in central Sonora. Our findings agree with the statements that in more arid environments the mule deer exhibit larger home ranges to satisfy their necessities. During summer in our study, desert mule deer home ranges were smaller than during any other season in both areas. Similar results were obtained by Fox and Krausman (1994), and Krausman and Etchberger (1995) for female mule deer from western Arizona. There were no differences in sizes of mule deer home ranges between spring and autumn in La Jubaivena. Conversely, home range sizes in winter and spring were larger than summer and autumn in El Americano. Our data were consistent with results of home range analysis in the Belmont and Big Horn Mountains in Arizona (Fox and Krausman 1994).

Buffelgrass areas comprised > 30% of the study area La Jubaivena. Mule deer inhabit all year in those areas. There was no difference in the size of home ranges of mule deer from inside buffelgrass areas versus the size of home ranges of the other collared mule deer. No previous documentation is available to contrast our results. Plantations of buffelgrass have been present since 1980's. Although most of shrub and tree plants were removed in preparation for seeding the buffelgrass, there is a combination of trees and shrubs that could provide enough resources for the mule deer to stay in those areas. Thermal cover inside buffelgrass areas (10.5%) was lower than in locations outside buffelgrass areas (18.4%).

Desert mule deer selected xeroriparian vegetation and the adjacent plains were selected or used in proportion to availability during spring and summer (warmer seasons) in both areas throughout the study. Trees and shrubs cover in those selected areas provide thermal shelter for desert mule deer, especially for pregnant or lactating females. Similar observations were made by Fox and Krausman (1994) who found that females selected areas with vegetation to protect their fawns. Tull et al. (2001) also found that desert mule deer selected bed sites in areas of relatively high thermal cover in all seasons.

Our data indicated that buffelgrass areas were avoided or used in proportion to availability but never selected. However, individual variability in proportion of habitat use minus proportion of availability suggests that mule deer selected home ranges with no regard of the alterations of buffelgrass pastures. Probably, the level of reduction in thermal cover and browse in buffelgrass areas is not a constraint for the use of these areas. Four of the 19 collared deer in central Sonora exhibited annual home ranges completely inside buffelgrass areas. Four other collared deer that were captured outside buffelgrass areas exhibited part of home ranges inside the same buffelgrass areas. One of them was located 48% of the time inside buffelgrass pastures.

Our data also indicate that desert mule deer selected sites closer to water sources. Free standing water was probably the reason for some mule deer to stay in buffelgrass areas. Water has been considered as an important limiting factor for desert mule deer (Leopold and Krausman 1991). Amount and distribution of water sources affect the distribution of mule deer in arid environments. In the southwestern United States mule deer are usually found within 2.4 km of free water (Hanson and McCulloch 1955, Swank 1958, Boroski and Mossman 1996). Some studies in the desert areas of southwestern Arizona showed similar observations where mule deer were found significantly closer to water sources during summer (Ordway and Krausman 1986, Hervert and Krausman 1986, Krausman et al. 1989, Rautenstrauch and Krausman 1989, Krausman and Etchberger 1995). Ranching has been the main activity in the rangelands of Sonora, Mexico since 1950. Thus, water sources for cattle have been established through the range of desert mule deer. Additionally, recent interest of ranchers in managing wildlife populations has added more water sources into mule deer habitat.

We could not conclude that desert mule deer use areas altered with buffelgrass differently than areas without buffelgrass. Our data suggest that desert mule deer used altered areas with buffelgrass but selected sites with higher thermal cover and closer to water sources.

MANAGEMENT IMPLICATIONS

Conditions for desert mule deer in the rangelands of Sonora are different than conditions in other regions of their distribution. Cattle grazing, removal of scrub vegetation, introduction of exotic forages, and the increased number of artificial water sources have obviously altered natural interactions among mule deer and their habitat. Undoubtedly, the reduction of cover and food availability in arid environments represent a major concern for conservation of desert mule deer. Managers should consider that even on altered habitats mule deer use areas with cover and forage from trees and shrubs. It is very important to minimize extensive transformation of new areas into open grasslands. Another major concern should be the potential risk of wild fires when increasing the dominance of buffelgrass stands. Areas where buffelgrass is not grazed may accumulate large loads of dry fuel that causes fires of high intensity. These fires affect cacti, shrubs, and trees that provide important food and cover for mule deer. It is important to continue with more research to quantify the level of those alterations and evaluate the performance of mule deer populations. Research and adaptive management should focus on identifying threshold limits of altered habitats, determining differences in mule deer densities, and evaluating the survival rates and productivity of desert mule deer in relation to those alterations.

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Table 1. Seasonal home ranges (km^2) of desert mule deer in central and western Sonora, Mexico, 2002-2004

	Study areas							
	La Jubaivena, Carbó, Sonora [a]				El Americano, Pitiquito, Sonora			
	Winter	Spring	Summer	Autumn	Winter	Spring	Summer	Autumn
Mean	--	6.04	4.45 [b]	7.63	12.31	10.08	5.06 [b]	6.92
SE	--	0.75	0.55	0.85	3.02	2.41	0.48	2.07
Range	--	1.3 - 11.2	1.3 - 8.7	2.4 - 15.2	1.3 - 36.6	3.6 - 32.3	3.1 - 9.1	2.1 - 14.3
No. animals	--	18	18	17	11	11	13	6
No. locations	--	334	286	321	172	236	262	84

[a] Home range sizes were different between areas (Kruskal-Wallis $X^2 = 17.98$, 6 df, $P = 0.006$).

[b] Statistically different ($P < 0.05$) among seasons in the same area.

Table 2. Utilization-availability of vegetation associations by desert mule deer in La Jubaivena, Carbo, Sonora, Mexico, 2002-2004.

Vegetation association	Total area (ha)	Relative area (%)	Expected usage	Observed usage	$\frac{(Obs-Exp)^2}{Exp}$	Bonferroni 95%C.I. lower	Bonferroni 95%C.I. higher	
Prju-Capu [1]	884	4	43.00	196	544.3667	0.1396	0.1940	(++) S [5]
Olte-Enfa [2]	14,382	60	699.60	698	0.0037	0.5583	0.6298	(-+)
Busp-Mila [3]	1,199	5	58.32	2	54.3929	0.0000	0.0047	(--) A
Buffelgrass [4]	7,690	32	374.07	279	24.1637	0.2064	0.2685	(--) A
Total	24,155	100	1,175	1,175				
				X^2 =	622.9270			

[1] Mesquite – bird-of-paradise – Xeroriparian

[2] Ironwood – brittlebush – Plains

[3] Elephant tree – catclaw mimosa – Foothills

[4] Buffelgrass pastures

[5] (++) S = used > expected, (--) A = used < expected, (-+) = used as expected.

Table 3. Utilization-availability of vegetation associations by desert mule deer in El Americano, Pitiquito, Sonora, Mexico, 2002-2004.

Vegetation association	Total area (ha)	Relative area (%)	Expected usage	Observed usage	$\frac{(Obs-Exp)^2}{Exp}$	Bonferroni 95%C.I. lower	Bonferroni 95%C.I. higher	
Prju-Olte [1]	1,050	1	10.48	63	263.1029	0.0517	0.1003	(++) S[7]
Busp-Jacu [2]	12,679	15	126.58	64	30.9407	0.0527	0.1017	(--) A
Latr-Cemi [3]	26,350	32	263.07	200	15.1201	0.2021	0.2805	(--) A
Latr-Frsp [4]	36,535	44	364.75	493	45.0941	0.5497	0.6397	(++) S
Latr-Papr [5]	5,915	7	59.05	5	49.4765	0.0000	0.0131	(--) A
Buffelgrass [6]	507	1	5.06	4	0.2227	0.0000	0.0112	(-+)
Total	83,036	100	829	829				
				X^2 =	403.9570			

[1] Mesquite – ironwood – Xeroriparian

[2] Elephant tree – limber bush – Northern foothills

[3] Creosote bush – paloverde – Hills

[4] Creosote bush – franseria spp. – Plains

[5] Creosote bush – etcho – Coastal plains

[6] Buffelgrass pastures.

[7] (++) S = used > expected, (--) A = used < expected, (-+) = used as expected.

Table 4. Selection (S) and avoidance (A) of vegetation associations by desert mule deer in La Jubaivena, Carbo, Sonora, Mexico, 2002-2004.

Season	X^2	No. locations	Vegetation association			
			Prju-Capu [1]	Olte-Enfa [2]	Busp-Mila [3]	Buffelgrass [4]
Winter	30.57	174	S[5]	--	A	A
Spring	51.33	255	S	--	A	A
Summer	50.46	267	S	--	A	--
Autumn	100.18	133	S	--	A	A

$X^2_{0.05,\,3} = 7.81$

[1] Mesquite – bird-of-paradise – Xeroriparian

[2] Ironwood – brittlebush – Plains

[3] Elephant tree – catclaw mimosa – Foothills

[4] Buffelgrass pastures

[5] S = used > expected, A = used < expected, (--) = used as expected.

Table 5. Selection (S) and avoidance (A) of vegetative associations by desert mule deer in El Americano, Pitiquito, Sonora, Mexico, 2002-2004.

Season	X^2	No. Locations	Vegetation association					
			Prju-Olte [1]	Busp-Jacu [2]	Latr-Cemi [3]	Latr-Frsp [4]	Latr-Papr [5]	Buffelgrass [6]
Winter	74.49	332	S[7]	--	--	--	A	A
Spring	54.75	171	S	A	--	S	A	--
Summer	61.97	361	S	A	A	S	A	--
Autumn	27.78	311	S	--	--	--	A	--

$X^2_{0.05, 5} = 11.07$

[1] Mesquite – ironwood – Xeroriparian

[2] Elephant tree – limber bush – Northern foothills

[3] Creosote bush – paloverde – Hills

[4] Creosote bush – franseria spp. – Plains

[5] Creosote bush – etcho – Coastal plains

[6] Buffelgrass pastures.

[7] S = used > expected, A = used < expected, (--) = used as expected.

Table 6. Differences in thermal cover (TC), ground cover (GC), and gravel on the ground (Gr) between selected and nearly random sites for desert mule deer in central and western Sonora, Mexico, 2002-2004.

	Selected			Random		
Season and area	TC	GC	Gr	TC	GC	Gr
Winter						
La Jubaivena	10.9*	33.6	4.7	7.0	45.0	5.9
El Americano	19.8	26.5*	23.8	11.2	10.9	35.1
Spring						
La Jubaivena	18.5*	24.3	0.0	3.5	21.0	0.0
El Americano	12.9*	19.5	7.8*	4.1	15.9	22.7
Summer						
La Jubaivena	27.9*	31.5	0.0	12.8	27.7	0.0
El Americano	16.4*	22.3	10.3	6.9	20.5	16.9
Autumn						
La Jubaivena	18.9	28.9	0.0	14.6	26.7	0.0
El Americano	23.5*	15.3	9.3	10.9	14.9	13.5

* Indicates difference ($P < 0.05$) between selected and random sites for the same characteristic.

FIGURE CAPTIONS

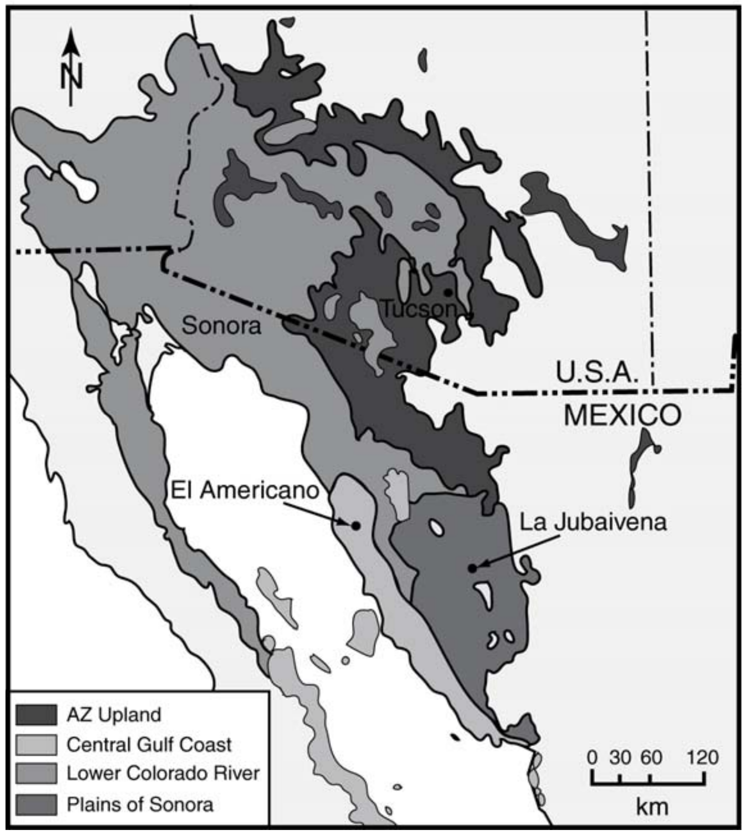
Fig. 1. Locations of study for analysis of home range and habitat use in altered habitats, central and western Sonora, Mexico.

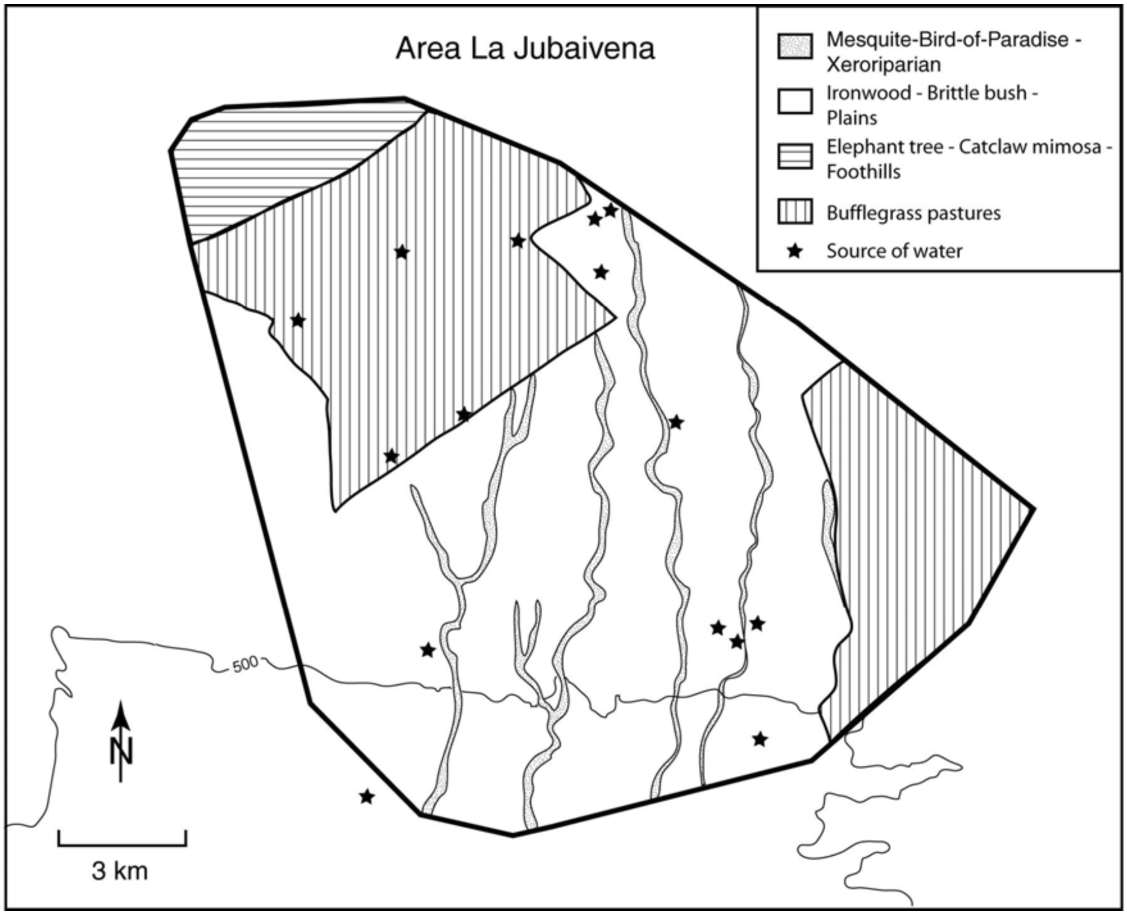
Fig. 2. Vegetation associations and location of water sources in area La Jubaivena, central Sonora, Mexico.

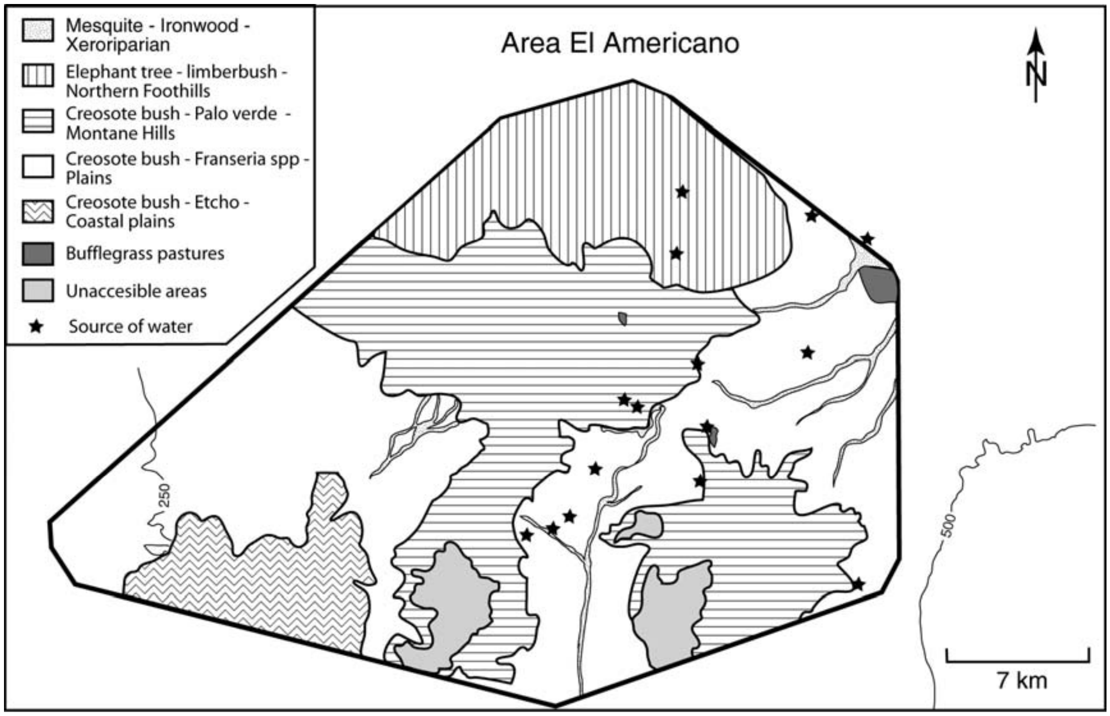
Fig. 3. Vegetation associations and location of water sources in area El Americano, western Sonora, Mexico.

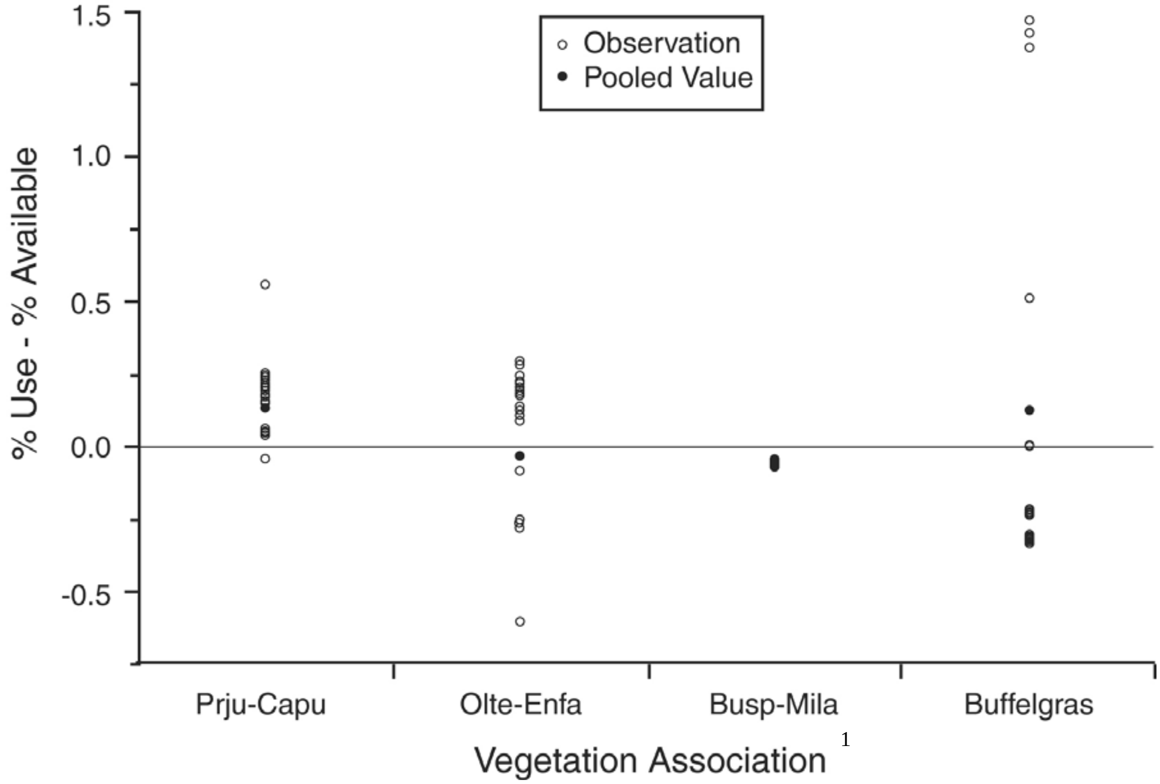
Fig. 4. Individual variation in proportion of vegetation association used by radiocollared mule deer in La Jubaivena, central Sonora, Mexico. Each individual is represented by an open circle. Closed circle represents the mean of all individuals' responses.

Fig. 5. Individual variation in proportion of vegetation association used by radiocollared mule deer in El Americano, western Sonora, Mexico. Each individual is represented by an open circle. Closed circle represents the mean of all individuals' responses.

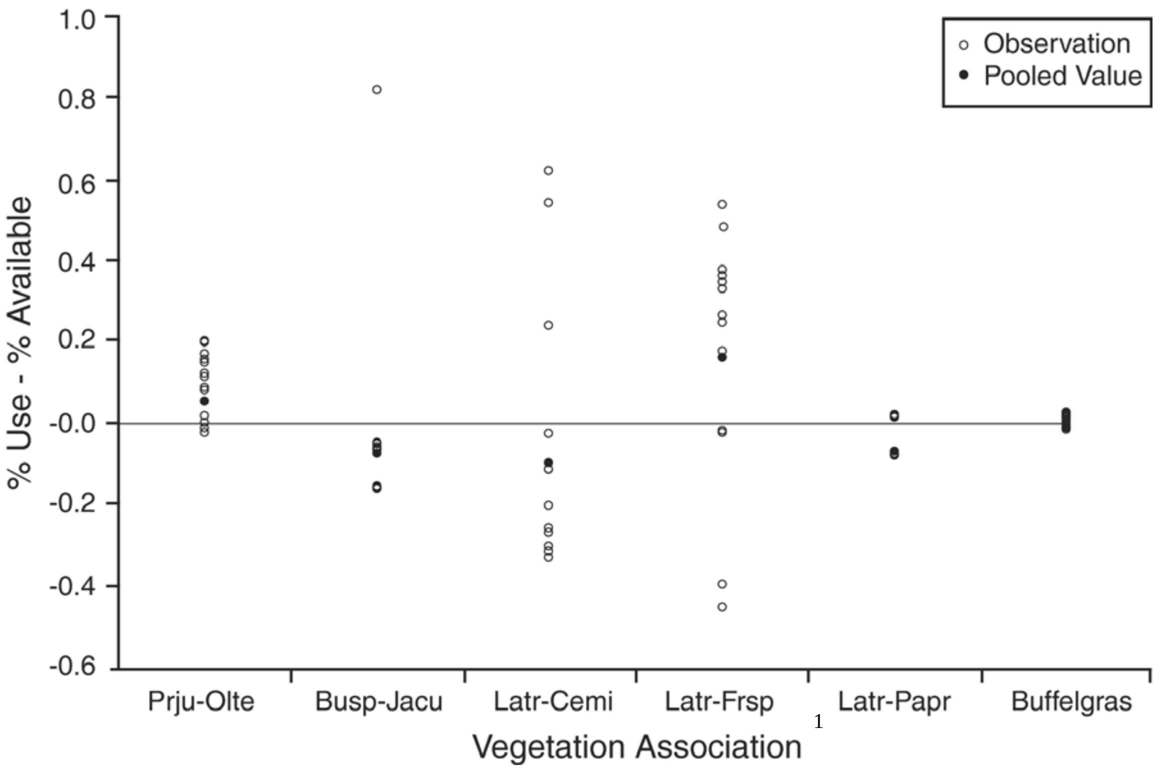

N
Sonora
Tucson
U.S.A.
MEXICO
El Americano
La Jubaivena
AZ Upland
Central Gulf Coast
Lower Colorado River
Plains of Sonora
0 30 60 120
km


Area La Jubaivena
Mesquite-Bird-of-Paradise - Xeroriparian
Ironwood - Brittle bush - Plains
Elephant tree - Catclaw mimosa - Foothills
Bufflegrass pastures
Source of water
500
N
3 km


Mesquite - Ironwood - Xeroriparian
Elephant tree - limberbush - Northern Foothills
Creosote bush - Palo verde - Montane Hills
Creosote bush - Franseria spp - Plains
Creosote bush - Etcho - Coastal plains
Bufflegrass pastures
Unaccesible areas
Source of water
Area El Americano
N
250
500
7 km



[1] Prju-Capu = Mesquite – bird-of-paradise – Xeroriparian
Olte-Enfa = Ironwood – brittlebush – Plains
Busp-Mila = Elephant tree – catclaw mimosa – Foothills
Buffelgrass = Buffelgrass pastures



[1] Prju-Olte = Mesquite – ironwood – Xeroriparian
Busp-Jacu = Elephant tree – limber bush – Northern foothills
Latr-Cemi = Creosote bush – paloverde – Hills
Latr-Frsp = Creosote bush – franseria – Plains
Latr-Papr = Creosote bush – etcho – Coastal Plains
Buffelgrass = Buffelgrass pastures

APPENDIX B. DRAFT MANUSCRIPT TO BE SUBMITTED TO RANGELAND ECOLOGY & MANAGEMENT: ALCALÁ-GALVÁN, C. H., AND P. R. KRAUSMAN. DIETS OF DESERT MULE DEER IN ALTERED HABITATS IN THE LOWER SONORAN DESERT.

Diets of Desert Mule Deer in Altered Habitats in the Lower Sonoran Desert

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Abstract

We conducted microhistological analyses of feces to identify diets of desert mule deer (*Odocoileus hemionus eremicus*) in 4 areas of central and western Sonora, Mexico, to determine seasonal variation in forage classes, and compare diets of mule deer and cattle in altered habitat with buffelgrass (*Cenchrus ciliaris* L). For mule deer, we identified 96 plant species, 69 of which have not previously been reported as forage for this wild herbivore. From these species, 44 occurred in the mule deer diet in $\geq$ 1%. Browse was the most important forage class consumed by mule deer at all study areas (77%-88%). Forbs comprised an average of 5% to 10% of the diet of mule deer among all areas. Use of succulents was highly variable among areas, but particularly one species (chainfruit cholla [*Opuntia fulgida* Engelm]) occurred consistently in all areas and most seasons. Grass species were the lowest forage class for desert mule deer throughout the areas and seasons, however higher consumption of native grasses occurred in one area of central Sonora. Buffelgrass was not important in diets of desert mule deer. Conversely, buffelgrass was the most important forage species for cattle. Also, two of the most important browse species (i.e., mesquite [*Prosopis juliflora* {Sw.} D.C.] and ironwood [*Olneya tesota* A. Gray]) for mule deer were the most important browse species for cattle. Desert mule deer and cattle shared 45 forage species from central Sonora. However, biological overlap of diets occurred only for spring (Morisita coefficient = 0.67). Plant diversity in diets of mule deer was slightly different among areas and seasons. Shannon-Wiener (H’) index was different ($P < 0.05$) only between the area with higher precipitation and the area with lowest precipitation. Our data contribute to understanding

the primary resources for desert mule deer in altered habitat of the Lower Sonoran Desert.

Resúmen

Realizamos análisis microhistológico de heces para identificar las dietas del venado bura (*Odocoileus hemionus eremicus*) en 4 áreas del centro y oeste de Sonora, México, determinar la variación estacional de las clases de forraje y comparar la dieta del venado bura y ganado en hábitat alterado con zacate buffel (*Cenchrus ciliaris* L). Para el venado bura, identificamos 96 especies vegetales, 69 de las cuales no habían sido reportadas como forraje para este herbívoro silvestre. De estas especies, 44 ocurrieron en la dieta del venado bura en > 1%. El ramoneo fue el forraje mas consumido por el venado bura en todas las áreas de estudio (77%-88%). Las herbáceas comprendieron entre el 5% y 10% de la dieta del venado bura en promedio para todas las áreas. El uso de suculentas fue altamente variable entre las cuatro áreas, pero particularmente una especie (i.e., cholla saltona [*Opuntia fulgida* Engelm]) ocurrió consistentemente en todas las áreas en la mayoría de las épocas. Los zacates comprendieron el forraje menos consumido por el venado bura entre áreas y épocas, sin embargo consumo elevado de zacates nativos ocurrió en una de las áreas del centro de Sonora. El zacate buffel no fue importante en las dietas del venado bura. Por otro lado, el zacate buffel apareció como la especie forrajera más importante para el ganado. Asimismo, dos de las especies de ramoneo (i.e., mesquite [*Prosopis juliflora* {Sw.} D.C.] y palo fierro [*Olneya tesota* A. Gray]) más importantes para el venado bura fueron también las especies de ramoneo más importantes para el ganado. El vendo bura y el ganado compartieron 45 especies forrajeras del centro de Sonora. Sin embargo sobreposición biológica significativa entre las dietas ocurrió solo para la época de primavera (Coeficiente de Morisita = 0.67%). La diversidad vegetal de las dietas del venado bura fue ligeramente diferente entre áreas y épocas. El índice de Shannon-Wiener (H') fue diferente (*P* < 0.05) solamente entre el área con mayor precipitación y el área con menor precipitación en el estudio. Nuestros datos contribuyen a entender los recursos más importantes para el venado bura del desierto en el Bajo Desierto Sonorense.

Key words: buffelgrass, cattle, diet diversity, diet overlap, *Odocoileus hemionus eremicus*, Sonora, Mexico

INTRODUCTION

Desert mule deer (*Odocoileus hemionus eremicus* Mearns) inhabit the southwestern United States and northwestern Mexico (Heffelfinger 2000). Diets of desert mule deer have been described in the southwestern United States (Krausman et al.1997) including California (Marshal et al. 2004), Arizona (Urness et al. 1971; McCulloch 1973; Anthony 1976; Anthony and Smith 1977; Short 1977; Krausman et al. 1989), New Mexico (Anderson et al. 1965; Boeker et al. 1972), and Texas (Krausman 1978; Leopold and Krausman 1987). However, there is no previous documentation of diets of desert mule deer from the Sonoran Desert, Sonora, Mexico. The Plains of Sonora and the Central Gulf Coast subdivisions in Sonora have distinctive biotic characteristics (Brown 1994). Furthermore, these regions have been overgrazed by cattle (Camou-Healy 1994) and transformed into pasture lands with the exotic buffelgrass (*Cenchrus ciliaris* L.). The introduction of buffelgrass is one of the most visible landscape changes in the central Sonoran rangelands. This exotic, was introduced in an effort to solve erosion problems and boost feed production on cattle pastures. By the 1990s, buffelgrass stands covered 1.2–1.6 million ha of Sonoran rangeland (Yetman and Búrquez 1994; Búrquez-Montijo et al. 2002). The effects of buffelgrass on wildlife and native vegetation are unknown; although tentative suggestions have been made that the grass is not favorable to native wildlife (Bock and Bock 1988; Martin *et al.* 1998). Because these extensive buffelgrass stands likely influence forage for desert mule deer, we wanted to know, if, and how they did. Our objectives were to determine diets of desert mule deer from central and western Sonora, Mexico, and compare diets of desert mule deer and cattle in habitat with buffelgrass pastures.

STUDY AREAS

We conducted diet analyses in 4 areas of central and western Sonora, Mexico. Area 1 was on Rancho San Luis-CIPES, 54 km north of Hermosillo in the central region of Sonora, Mexico (lat29° 32' and 29° 35'N, long 111° 01' and 111° 08'W) (CETENAL 1974). This area encompasses 20 500 ha of the Plains of Sonora Subdivision of the Sonoran Desert (Brown 1994). Approximately 5 600 ha (27%) were converted from native vegetation to buffelgrass. Elevations ranged from 450 m to 550 m on flats and plains to 551 to 750 m of rough terrain (e. g., Sierra La Cobriza). Soils were recent alluvium, weathered from granitic rocks 2 to 6 m deep (Hendricks 1975). Average annual precipitation was 320 mm (Centro de Investigaciones Pecuarias del Estado de Sonora 1989). Precipitation was bimodal: approximately 60% occurred between July and September, and 40% occurred between November and March. The remaining months were usually dry. Summer rainfall occurred as thunderstorms that were of high intensity. Annual mean temperature was 23°C. Daytime temperatures averaged 34° C, but frequently exceed 40° C in June through August. Night-time temperatures averaged 8° C in winter, and approached 0° C in December, January, and February. Vegetation in Rancho San Luis was representative of the arbosuffrutescent desert-scrub in the Plains of Sonora Subdivision of the Sonoran Desert (Shreve and Wiggins 1964; Brown 1994). Shrubs and small to medium sized trees dominated overstory vegetation. Common species were ironwood (*Olneya tesota* A. Gray), mesquite (*Prosopis juliflora* (Sw.) D.C.), paloverde (*Cercidium microphyllum* (Torr.) Rose & Johnston), bird-of-paradise (*Caesalpinia pumila* (Britt & Rose) Hermann), brittle bush (*Encelia farinosa* A. Gray), and snakewood (*Condalia* spp. Cav) Understory vegetation was represented by perennials including woolly tidestromia (*Tidestromia lanuginosa* (Nutt.) Standl.), milkweeds (*Euphorbia* spp.), and ambrosia (*Ambrosia* spp.), and grasses including false grama (*Cathestecum brevifolium* Vasey & Hack.), spidergrass (*Aristida ternipes* Cav.), sixweeks threeawn (*Aristida adscencionis* L), false sideoats (*Bouteloua reflexa* Swallen) and bristlegrass (*Setaria macrostachia* H.B.K.). Cacti were present but sparse. Common cacti were organ pipe cactus (*Lemaireocereus thurberi* [Engelm.] Britt. & Rose), and chainfruit cholla (*Opuntia fulgida* Engelm). This area was used for cattle production and the condition of rangeland was considered good to excellent.

Area 2 was on Rancho La Jubaivena and adjacent lands. This area was located 54 km north of Hermosillo and 14 km west of area 1 in the central region of Sonora, Mexico (lat 29° 34' and 29° 41' N, long 111° 12' and 111° 18' W) (CETENAL 1974). Elevations ranged from 500 to 650 m. Climate, soil, and vegetation were similar to area San Luis. The core of the study area comprised 10 500 ha of native arbosuffrutescent scrub surrounded by buffelgrass pastures. This area has been overgrazed by cattle. Understory vegetation was very scarce and bare ground was common and eolic and hydric erosion were evident.

Area 3 was on Rancho La Pintada located 52 km south of Hermosillo, at the northwest base-plains of Sierra Libre, central Sonora, Mexico (lat 28° 38' and 28° 42'N, long 110° 57' and 111° 01'W). This area was located in the southern portion of the Plains of Sonora Subdivision of the Sonoran Desert. Native desert scrub has also been converted to buffelgrass pastures in more than 50% of the land. Average annual precipitation was 260 mm. Temperature regimes were 1° to 2° C warmer than area San Luis and area La Jubaivena. Common shrubs and tree species included ironwood, mesquite, paloverde, bird-of-paradise, brittle bush, sanjuanico (*Jacquinia pungens* A. Gray), and catclaw mimosa (*Mimosa laxiflora* Benth). The cacti present were organpipe cactus (*Lemaireocereus thurberi* [Engelm.] Britt. & Rose), chainfruit cholla, teddybear cholla (*Opuntia bigelovii* Engelm), and barrel cactus (*Ferocactus* spp. Britt. and Rose). Herbaceous vegetation was scarce were native vegetation occurred.

Area 4 was on Rancho El Americano and its surrounding lands, 25 km north of Puerto Libertad, in Pitiquito, Sonora, (lat 30° 00' and 30°17'N, long 112°17' and

112°43’W). This area encompassed 83 000 ha where physiognomic and vegetational characteristics represented two of the Subdivisions of the Sonoran Desert: Central Golf Coast and Lower Colorado River Valley. The southern and western portions of the area of study were plains inclined to the sea that were part of the Central Gulf Coast Subdivision of the Sonoran Desert. The central and northern portions of area El Americano coastal plains merged into rough terrain and northern plains with characteristics of the Lower Colorado River Valley Subdivision (Shreve and Wiggins 1964; Brown 1994). Elevations ranged from 150 m to 500 m in coastal plains and from 500 to 750 in desert mountains (i.e. Sierra Aguirre and Sierra Picu). Precipitation was also bimodal with 70 % in summer months. Average annual precipitation was 180 mm. Annual mean temperature was 23 °C. Vegetation in coastal plains was characteristic of the sarcocaulescent desert-scrub and vegetation in foothills and northern plains was microphyllous desert-scrub (Shreve and Wiggins 1964; Brown 1994). Common plants in the sarcocaulescent area were elephant tree (*Bursera microphylla* A. Gray), lomboy bushes (*Jatropha cuneata* Wigg. And Roll. and *Jatropha cinerea* [C. G Ortega] Muell). Also present were creosote bush (*Larrea tridentata* [Sessé and Moc. ex DC.] Coville), burrobush (*Ambrosia dumosa* A. Gray), brittlebush with the cacti cardon (*Pachycereus pringlei* [S. Wats] Britt. and Rose) and teddy bear cholla. Microphyllous desert in foothills and northern plains included creosote bush, ocotillo (*Fouquieria splendens* Engelm), blue paloverde (*Cercidium floridum* Benth), paloverde, burro bush, brittlebush, and lomboy bush. Common cacti were organpipe cactus, saguaro (*Carnegia gigantea* [Engelm ex Emory] Britt and Rose), barrelcactus and pencil cholla (*Opuntia arbuscula*

Engelm). Riparian associations contained ironwood, mesquite, paloverde and catclaw acacia (*Acacia occidentalis* Rose). Buffelgrass was present but in lower proportions than in areas the other three areas. Small and localized areas converted to buffelgrass represented < 2% of area El Americano. Because of lower precipitation, cattle grazing was common year-round in all four areas, however stocking rates were lower in area El Americano, where rangeland offered a comparatively reduced amount of forage for cattle. Large and medium-sized mammals other than mule deer and cattle present in all 4 areas included white-tailed deer (*Odocoileus virginianus*), collared peccary (*Pecari tajacu*), mountain lion (*Puma concolor*), coyote (*Canis latrans*), antelope jackrabbit (*Lepus alleni*), and desert cottontail (*Sylvilagus audubonii*). Feral burros (*Equus asinus*) and black-tailed jackrabbitt (*Lepus californicus*) were also present in area El Americano.

We determined seasons for our study areas from bimodal precipitation and temperature regimes (Krausman 1985). The seasons were cold-wet (winter: January-March), hot-dry (spring: April-June), hot-wet (summer: July-September), and cold-dry (autumn: October-December).

METHODS

We determined diets of desert mule deer in all four study areas and diets of cattle in area San Luis using microhistological identification of plant epidermal fragments in fecal material (Sparks and Malechek 1968; Peña and Habib 1980; Vavra and Holechek 1980).

In Rancho San Luis the study was conducted during 1991 and 1992. Mule deer fecal pellets were collected from 1 200 permanent plots distributed along 12 sampling transects with 50 plots. Plots were lined up with 20 m separations, forming a 1 000-m long line. Each group of plots consisted of two 8-m^2 circular plots placed 3 m apart at each side of the line. The center of each plot was marked with a permanent stake in the ground. A 1.6-m cord served as radius in defining the circular plot when sampling. We obtained cattle fecal samples from permanent plots placed on areas of major animal concentrations like watering, resting, and salt licking areas. Cattle fecal plots were 20 m x 2 m and were marked at each corner with a 60-cm wooden stake. Sampling plots were set in paddocks with native desert scrub and not intentionally seeded with buffelgrass. However, buffelgrass had spread out naturally from contiguous seeded areas.

At the beginning of the study and previous to the collection period, all pellet plots were cleared of existing fecal material. Collection of fecal samples was initiated in January 1991 and completed in December 1992. All fecal droppings present in mule deer and cattle plots were collected every month during the two years of study. Every pellet group from mule deer was considered as an individual sample. A portion (50-70 g) of collected cattle dung was considered as an individual sample.

We prepared composite fecal samples by month using $\geq$ 5 pellets from 5 to 12 individual samples for mule deer and 10 g of fecal material from $\geq$ 5 individual samples for cattle. We then prepared a pooled sample/ animal species, season, and year.

In La Jubaivena, La Pintada, and El Americano we collected pellets of mule deer in 2002, 2003 and 2004. We collected fresh fecal samples from each area from $\leq$ 18 pellet groups/ month. We collected samples throughout the study area while conducting a radiotelemetry study of mule deer. We only collected pellets from mule deer. For all study areas we dried fecal samples at room temperature/ or in a forced-draft oven at 40° C for 72 hours and stored them in paper bags until analyses.

All microscopic analyses were conducted at the Range Management Laboratory of the CIPES Experimental Station (Centro de Investigaciones Pecuarias del Estado de Sonora A. C.), Carbó, Sonora.

We prepared reference slides from plant material and slides from fecal samples for all areas using the method developed by Sparks and Malechek (1968) as described by Peña and Habib (1980) and Holechek (1982).

We analyzed 5 slides for each year–season combination by examining 20 field slides at 100x under a compound phase-contrast binocular microscope (Sparks and Malechek 1968; Dearden et al. 1975; Todd and Hansen 1973; Gretchen and Dahl 1980). We computed the frequency for each plant species (Fracker and Brischle 1944) and converted them to relative particle density (Sparks and Malechek 1968). We classified data as browse (e.g., parts from shrubs or trees), forbs (e.g., parts from herbaceous plants), grass (e.g., parts from Poaceae species plants), or succulents (e.g., cacti). The technician responsible for microhistological identification was experienced and tested to ensure reliability (Holechek and Gross 1982; Krausman et al. 1989).

We used Morisita's similarity index (Morisita 1959) as modified by Horn (1966) and presented by Krebs (1999) to quantify similarities of desert mule deer and cattle diets within seasons. We considered values of similarity $\geq$ 0.60 as biological overlap (Alcoze and Zimmerman 1973). We determined botanical diversity of mule deer diets for all study areas with the Shannon-Wiener index (*H'*) (Krebs 1999). We preferred the use of

H' because this measure of heterogeneity is more sensitive to the abundance of the rare species in a community (Hill 1973, Peet 1974). We tested diversity measures ($P < 0.05$) for differences by animal species, season, and years (Zar 1996).

RESULTS

Diets of Mule Deer

Diets of mule deer at the four areas included 96 plant taxa: 45 browse, 33 forb, 12 grasses, and 6 succulents (Table 1). In San Luis, 29% of the plants in the diet of mule deer occurred $\geq$ 1%. In the other three areas > 48% of plants identified contributed $\geq$ 1% to the diet of mule deer: 49, 51, and 58% for La Jubaivena, La Pintada, and El Americano, respectively.

Browse was the most important forage class consumed by mule deer at all study areas (77%-88%) (Table 1). Browse species with the highest annual percent (>10 %) of the diet were mesquite (11%, 14%, and 24% in areas La Pintada, La Jubaivena, and San Luis respectively), ironwood (15% in area San Luis), jojoba (*Simmondsia chinensis* [Link] Schnider) (13.4% in area El Americano), bird-of-paradise (11.9% in area La Pintada), and fairy duster (11.3% in area La Jubaivena). Other important browse species comprising 5%-10% of the diet annually were palo verde (in area San Luis), ironwood and catclaw mimosa (in areas La Jubaivena and La Pintada), chuparosa (*Beloperone californica* Benth) (areas La Jubaivena and El Americano), bird-of-paradise (area La Jubaivena), blue paloverde, (area El Americano), Tahitian kidneywood (*Eysenhardtia orthocarpa* [A. Gray] S. Wats) , and guayacan (*Guaiacum coulteri* A. Gray) (area La

Pintada), fairy duster (*Calliandra eriophylla* Benth), sangre-de-Cristo (*Jatropha cardiophylla* Muell), and little leaf ratany (*Krameria parvifolia* Benth) (area El Americano).

Forbs comprised an average of 5% to 10% of the diet of mule deer from 8 seasons among all four areas. Moradia (*Verbena delticola* Small ex Perry) was the only 1 of 33 forb species that accounted for $\geq$ 5% of the annual diet of mule deer (3% and 6% in areas La Jubaivena, and La Pintada respectively).

Grass was the lowest forage class consumed by mule deer in all areas. Combined grass species comprised < 1 % of average annual diets in areas La Jubaivena and El Americano, 2% of diet in area La Pintada, and 9% of diet in area San Luis. No grass species occurred $\geq$ 1 % of mule deer diet in areas La Jubaivena, La Pintada, and El Americano. Five species contributing 1%-2% each of the annual diet occurred in area San Luis.

Succulents were the most variable forage class in the diet of mule deer among the four areas. Succulent forage ranged from 2% in El Americano to 12% in La Pintada (Table 1). Chainfruit cholla was the most consumed succulent species. This species occurred in diets in all areas and comprised between 6% and 10% of diets in areas San Luis, La Jubaivena and La Pintada.

Diets of desert mule deer varied among areas, years, and seasons (Tables 2-5). In San Luis two species contributed > 10% each and two species contributing 5%-10% each, comprised 59% of the annual diet of mule deer. In La Jubaivena and La Pintada two species contributed >10% each and 6 species contributed 5%-10% each made up 65%

and 62% of the annual diet in those areas, respectively. In El Americano only one species accounted for > 10% (i.e., jojoba) of the annual diet. Jojoba combined with 5 species that contributed 5%-10% each, made up > 47% of the diet. The number of species contributing 1%-5% were also different among areas (*n* =15 in San Luis, *n* = 12 in La Jubaivena, *n* = 14 in La Pintada, and *n* = 19 in El Americano). A larger number of those species contributing < 1% to the annual diet occurred in area San Luis (*n* = 47), followed by La Pintada (*n* = 21), La Jubaivena (*n* = 20), and El Americano (*n* = 18).

Seasonal contribution of browse occurred as >75% for the majority of seasons in all areas. Seasons in which browse occurred in < 75% were the summers of 1991 (46%) and 1992 (66%) in San Luis, and the spring of 2002 (62%) in La Pintada.

Forbs occurred in higher variation among season and areas. With the exception of autumn 1991 and 1992 in San Luis (Table 2), forbs occurred in all seasons and areas of the study. The lowest variation in occurrence of forbs was in La Jubaivena with seasonal average of 9% (Table 3). Generally, forbs consumption increased during or following a rainy season in summer or winter, when annual herbaceous appear. Occurrence of forb was highest in autumn 2002 in El Americano (21%) (Table 5). However, average values from similar seasons showed that summer in La Pintada (Table 4) had the highest occurrence of forb (16%) compared to the same value of autumn in El Americano (14%). The most commonly occurring forb species was moradia, which occurred (4%-9%) in 7 seasons in La Jubaivena (Table 3) and in 5 seasons in La Pintada (Table 4). The forb prostrate sandmat (*Euphorbia prostrata* Ait) had the highest occurrence (12%) in diets of mule deer for a particular season (winter 2004 in El Americano) (Table 5). Other common forb taxa were goosfoot (*Chenopodium sp*. L) ($\leq$ 10%), perennial sandmat (*Euphorbia tomentulosa* S. Wats) ($\leq$ 9%), milkweed (*Asclepias* sp. L) ($\leq$ 7%), and panamint cryptantha (*Cryptantha angustifolia* [Torr.] Greene) ($\leq$ 6 %).

Grass species occurred consistently in lower percentages of the mule deer diet throughout seasons in La Jubaivena, La Pintada, and El Americano (2002 –2004) (Tables 3 - 5). Moreover, grass species were < 1% in all seasons at La Jubaivena and El Americano (Tables 3 and 5). Slight differences occurred at La Pintada were in 5 out of 8 seasons mule deer used grass forage in < 1% (Table 4). However, use of grass species was different in San Luis (1991-1992) (Table 2). The use of grass forage was similarly low during spring and autumn (< 1%) and winter ($\leq$ 4%). Contrarily, grass species comprised 45% and 19% (32% in average) in summers of 1991 and 1992, respectively. The highest seasonal percent of grass species were slender grama (*Bouteloua repens* [Kunth] Scribn. & Merr.) ($\leq$ 12%), niddle grama (*Bouteloua aristidoides* [Kunth] Griseb) ($\leq$ 10%), jungle rice (*Echinochloa colonum* [L.]Link) ($\leq$ 8%), and false sideoats (7%). The exotic grass species buffelgrass occurred in area San Luis ($\leq$ 5 %), La Pintada ($\leq$ 3 %), and La Jubaivena ($\leq$ 1 %). Averaged use of buffelgrass was < 1% in all 3 areas.

Succulent forage was used differently among areas and seasons. Mule deer consumed succulent species in all areas during all seasons. Highest seasonal average of use of succulent species occurred in La Pintada (14%), followed by San Luis (10%), La Jubaivena (7%), and El Americano (3%). Occurrence of succulents was lowest during winter 2004 in El Americano (< 1%) (Table 5), and highest during spring 2002 in La

Pintada (28%) (Table 4). The most used succulent species was chainfruit cholla (≤ 26%) that occurred the most through the seasons in all areas.

Diets of Cattle

Diets of cattle in the Rancho San Luis consisted mainly of grass forage, although important proportion of browse occurred year-round. We identified 57 plant species consumed by cattle: 20 browse, 22 forbs, 14 grasses, and 1 succulent. However, 6 out of 20 browse species, 3 out of 22 forbs, and 11 out of 14 grasses contributed >1% of the average annual diet of cattle. Overall, grasses comprised 57% of the diet followed by browse (30%), forbs (9%), and succulents (4.5%) (Table 2). Grass and forbs comprised > 65% of the annual cattle diet. Buffelgrass was the most important species in the cattle diet, accounting for 21% of the diet throughout the study. The highest use of this grass species occurred during summer (21%-25%) and autumn (23%-29%). Other grasses commonly used by cattle were false sideoats (≤ 11%), slender grama (≤ 9%), and false grama (≤ 8%). These 3 grasses comprised >18% of the average annual diet of cattle.

The highest use of browse occurred during spring, when the average (1991 and 1992) was 45%. The most commonly occurring browse in the diet of cattle was ironwood (≤ 17%) and mesquite (≤ 14%). Other browse species used by cattle were brittle bush (7%) and bird-of-paradise (5%).

Forbs comprised > 9% of the cattle diet, the lowest component in the cattle diet. The highest consumption of forb by cattle occurred during spring and summer. The most commonly occurred forb species in cattle diet were flatsedge (*Cyperus* sp. L) (≤ 2%), melon loco (*Apodanthera palmeri* S. Wats) ($\leq$ 2%), and wild dwarf morning-glory (*Evolvulus arizonicus* Gray) ($\leq$ 1%).

Only one succulent (chainfruit cholla) occurred in the diet of cattle. With the exception of winter 1992 this species was used by cattle in all seasons. Highest occurrence of this species was in summer (5%-6%) and autumn (2%-7%).

Diet Overlap

Mule deer and cattle used 77 of the same plant species in the San Luis. However, only 45 plant species were used for both herbivores in $\geq$ 1 season. Overall there was no biological overlap of diets in San Luis (similarity index = 0.50). Morisita coefficients for seasonal diets of mule deer and cattle were = 0.29, 0.67, 0.54, and 0.31 for winter, spring, summer, and autumn respectively. Thus, biological overlap in diets of mule deer and cattle occurred only during spring.

Diet Diversity

Plant diversity in diets of mule deer was slightly different among areas and seasons. Shannon-Wiener (H') diversity index was highest in El Americano (1.383), followed by La Pintada (1.341), La Jubaivena (1.284), and San Luis (1.217) (Table 6). We generated a *t* statistic for all possible paired comparisons among areas (annual basis diets) and seasons to test for differences in diversity indices. Statistical difference ($P < 0.05$) in diversity of mule deer diets was detected only between areas San Luis and El Americano. Diversity of cattle diet (1.327) was not statistically different than the diversity of mule deer diet (1.217) ($P > 0.05$) in San Luis.

Seasonal differences were detected in diet diversity of San Luis, La Pintada, and El Americano. Diversity of diets of desert mule deer in La Jubaivena and cattle in San Luis were no different ($P > 0.05$) among seasons. Summer and spring had the first or second most diverse index in the majority of areas with the exception of El Americano (Table 6). Diversity of mule deer diet for summer in San Luis was higher ($P < 0.05$) than the same value index for other seasons. Winter had the highest diversity of mule deer diet in area La Pintada, where more differences were detected in paired comparisons between seasons. Conversely, autumn had the highest diversity in Rancho El Americano, where the only difference detected was between autumn and winter.

DISCUSSION

Ninety six plant species were identified in diets of desert mule deer from central and western Sonora. Of the 96 species identified in the analyses, 69 species have not previously been reported as forage for desert mule deer: 30 browse, 25 forbs, 11 grasses, and 3 succulents (Table 1). From these species, 44 occurred in the diet $\geq$ 1%, in $\geq$ 1 season, and in $\geq$ 1 area of our studies (Tables 2-5).

Composition of the diets of desert mule deer varied among areas, seasons and years in Sonora, Mexico. Similar variation in diets of mule deer has been observed in other areas of the desert mule deer range (Krausman et al. 1997; Marshal et al. 2004). Studies from southwestern United States have demonstrated that browse is the dominant forage consumed by desert mule deer (McCulloch 1973; Krausman et al. 1997; Marshal 2004). Our studies indicate that browse was similarly the most important forage for desert mule deer throughout central and western Sonora, Mexico. Variation in composition of diets is strongly related to the variation on the availability of resources in the habitat (Krausman et al. 1989).

Desert mule deer used higher amounts of forbs during spring and summer. Some researchers found that forbs may become the annually dominant forage during wet years (Anderson et al. 1965). Thus, contribution of forb species to the diets of desert mule deer is highly variable throughout their range. Such variation is related to spatial and temporal variation in precipitation regimes (Peek and Krausman 1996; Krausman et al. 1997). In central and western Sonora climate characteristics are similar to the rest of the desert mule deer range. Generally, the availability of annual plants and perennial-plants sprouts increase following rainy seasons. In our study the consumption of forb forage varied by seasons and areas, with a range from 0 to 21% in diets of desert mule deer. With the exception of Rancho San Luis, desert mule deer used forbs $\geq$ 1% during all 8 seasons in all areas. The highest use of forb by desert mule deer coincided with occurrence of precipitation in summer for the Plains of Sonora and early autumn for the Central Gulf Coast.

According to Krausman et al. (1997), grasses rarely occur >1% and never exceeded 7% of the seasonal diet of desert mule deer throughout their range in southwestern United States. Results of our study are consistent with reports by Krausman et al. (1997) for most of the seasons and areas. However, extremely higher percent of grasses occurred in summer (32%) at Rancho San Luis. The grasses consumed by mule deer were mainly native species. Five native grasses comprised > 65% of the total consumption of grasses throughout the year. The non-native buffelgrass comprised $\leq$ 5% of the summer diet of desert mule deer, and accounted for <1% of the annual diet. Thus, desert mule deer did not prefer buffelgrass regardless of the high availability of this forage in the study area.

Large areas of central Sonora have been seriously overgrazed (Aguirre 1980). Consequently, poor herbaceous cover and extended bare-ground areas are very common (Navarro et al.1986; Johnson 1990). Particularly during the period of study, Rancho San Luis had large areas with good cover and well established native grasses. This is a distinctive characteristic of the Plains of Sonora rangelands in good condition. Most of the extensive level areas in the Plains of Sonora were formerly covered by summer-active root perennial grasses and are discussed as Sonoran savanna grassland (Brown 1994). Differences in availability of grasses may have caused the differentially higher consumption of grasses in Rancho San Luis, in comparison to the rest of the areas and to other areas of the desert mule deer range. Some researchers have reported high consumption of grass by other mule deer. For example, Hungerford (1974) reported that grasses made up 4 to 47% in summer diets of mule deer in the Kaibab Plateau of Arizona. Neff (1974) equally reported that grasses comprised $\geq$ 32% of mule deer diets in the Beaver Creek at northcentral Arizona. However, comparisons should consider that methods for diet determination were different than methods in our study. Therefore, consumption of grass in central Sonora is not conclusive and it is necessary to conduct more research to clarify differential use of forage under varied rangeland conditions. Studies should also consider previous research on the physiological adaptations of mule deer. It is been presumed mule deer lack of capability to digest grasses because of their small rumen-to-body-weight ratio (Hanley 1982). Mubanga et al. (1985) reported that confined mule deer had digestive problems and limited forage intake when high proportions of grass were offered in the diet.

In a comparative view of diets between desert mule deer and cattle (using simultaneously the same rangeland in Rancho San Luis), browse was notably important for both herbivores. Although grass and forb forage classes together comprised > 65% of the annual cattle diet, browse averaged 30% of seasonal diets. Similar use of browse by cattle was reported previously for a similar area in the same region (Velásquez-Caudillo 1997). Buffelgrass was the most important forage species in cattle diet. This exotic grass was highly used by cattle in the area of the study, since buffelgrass was not the dominant forage as it is on reseeded areas. The highest use of this grass species occurred during summer and autumn. During these seasons, forage availability of buffelgrass increased due to favorable rain and temperature conditions. Seasonal use of forbs presented similar tendency in diet of both herbivores. Forbs comprised equally the lowest used foods by mule deer and cattle. This tendency is likely a response to a proportionally lower availability of forage from these plants. Browse, the most important forage class in the desert mule deer diet, was not the most important in cattle diet. However, the two most important browse species for mule deer were also the most important browse species for cattle (i.e., ironwood and mesquite). Similarly to desert mule deer, cattle used succulents during all seasons in Rancho San Luis. Chainfruit cholla was the only succulent used by cattle, ranging from 3% to 5% of their diet.

Desert mule deer and cattle shared 45 forage species from central Sonora. However, biological overlap occurred only for spring season. The Morisita coefficient for summer was moderately higher when comparing to winter and autumn. Higher similarity coefficients can be explained by the atypically heightened percent of browse that cattle used in spring and the atypically heightened percent of grass that desert mule deer used in summer.

The diets of desert mule deer in central and western Sonora were highly diverse. Shannon-Wiener indices confirmed that desert mule deer adjust spatially and temporally to differences in availability of forage resources. There was a gradient in diversity of diets of desert mule deer that related to the gradient of precipitation. Diversity of diets increased as amount of rain decreased among areas and seasons.

Management Implications

Desert mule deer use forage species that are widely distributed throughout their range and species that occur particularly in the Plains of Sonora and Central Gulf Coast Subdivisions of the Sonoran Desert. Natural distinctive characteristics plus habitat alteration caused by extensive management for cattle in these regions of the Sonoran Desert require special consideration. Buffelgrass is widely spread throughout the Plains of Sonora and this exotic grass is not preferred by desert mule deer. Moreover, the reduction of cover and browse from shrubs and trees in those altered habitat represents a challenge for wildlife managers and the conservation of desert mule deer in northwest

Mexico. The identification of primary resources for desert mule deer and the relationships to each other is essential to enhance habitat conditions.

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Table 1. Percent relative density of plant species in annual diets of desert mule deer, central and western Sonora, Mexico, 1991-1992 and 2002-2004

	Areas and periods of study			
	.1991-1992.	. 2002-2004 .		
Species[a]	San Luis Carbo	La Jubaivena Carbo	La Pintada Hermosillo	El Americano Pitiquito
Browse (45 species)				
Indian mallow (*Abutilon lignosum* [Cav] G. Don) 1	< 1			
Pringle's abutilon (*Abutilon pringlei* Hochr)		< 1	< 1	< 1
Whitehorns acacia (*Acacia constricta* Benth)		< 1		
Sweet acacia (*Acacia farnesiana* [l] Wild) 1,2	2.0	2.3	< 1	3.1
Catclaw acacia (*Acacia occidentalis* Rose) 1,2	< 1			
Whitebrush (*Aloysia lycioides* Cham) 1	< 1			
Burr rageweed (*Ambrosia cordifolia* A. Gray) 1	< 1	< 1		< 1
Burrobush (*Ambrosia dumosa* A. Gray)				< 1
Aster (*Aster exilis* Ell) 1,2	< 1	< 1	2.1	2.2
Vomitbush (*Atamisquea emarginata* Miers) 1,2		2.5		1.1
Fourwing saltbush (*Atriplex canescens* [Pursh] Nutt)	< 1	3.7		< 1
Mule's fat (*Baccharis glutinosa* Pers) 1	< 1			
Chuparosa (*Beloperone californica* Benth) 1,2		5.9	2.4	7.5
Bursera (*Bursera laxiflora* S. Wats) 1,2	3.2			
Elephant tree (*Bursera microphylla* A. Gray) 1,2				2.6
Bird-of-paradise (*Caesalpinia pumila* [Britt & Rose] Hermann) 1,2	3.4	7.9	11.9	2.1
Fairy duster (*Calliandra eriophylla* Benth)		11.3	2.8	7.0
Spiny hackberry (*Celtis pallida* Torr) 1,2	1.2		< 1	
Blue paloverde (*Cerciduium floridum* Benth)	1.4	< 1	6.3	8.1
Paloverde (*Cerciduium microphyllum* [Torr.] Rose & Johnston)	10.0			
Rosary baby bonnets (*Coursetia glandulosa* A. Gray) 1,2		2.8	3.0	3.9
Sonoran croton (*Croton sonorae* Torr.) 1,2	< 1		1.2	
Coville's bundleflower (*Desmanthus covillei* [Britt & Rose] Wiggins) 1,2			< 1	< 1

Table 1. Continued

Species	Areas and periods of study			
	1991-1992	2002-2004		
	San Luis Carbo	La Jubaivena Carbo	La Pintada Hermosillo	El Americano Pitiquito
Bundleflower (Desmanthus palmeri [Britt & Rose] Wiggins) 1,2	< 1			
Brittle bush (*Encelia farinosa* A. Gray)	4.2	2.2	< 1	< 1
Tahitian kidneywood (*Eysenhardtia orthocarpa* [A. Gray] S. Wats) 1,2	< 1	< 1	6.8	
Palo Adan (Fouquieria macdougalii Nash) 1,2		< 1	1.1	1.0
Ocotillo (*Fouquieria splendens* Engelm)	2.9			1.9
Guayacan (*Guiacum coulteri* A. Gray) 1,2	3.3	2.6	5.6	
Hibiscus biseptus S. Wats 1,2		1.4	1.3	3.9
Ipomoea arborescens (Humb & Bonpl) G. Don 1	< 1	< 1		
Sangre de Cristo (*Jatropha cardiophylla* Muell) 1,2	< 1			5.4
White ratany (*Krameria grayi* Rose & Painter)	< 1	2.0	1.9	
Little leaf ratany (*Krameria parvifolia* Benth)				6.3
Indian shrub verbena (*Lantana horrida* H.B.K.) 1,2	< 1	4.7	3.5	< 1
Water jacket (Lycium andersoni A. Gray)	< 1			
Lycium carinatum S. Wats 1			< 1	
Catclaw mimosa (*Mimosa laxiflora* Benth) 1,2	< 1	6.7	5.1	1.4
Ironwood (*Olneya tesota* A. Gray)	15.0	8.1	6.2	4.8
Retama (*Parkinsonia aculeata* L.) 1,2	3.3	< 1		
Mesquite mistletoe *(Phoradendron californicum* Nutt)	< 1	< 1	< 1	
Mesquite (*Prosopis juliflora* [Sw.] D.C.)	24.0	13.8	11.0	3.6
Salvia (*Salvia humilis*Benth) 1,2	< 1	2.5	< 1	4.1
Sage (*Salvia sp.* L.) 1,2			1.7	
Jojoba (*Simmondsia chinensis* [Link] Schnider)				13.4
TOTAL	**76.6**	**83.0**	**76.8**	**87.9**
No. species	30	26	25	26

Table 1. Continued

Species	Areas and periods of study			
	1991-1992	2002-2004		
	San Luis Carbo	La Jubaivena Carbo	La Pintada Hermosillo	El Americano Pitiquito
<u>Forbs (33 species)</u>				
Careless weed (*Amaranthus palmeri* S. Wats) 1,2	< 1	< 1	< 1	< 1
Crested anoda (*Anoda cristata* [L] Schlecht) 1			< 1	
Melon loco *(Apodanthera palmeri* S. Wats) 1	< 1			
Milkweed (*Asclepias sp.* L.) 1,2				2.4
Rush milkweed (*Asclepias subulata* Decne) 1	< 1			
Asteraceae		< 1	< 1	< 1
Spiderling (*Boherhaavia rosei* Standley) 1	< 1			
Paux persil (*Cardiospermum corindum* L.) 1	< 1			
Coves' cassia (*Cassia covesii* Gray) 1		< 1		< 1
Goosefoot (*Chenopodium sp.* L.)				1.3
Whitemouth dayflower (*Commelina erecta* L.) 1,2	< 1			
Low rattlebox (*Crotalaria pumila* Ortega) 1	< 1			
Panamint cryptantha (*Cryptantha angustifolia* [Torr.] Greene) 1,2		< 1	< 1	1.0
Flatsedge (*Cyperus sp.* L.) 1,2	< 1			
Arizona foldwing (*Dicliptera resupinata* [Vahl] Juss) 1,2	< 1		1.2	
Desert silverbush (*Ditaxis adenophora* [Gray] Pax & K. Hoffman) 1	< 1			
False daisy (*Eclipta alba* [L.] Hassk.) 1	< 1			
California poppy (*Eschscholtzia mexicana* Greene) 1	< 1			
Prostrate sandmat (*Euphorbia prostrata* Ait.) 1,2		< 1	2.8	2.7
Perennial sandmat (*Euphorbia tumentulosa* S. Wats) 1,2				1.8
Wild dwarf morning-glory (*Evolvulus arizonicus* Gray)	1.6			
Indigo (*Indigofera laevis* Rydb)	< 1			

Table 1. Continued

Species	1991-1992 San Luis Carbo	2002-2004 La Jubaivena Carbo	2002-2004 La Pintada Hermosillo	2002-2004 El Americano Pitiquito
	Areas and periods of study			
Arizona poppy (*Kallstroemia grandiflora* Torr ex Gray)	< 1			
Texas toadflax (*Linaria texana* [Scheele] D.A. Sutton) 1	< 1			
Annual monsterwort (*Parthenice mollis* Gray) 1	< 1			
Violet dock (*Rumex violascens* Rech. f.) 1,2	< 1			
Spreading fanpetals (*Sida procumbens* Sw.) 1		< 1		< 1
London rocket (*Sisymbrium irio* L.)	< 1		< 1	
Coulter's globemallow (*Sphaeralcea coulteri* [S. Wats.] Gray) 1	< 1			
Woolly tidestromia (*Tidestromia lanuginosa* [Nutt.] Standl.)	< 1			
Moradia (*Verbena delticola* Small ex Perry) 1,2		5.7	3.1	
Hillside vervain (*Verbena neomexicana* [Gray] Small) 1,2	< 1			
Unidentified forb	< 1		< 1	
TOTAL	**4.9**	**7.6**	**8.9**	**9.8**
No. species	23	7	9	9
Grasses (12 species)				
Sixweeks threeawn (*Aristida adscensionis* L.) 1	< 1		< 1	< 1
Spidergrass (*Aristida ternipes* Cav.) 1	< 1		< 1	< 1
Niddle grama (*Bouteloua aristidoides* [Kunth] Griseb) 1,2	1.2		< 1	
False sideoats (Bouteloua reflexa Swallen*)* 1,2	1.8			
Slender grama (*Bouteloua repens* [Kunth] Scribn. & Merr.) 1,2	1.1			
Rothrock's grama (*Bouteloua rothrockii* Vasey) 1,2	< 1	< 1	< 1	< 1
False grama (*Cathestecum erectum* Vasey & Hack.) 1,2	< 1	< 1	< 1	< 1
Buffelgrass (*Cenchrus ciliaris* L.) 1,2	< 1	< 1	< 1	
Feather fingergrass (*Chloris virgata* Sw.) 1,2	1.0			

Table 1. Continued

Species	Areas and periods of study 1991-1992 San Luis Carbo	2002-2004 La Jubaivena Carbo	La Pintada Hermosillo	El Americano Pitiquito
Jungle rice (*Echinochloa colonum* [L.] Link) 1,2	1.2			
Mexican panicgrass (*Panicum capillare* A.S. Hitchc. & Chase) 1	< 1			
Unidentified grass	< 1			
TOTAL	**8.9**	**0.17**	**1.90**	**0.2**
No. species	12	3	6	4
Succulents (6 species)				
Barrel cactus (*Ferocactus acanthodes* [Lem.] Britt. & Rose) 1		< 1		< 1
Organpipe cactus (*Lemaireocereus thurberi* [Engelm.] Britt. & Rose) 1		< 1	< 1	< 1
Chainfruit cholla (*Opuntia fulgida* Engelm.)	9.6	5.6	9.2	1.7
Christmas cactus (*Opuntia leptocaulis* DC.) 1,2		1.7		
Pricklypear (*Opuntia sp.* P. Mill)			3.0	< 1
Walkingstick cactus (*Opuntia spinosior* [Engelm.] Toumey)		1.8		
TOTAL	**9.6**	**9.2**	**12.4**	**2.1**
No. species	1	5	3	4
Gran Total	100.0	100.0	100.0	100.0
Plants contributing ≥ 1%	19	20	22	25
Total No. species	66	40	43	43

[a]1 = Species not previously reported as forage for desert mule deer.

2 = Occurred in the diet > 1%, in > 1 season, and in > 1 area of our study.

Table 2. Percent relative densities of plant species in seasonal diets of desert mule deer and cattle in the Rancho San Luis, Carbó, central Sonora, México, 1991-1992.

	Winter (Jan-Mar)		Spring (Apr-Jun)		Summer (Jul-Sep)		Autumn (Oct-Dec)	
SPECIES	Mule deer	Cattle	Mule deer	Cattle	Mule deer	Cattle	Mule deer	Cattle
Browse (30 species)								
Indian mallow					0.2			
Sweet acacia	0.4			0.6	2.2	1.9	5.4	
Catclaw acacia		0.6	1.2		0.2		0.8	
Whitebrush					0.2			0.4
Burr rageweed					0.2			
Aster			0.2					
Fourwing saltbush			0.4					
Mule's fat			0.2					
Bursera	3.0	0.6	3.3	0.3	5.1	0.6	1.5	1.1
Bird-of-paradise	1.4	1.5	4.8	4.6	3.4		4.1	2.8
Spiny hackberry	4.5			3.3		3.4	0.4	0.2
Blue paloverde	1.1		1.0		1.5		1.9	
Paloverde	14.4	0.9	10.0	1.3	4.0	1.1	11.5	0.3
Sonoran croton					0.4			
Bundleflower	0.1	3.5				0.6		
Brittle bush	4.8	1.8	7.3	1.7	3.8	0.5	0.9	2.3
Tahitian kidneywood	0.3	0.3	0.3	0.9			0.6	
Ocotillo	5.7		1.7		2.4		1.7	0.2
Guayacan	2.1		1.9		1.6	1.2	7.4	0.8
Ipomoea arborescens G. Don			0.3	0.6		0.6		
Sangre de Cristo	0.4	0.6	2.2					
White ratany		0.3			0.2			
Indian shrub verbena		0.6	0.3			1.2		1.0
Water jacket			0.3	0.4			0.2	
Catclaw mimosa	0.1				1.0		0.4	

Table 2. Continued

SPECIES	Winter (Jan-Mar)		Spring (Apr-Jun)		Summer (Jul-Sep)		Autumn (Oct-Dec)	
	Mule deer	Cattle	Mule deer	Cattle	Mule deer	Cattle	Mule deer	Cattle
Ironwood	21.1	6.7	14.5	17.1	9.4	8.8	14.9	8.7
Retama	2.6		1.5		0.2		8.9	
Mesquite mistletoe	19.1	4.1	28.9	14.0	19.4	7.3	28.7	6.5
Mesquite					0.2	0.6		1.2
Salvia					0.2			
Total	**81.1**	**21.4**	**80.1**	**44.8**	**55.7**	**27.6**	**89.5**	**25.6**
No. species	16	12	19	11	20	12	16	12
Forbs (31 species)								
Careless weed		0.3			0.2	0.4		
Melon loco				4.7	0.4	1.9		0.6
Rush milkweed				0.3	0.2	0.2		
Spiderling	0.3							0.3
Paux persil			0.3					
Whitemouth dayflower	1.0				0.2			
Low rattlebox				0.7	0.2			
Flatsedge		0.6	1.0	2.2	1.5	5.5		0.5
Arizona foldwing			0.4					0.6
Desert silverbush			0.3					
Cyperaceae		0.9				0.5		1.7
False daisy			0.4		0.2			
California poppy					0.3			
Wild dwarf morning-glory		1.5	4.5	0.6	2.0	1.4		2.1
Goldenweed (*Haplopappus gracilis* [Nutt.] Gray)						0.2		
Indigo			0.3		0.2			
Arizona poppy			0.3					

Table 2. Continued

SPECIES	Winter (Jan-Mar) Mule deer	Winter (Jan-Mar) Cattle	Spring (Apr-Jun) Mule deer	Spring (Apr-Jun) Cattle	Summer (Jul-Sep) Mule deer	Summer (Jul-Sep) Cattle	Autumn (Oct-Dec) Mule deer	Autumn (Oct-Dec) Cattle
Texas toadflax	0.5			0.6	0.5			
Desert evening-primrose (*Oenothera primiveris* Gray)				0.3				
Lineleaf whitepuff (*Oligomeris linifolia* J.F. Macbr)				0.3				0.6
Annual monsterwort			0.4			0.3		
Rockdaisy (*Perityle* sp. Benth)						0.4		
Ruellia intermedia Leonard						0.4		
Violet dock	0.3	0.3		0.9	1.0			0.6
Spreading fanpetals						0.8		
London rocket	0.3			0.9				
Coulter's globemallow	0.3			0.6	0.2			
Woolly tidestromia					0.4			
Tithonia sp. Desf ex. Juss						0.8		0.8
Hillside vervain			0.2		1.2			
Unidentified					0.2			
Total	**2.6**	**3.5**	**8.1**	**12.3**	**8.8**	**12.6**	**0.0**	**7.8**
No. species	6	5	10	11	16	12	0	9
Grasses (15 species)								
Sixweeks threeawn	0.3	6.5		2.1	0.7	0.3		1.0
Spidergrass	0.1	2.1	0.3		0.4	2.4		1.8
Niddle grama		1.7		3.9	4.8	2.1	0.2	0.8
False sideoats		11.2		4.0	3.9	3.3	0.1	6.8
Slender grama		8.8		2.1	7.0	4.8		5.4
Rothrock's grama	1.2	9.4		2.2	3.1	2.6		5.7
False grama		3.3		6.3	1.6	8.3		7.7
Buffelgrass	1.0	19.9		14.0	3.1	23.2		26.1

Table 2. Continued

SPECIES	Winter (Jan-Mar)		Spring (Apr-Jun)		Summer (Jul-Sep)		Autumn (Oct-Dec)	
	Mule deer	Cattle	Mule deer	Cattle	Mule deer	Cattle	Mule deer	Cattle
Feather fingergrass	0.3	3.0		0.4	2.2	1.1		3.1
Jungle rice		1.2		1.2	5.0	0.5		0.4
Canyon cupgrass								
(*Eriochloa lemmonii* Vasey and Scrib.)		0.3		0.2		0.3		1.0
Leptochloa filiformis Beauv.		1.2				1.4		0.4
Mexican panicgrass		0.9		1.9	0.2	1.4		0.7
Bristlegrass								
(*Setaria macrostachya* Kunth)		2.7				2.7		0.8
Unidentified grass	0.4							
Total	**3.3**	**72.1**	**0.3**	**38.2**	**31.9**	**54.4**	**0.3**	**61.7**
No. species	6	14	1	11	11	14	2	14
Succulents (1 species)								
Chainfruit cholla	13.0	2.9	11.6	4.6	3.6	5.4	10.3	5.0
Grand Total	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
No. species total	29	32	31	34	48	39	19	36

Table 3. Percent relative densities of plant species in seasonal diets of desert mule deer in the Rancho La Jubaivena, Carbó, central Sonora, Mexico, 2002-2004.

	Winter (Jan-Mar)		Spring (Apr-Jun)		Summer (Jul-Sep)		Autumn (Oct-Dec)	
Species	2003	2004	2002	2003	2002	2003	2002	2003
Browse (26 species)								
Pringle's abutilon				0.4				
Whitehorns acacia		0.5			0.3			
Sweet acacia	1.6	0.9	2.4	4.7	1.4	4.7	2.0	0.3
Burr rageweed		0.3	1.8	0.8	1.2			
Aster							0.2	
Vomitbush	0.7	0.4			0.1	5.1	6.9	6.9
Fourwing saltbush		7.4	6.7	9.0	5.9	0.7		
Chuparosa	5.9	5.6	5.3	5.6	2.6	3.7	4.6	14.3
Bird-of-paradise	15.0	12.5	7.6	7.3	8.3	5.6	3.3	4.0
Fairy duster	14.5	11.6	11.2	8.6	11.6	8.1	10.2	14.5
Blue paloverde	0.4	0.4	0.3	0.5	0.7	0.6	0.9	0.3
Rosary baby bonnets	1.9	0.8	2.9	0.5	3.8	4.5	2.8	4.9
Brittle bush	0.5	0.6	0.8	0.9	0.7	1.6	1.4	10.7
Tahitian kidneywood	1.3		0.7	0.3	0.4	0.3	0.6	
Palo Adan	1.1	1.2	0.8	0.3	0.5	0.6	0.8	1.9
Guayacan	3.4	1.0	1.2	6.7	0.6	1.0	0.5	6.5
Hibiscus biseptus S. Wats 1,2	0.3	1.9	0.9	1.0	1.4	3.9	1.2	0.3
Ipomoea arborescens G. Don			0.9					
White ratany	1.6	1.5	3.9	1.9	2.0	4.2	0.8	
Indian shrub verbena	1.1	6.4	6.1	2.9	6.2	6.0	7.4	1.4
Catclaw mimosa	10.0	4.8	4.6	7.1	7.8	8.0	7.0	4.4
Ironwood		12.2	9.7	10.8	14.0	8.0	8.7	1.0
Retama	0.1			0.1				
Mesquite mistletoe						0.2	0.6	
Mesquite	15.0	9.8	12.8	14.6	11.2	15.0	20.3	11.7

Table 3. Continued

Species	Winter (Jan-Mar)		Spring (Apr-Jun)		Summer (Jul-Sep)		Autumn (Oct-Dec)	
	2003	2004	2002	2003	2002	2003	2002	2003
Salvia	1.0	3.4	3.6	3.2	2.9	1.3	0.1	4.2
Total	**75.5**	**83.1**	**84.0**	**87.2**	**83.5**	**83.1**	**80.4**	**87.4**
No. species	18	20	20	21	21	20	20	16
Forbs (7 species)								
Careless weed	0.8	1.5	1.1	0.9	2.8	0.6		
Coves' cassia								0.2
Panamint cryptantha		0.4	0.5	0.3		2.6		
Prostrate sandmat	0.7	0.3		1.1	0.2	0.2		0.5
Asteraceae						0.2	0.6	0.1
Spreading fanpetals							0.1	
Moradia	0.7	4.0	7.4	4.9	9.0	7.9	6.8	4.5
Total	**2.1**	**6.2**	**9.0**	**7.1**	**12.1**	**11.5**	**7.5**	**5.3**
No. species	3	4	3	4	3	5	3	4
Grasses (3 species)								
Rothrock's grama		0.1	0.3	0.1	0.1	0.2		0.1
False grama				0.1	0.1			
Buffelgrass		0.1						
Total	**0.0**	**0.3**	**0.3**	**0.2**	**0.2**	**0.2**	**0.0**	**0.1**
No. species	0	2	1	2	2	1	0	1

Table 3. Continued

Species	Winter (Jan-Mar) 2003	Winter (Jan-Mar) 2004	Spring (Apr-Jun) 2002	Spring (Apr-Jun) 2003	Summer (Jul-Sep) 2002	Summer (Jul-Sep) 2003	Autumn (Oct-Dec) 2002	Autumn (Oct-Dec) 2003
Succulents (5 species)								
Barrel cactus				0.1				
Organpipe cactus				0.1				
Chainfruit cholla	16.0		5.7		3.9	3.8	10.4	4.7
Christmas cactus	6.3	0.4	1.0	0.4	0.3	1.4	1.7	2.5
Pricklypear		10.0		4.7				
Total	**22.3**	**10.4**	**6.7**	**5.4**	**4.1**	**5.2**	**12.1**	**7.2**
No. species	2	2	2	4	2	2	2	2
Grand Total	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
No. species total	23	28	26	31	28	28	25	23

Table 4. Percent relative densities of plant species in seasonal diets of desert mule deer in the Rancho La Pintada, Carbó, central Sonora, Mexico, 2002-2004.

	Winter (Jan-Mar)		Spring (Apr-Jun)		Summer (Jul-Sep)		Autumn (Oct-Dec)	
Species	2003	2004	2002	2003	2002	2003	2002	2003
Browse (25 species)								
Pringle's abutilon							0.1	
Sweet acacia	0.1				2.0			
Aster	5.3	2.2		2.0	4.1		0.1	3.0
Chuparosa	4.6	4.1	0.2	0.2	3.8		1.3	4.8
Bird-of-paradise	8.7	5.1	12.8	14.8	10.1	9.4	16.8	17.5
Fairy duster	3.0	2.6	0.7		4.3	7.5	0.1	4.2
Spiny hackberry		4.9		0.7		1.8		
Blue paloverde	5.1	8.6	7.4	6.8	2.1	10.3	8.5	1.7
Rosary baby bonnets	2.6	1.2	4.0	5.1	3.4	1.8	4.0	1.6
Sonoran croton	1.4	2.8			0.4		3.0	1.9
Coville's bundleflower					2.4	0.7		
Brittle bush	1.7	1.5	1.1	0.2	0.5		0.7	0.1
Tahitian kidneywood	6.0	4.9	8.4	9.9	6.5	4.6	9.4	5.0
Palo Adan	1.4		1.9	1.7	1.7	0.9	1.3	0.3
Guayacan	7.5	4.9	2.5	6.0	8.0	5.7	7.9	2.5
Hibiscus biseptus S. Wats	3.5	0.6	1.1		0.7	0.2	0.8	3.7
White ratany	2.0	2.4	0.5		3.2	0.4	1.7	4.8
Indian shrub verbena	2.1	8.6	0.9	4.1	2.6	0.9	2.9	6.0
Lycium carinatum S. Wats							0.4	
Catclaw mimosa	5.3	4.1	0.5	5.5	7.6	8.5	3.8	5.5
Ironwood	9.2	10.0	7.2	1.7	5.4	3.6	8.5	3.7
Mesquite mistletoe	0.6	0.3					0.5	1.0
Mesquite	5.4	9.1	11.7	15.7	7.3	18.0	11.5	9.0

Table 4. Continued

Species	Winter (Jan-Mar)		Spring (Apr-Jun)		Summer (Jul-Sep)		Autumn (Oct-Dec)	
	2003	2004	2002	2003	2002	2003	2002	2003
Salvia	0.5			0.4	1.1		0.5	0.3
Sage	0.3	4.7	0.7	2.9	3.6	0.9	0.3	0.1
Total	**76.4**	**82.3**	**61.7**	**77.7**	**80.9**	**75.3**	**84.1**	**76.3**
No. species	21	19	16	16	21	16	22	20
Forbs (9 species)								
Careless weed	1.6	0.3			1.8	0.9		0.1
Crested anoda				0.5				0.1
Asteraceae					0.1			
Panamint cryptantha	5.3						1.5	
Arizona foldwing					4.7	4.6		
Prostrate sandmat	2.6	0.5	9.4	0.4	3.4	4.6	1.5	0.3
London rocket	0.1							
Moradia	4.6	4.4			6.5	5.5	3.7	
Unidentified	1.6				0.3			
Total	**15.7**	**5.1**	**9.4**	**0.9**	**16.8**	**15.6**	**6.8**	**0.5**
No. species	6	3	1	2	6	4	3	3
Grasses (6 species)								
Sixweeks threeawn	0.9	0.1			0.1			
Spidergrass						0.7	0.4	
Niddle grama	1.0	0.3	0.4	1.9	0.5			
Rothrock's grama						4.4	0.1	0.3
False grama			0.2			0.2	0.1	
Buffelgrass	2.7	0.3			0.1	0.2		0.3
Total	**4.6**	**0.7**	**0.5**	**1.9**	**0.8**	**5.5**	**0.7**	**0.5**
No. species	3	3	2	1	3	4	3	2

Table 4. Continued

Species	Winter (Jan-Mar)		Spring (Apr-Jun)		Summer (Jul-Sep)		Autumn (Oct-Dec)	
	2003	2004	2002	2003	2002	2003	2002	2003
Succulents (3 species)								
Organpipe cactus			0.5	0.9				
Chainfruit cholla	1.4	11.8	26.3	12.9	0.6	3.6	8.0	9.0
Pricklypear	1.8		1.5	5.8	0.9		0.4	13.6
Total	**3.3**	**11.8**	**28.3**	**19.6**	**1.6**	**3.6**	**8.4**	**22.6**
No. species	2	1	3	3	2	1	2	2
Grand Total	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00
No. species total	32	26	22	22	32	25	30	27

Table 5. Percent relative densities of plant species in seasonal diets of desert mule deer in the Rancho EL Americano, Pitiquito, western Sonora, Mexico, 2002-2004.

	Winter (Jan-Mar)		Spring (Apr-Jun)		Summer (Jul-Sep)		Autumn (Oct-Dec)	
Species	2003	2004	2002	2003	2002	2003	2002	2003
Browse (26 species)								
Pringle's abutilon		0.3	1.0	1.8	0.2	1.1	1.1	1.0
Sweet acacia	0.9	5.0	5.2	2.0	5.2	3.3	1.8	1.0
Burr rageweed	1.5	0.1	0.2	1.0	0.7	0.4	1.7	0.7
Burrobush	2.0	1.7	4.9	8.0	5.4	1.0	7.2	0.8
Aster	3.2	3.9	1.1	1.6	1.2	1.9	2.0	2.6
Vomitbush	0.8	1.2	0.3	2.3	0.4	1.5	2.0	0.6
Fourwing saltbush		0.3	1.0	0.8	0.1	0.4	0.4	0.2
Chuparosa	6.7	7.1	5.8	5.6	6.8	11.0	5.8	10.9
Elephant tree	4.2	3.1		8.4	0.1	0.2	2.3	2.7
Bird-of-paradise		0.6	9.5		5.6	0.2	0.7	
Fairy duster	13.6	7.5	10.0	8.0	0.9	10.0	2.9	3.4
Blue paloverde	8.0	5.0	10.0	8.0	11.7	4.3	7.0	11.0
Rosary baby bonnets	8.0	5.0				10.0	0.2	7.9
Coville's bundleflower			0.8	1.2	1.5	0.5	0.9	
Brittle bush	3.2	0.8	0.3	0.2		0.3	1.0	0.3
Palo Adan	1.5		0.8	1.0	0.4	1.2	1.4	1.7
Ocotillo	0.3	0.8	0.6			5.0		8.1
Hibiscus biseptus S. Wats					5.9			
Sangre de Cristo	6.5	6.0	5.0	6.3	2.3	4.5	7.0	5.9
Little leaf ratany	7.3	9.2	10.0	2.3	8.0	3.0	6.8	4.0
Indian shrub verbena			0.6		2.6			
Catclaw mimosa	2.0	1.9	2.3	1.2	1.2	1.1	1.1	0.5
Ironwood	0.5	1.6	3.0	8.0	14.3	2.3	2.0	6.5

Table 5. Continued

Species	Winter (Jan-Mar)		Spring (Apr-Jun)		Summer (Jul-Sep)		Autumn (Oct-Dec)	
	2003	2004	2002	2003	2002	2003	2002	2003
Mesquite	2.0	6.0	5.0	2.3	3.1	4.8	1.1	4.8
Salvia	0.9	1.5	3.3	3.5	5.2	9.9	6.2	2.5
Jojoba	16.7	15.3	7.2	15.7	8.0	17.8	14.5	11.9
Total	**89.8**	**84.0**	**87.8**	**89.0**	**90.7**	**95.5**	**77.1**	**89.2**
No. species	20	22	23	21	22	24	23	22
Forbs (9 species)								
Careless weed	0.0				0.0	0.0		
Milkweed	7.1	1.8	1.3	1.4	0.4	2.7	1.0	3.7
Asteraceae			0.2				1.1	
Coves' cassia	0.1	0.1	0.2	0.8	0.7		0.6	
Goosefoot				0.4		0.1	10.0	
Panamint cryptantha		0.5		1.4			6.0	0.2
Prostrate sandmat	0.7	1.1	9.1	0.8	1.1	1.3	0.3	0.3
Perennial sandmat	1.2	12.4	0.2	2.7	0.1		2.3	2.9
Spreading fanpetals					0.3			
Total	**9.0**	**15.9**	**10.9**	**7.4**	**2.6**	**4.1**	**21.3**	**7.1**
No. species	5	5	5	6	6	4	7	4
Grasses (4 species)								
Sixweeks threeawn	0.3						0.2	
Spidergrass	0.2							
Rothrock's grama								0.2
False grama				0.2	0.4		0.4	0.1
Total	**0.5**	**0.0**	**0.0**	**0.2**	**0.4**	**0.0**	**0.5**	**0.3**
No. species	2	0	0	1	1	0	2	2

Table 5. Continued

Species	Winter (Jan-Mar)		Spring (Apr-Jun)		Summer (Jul-Sep)		Autumn (Oct-Dec)	
	2003	2004	2002	2003	2002	2003	2002	2003
Succulents (4 species)								
Barrel cactus				0.2	0.2	0.1		
Organpipe cactus		0.1			0.3	0.3		0.4
Chainfruit cholla	0.7		0.3	2.3	5.9		1.1	3.0
Pricklypear			1.0	1.0				
Total	**0.7**	**0.1**	**1.3**	**3.5**	**6.4**	**0.4**	**1.1**	**3.4**
No. species	1	1	2	3	3	2	1	2
Grand Total	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
No. species total	28	28	30	31	32	30	33	30

Table 6. Shannon-Wiener (H') diversity indices for diets of desert mule deer in central and western Sonora, Mexico 1991-1992 and 2002- 2004

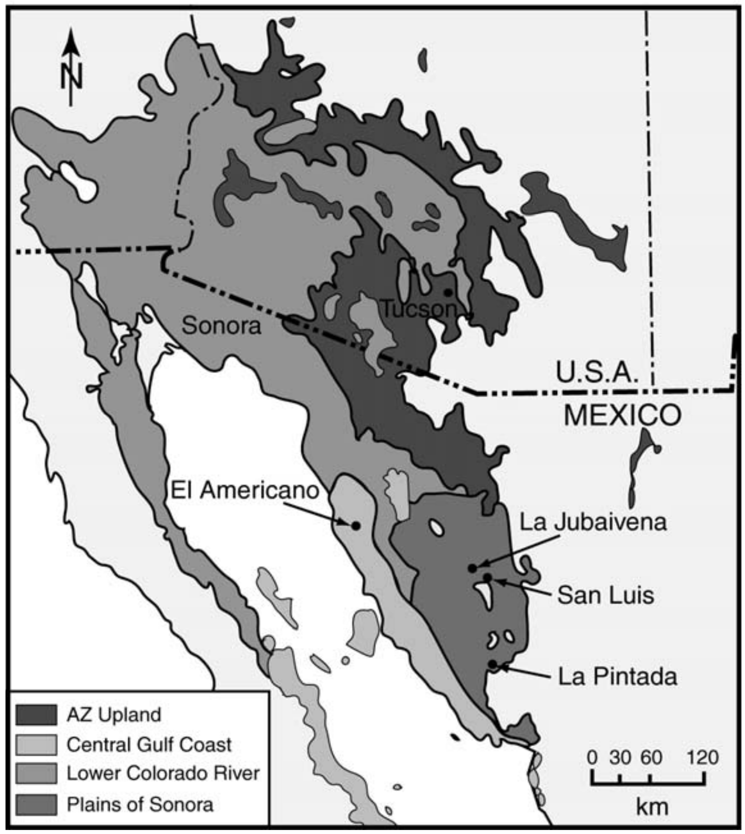
	Study Areas			
	San Luis	La Jubaivena	La Pintada	El Americano
	1991-1992	2002 - 2004		
Annual basis	1.2166 *[1]	1.2841	1.3409	1.3834 *
Winter	1.0454 a[2]	1.2211	1.3686 a	1.2441 a
Spring	1.0478 b	1.2596	1.1253 a b	1.3279
Summer	1.3502 abc	1.2530	1.3222 b	1.3127
Autumn	0.9638 c	1.1964	1.2454 a	1.3533 a

[1] Asterisk shows difference (P < 0.05) between areas in annual diets.

[2] Same literal shows difference (P < 0.05) between seasons for the same area.
No comparisons were made among areas in a single season.

FIGURE CAPTIONS

Fig. 1. Locations of study for desert mule deer diets in altered habitats, central and western Sonora, Mexico.


N
Tucson
Sonora
U.S.A.
MEXICO
El Americano
La Jubaivena
San Luis
La Pintada
AZ Upland
Central Gulf Coast
Lower Colorado River
Plains of Sonora
0 30 60 120
km